Puget Sound Steelhead Foundations: A Primer for Recovery Planning

PugetSoundPartnership
LEADING PUGET SOUND RECOVERY

Washington Department of FISH and WILDLIFE

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Acknowledgments

This work represents a partnership among the Washington Department of Fish and Wildlife (WDFW), Northwest Indian Fisheries Commission (NWIFC), National Oceanic and Atmospheric Administration (NOAA), Puget Sound Partnership (PSP), Recreation and Conservation Office (RCO), and the Governor's Salmon Recovery Office (GSRO).

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Cover photo by Terry Roelofs

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Purpose of the Puget Sound Steelhead Foundations Project

The Steelhead Foundations project is a cooperative agreement among the Washington Department of Fish and Wildlife, National Marine Fisheries Service (NOAA Fisheries), Puget Sound Partnership, Recreation and Conservation Office, Governor's Salmon Recovery Office, and Northwest Indian Fisheries Commission. The goal of the project is to form the basis ('foundation') for a steelhead recovery plan in Puget Sound.

This report provides information on Puget Sound steelhead taxonomy, natural life history strategies, and general habitat use. To provide a context for status evaluation and recovery of steelhead, a description of individual watersheds within the Puget Sound basin is included. We summarize habitat factors contributing to the depressed status of steelhead in Puget Sound and review current threats and stressors within each basin. To build on previous recovery work targeted at Chinook salmon, chum salmon, and bull trout, an information gap analysis is also provided to address the most important elements of steelhead recovery that are not covered in these existing plans. This report does not address environmental pollution challenges, such as potentially harmful chemical mixtures found in stormwater runoff, endocrine disruptors, pharmaceuticals or other forms of chemical pollution entering receiving waters of Puget Sound, and their potential adverse impacts on steelhead. In addition, harvest management, and current hatchery practices are not specifically addressed by this report; such a review is beyond the scope of this effort, but is anticipated to be addressed in the final steelhead recovery plan.

Introduction

Puget Sound steelhead (*Oncorhynchus mykiss*) were designated as an evolutionarily significant unit (ESU) in 1996 following a status review of west coast steelhead (Busby et al. 1996). Steelhead (the anadromous form of *O. mykiss*) occurring downstream of natural migration barriers in rivers draining to Puget Sound, Hood Canal, and Strait of Juan de Fuca (on the Olympic Peninsula west to the Elwha River) were included in the ESU. In 2004 the National Marine Fisheries Service (NMFS) was petitioned to list Puget Sound steelhead under the Endangered Species Act (ESA) as threatened or endangered. The petition engendered a new status review (Hard et al. 2007) and based on its findings, Puget Sound steelhead were ESA-listed as a threatened species effective 11 June 2007. Due to the shared jurisdiction over *O. mykiss* between NMFS and the U.S. Fish and Wildlife Service (USFWS), the ESU designations for west coast steelhead were re-described as distinct population segments (DPS) (National Marine Fisheries Service 2006), which are the ESA 'species' designations used by the USFWS. Thus, the Puget Sound steelhead ESU became a DPS, with no changes to geographic boundaries, and subsequent federal documents use the DPS language.

Factors that supported the threatened status of the Puget Sound steelhead DPS were widespread declines in abundance and productivity, steeply declining abundance of some populations, releases of hatchery stocks not included in the DPS, reduced habitat quality, habitat fragmentation, urbanization, and declining marine survival rates (Hard et al. 2007). Three years after the listing decision, the status of Puget Sound steelhead regarding risk of extinction had not changed (Ford et al. 2010), although estimated abundance of most populations within the DPS continued to exhibit downward trends (Ford et al. 2010; Figure 1.).

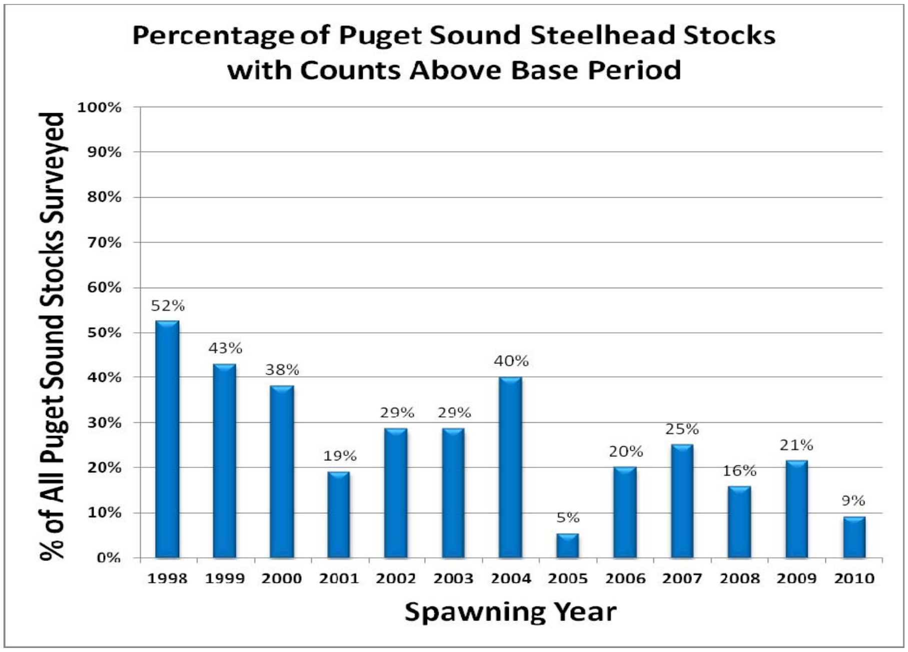


Figure 1. Percentage of Puget Sound steelhead stocks with spawner escapement (number of fish returning to a stream or river to spawn) exceeding their 1993-97 pre-Endangered Species Act (ESA) listing base period.

Various activities are underway to begin reducing extinction risks and plan recovery efforts. For example, a Puget Sound steelhead harvest management plan is being developed by WDFW and western Washington treaty tribes. Hatchery production and management have been altered to address risks to wild steelhead by actions such as reducing the number of hatchery smolts released in some watersheds. NMFS convened the Puget Sound steelhead Technical Recovery Team (TRT) that will delineate historical, demographically independent populations. After Puget Sound steelhead stocks are delineated recovery targets will be developed, and viability assessments will be conducted.

There are numerous “stressors” that can adversely affect ecosystem processes, habitats, and fish species such as steelhead. Stressors can be grouped into three general categories that include chemical, biological, or physical habitat perturbations. Chemical stressors can range from agricultural runoff, stormwater pollutants, sewer overflow, or pharmaceutical chemicals that can mimic hormones (endocrine disrupting chemicals). Examples of biological stressors to steelhead are bacterial or viral infections, parasites, competition, or predation, including those fostered by invasive species. Habitat stressors can range from low in-stream flows, elevated temperature regimes, elevated sediment loads, fish passage barriers caused by improperly designed or installed culverts, dikes and levees that cut off access to historical flood plains and habitat.

Success in Puget Sound steelhead recovery will require the ability to identify, reduce and eliminate the various stressors adversely impacting steelhead. Table 1 provides general steelhead life history stages, functional requirements and types of stressors that can adversely affect those life stages. In addition, tables that identify habitat viability stressors on a watershed-by-watershed basis can be found in the *Puget Sound Habitat Stressors* section of this report.

Planning habitat restoration and protection actions directed at steelhead requires knowledge of habitat use and existing conditions that may be limiting productivity in Puget Sound watersheds and marine areas. Using a watershed focus, we have compiled in this document biological, ecological and environmental information that will serve as a foundation for developing a formal recovery plan for Puget Sound steelhead.

Table 1. Habitat stressors of Puget Sound steelhead.

Summary of Stressors and Impacts for Steelhead in Puget Sound						
		Life Stage				
		Adult migration	**Spawning**	**Incubation and emergence**	**Juvenile rearing**	**Juvenile migration**
Functional requirement	***Stressors***	**Negative impact**				
Sufficient flow	*Depressed groundwater, Lack of flow from effluent sources, Change in flows*	Inability to reach spawning area	Decrease in usable riffle area	Drying of redds, Insufficient transfer of nutrients and waste, Unhealthy temperature	Unhealthy temp, Increased predation	
No migration barriers	*Diversion dams, Utility crossings ,Bridge sills, Excessive sediment, Unscreened diversions, Road culverts, Road crossings, Dams*	Inability to reach spawning area, Increased poaching at barriers	Prespawning mortality		Increased predation at barriers, Stranding, Blocked access to refugia habitats	
Channel Complexity: Instream-cobble, boulders, undercut banks, pools, riffles, riparian-large woody debris, streamside vegetation, natural channel morphology (unaltered – armored, etc.)	*Sedimentation from in channel and upland erosion, Flood control maintenance, Homeowner maintenance, Grazing, Poor stormwater management*	Lack of optimal velocity through a range of flows, Lack of resting pools	Lack of clean spawning gravel	Poor percolation for nutrients and waste removal, Inability to emerge from gravel, Scouring of redds	Increased predation, Suboptimal food supply (instream and terrestrial sources), Suboptimal velocity for growth	
Appropriate temperature	*Inadequate vegetation, Lack of substrate complexity, Inadequate flow, Impoundments, Effluent*	Pre-spawning mortality	Increased mortality of eggs	Mortality	Decreased vigor, size, Increased disease and mortality	
Good water quality	*Poor stormwater management, Homeowner maintenance, Industrial discharge*	Pre-spawning mortality	Increased mortality of eggs	Poor development, Increased mortality	Increased disease, stress, and mortality.	Early ocean entry, Increased predation
Biological: Increased numbers of returning salmon/steelhead contribute to nutrient enhancement	*(All the above including harvest)*				Decrease in food supply	
Healthy diverse resident trout populations	*(All the above including harvest)*		Reduction in spawning pairs			

General Description of Steelhead/Rainbow Trout

Scientific name: *Oncorhynchus mykiss* (Walbaum, 1792)

Common name: steelhead, coastal rainbow trout, redband trout, rainbows, sea run trout, ocean trout
Family: Salmonidae

Taxonomy

Johann Julius Walbaum was the first to describe the species in 1792, based on specimens from Kamchatka, and he assigned the name *Salmo mykiss* (from the local Kamchatkan dialect 'mykizha'). Junior synonyms were assigned by Richardson (1836), who named a specimen *S. gairdneri*, and W. P. Gibbons (1885), who described a population of *S. iridia* (then later *S. irideus*). Genetic analysis has demonstrated the species to be more closely related to Pacific salmon (*Onchorhynchus* spp.) than to trout (*Salmo* spp.), thus in 1989 the genus was changed. Two subspecies of *O. mykiss* are recognized in Washington: the coastal rainbow trout *O. mykiss irideus* and the inland rainbow trout, or redband trout, *O. mykiss gairdneri* (Small et al. 2007). For a complete taxonomic history, consult Smith and Stearley (1989), Behnke (2002), and Quinn (2005).

Life History Diversity

Life history trajectories expressed by steelhead vary substantially with geographic and environmental conditions (Shapolov and Taft 1954, Thorpe 2007, Narum et al. 2008, Satterthwaite et al. 2009). Individual fish that entirely reside in freshwater systems are called rainbow trout, while individuals that rear for a time in marine waters before returning to freshwater to spawn are called steelhead. In preparation for emigration to marine environments, juvenile steelhead undergo smoltification, where they lose the rainbow pigmentation of the freshwater form, becoming silver, and experience a series of physiological changes that adapt them for life in salt water (Nichols et al. 2008). Smoltification is a stressful process where fish must rapidly acclimate to changes in salinity, temperature, food availability, and chemical processes (Wagner 1974, Zaugg and Wagner 1973). Emigration from freshwater to saltwater environments can occur at any time during the first five years of life (Figure 2, Burgner et al. 1992) and is both genetically and environmentally controlled (Small et al. 2007, Narum et al. 2008). Research at Waddell Creek, California identified a total of 34 steelhead life history categories, although on average only four of them exceeded five percent of the run (Shapovalov and Taft 1954). Diversity of life history trajectories enables the species to occupy an extensive geographical area of the North Pacific from California to Kamchatka.

The complexity of steelhead life history is similar to that of the masu salmon (*O. masou),* and that of the bull trout *(Salvelinus confluentus).* Life history complexity exhibited by these three species contrasts markedly with the evolutionary trend of other anadromous *Oncorhynchus* species, such as chum (*O. keta*) and pink salmon (*O. gorbuscha*), toward an emphasis on the oceanic portion of their life cycle and a narrow expression of life history variations. Unlike salmon, which die after spawning (semelparity), most steelhead survive spawning and begin a migration back to the ocean (iteroparity), although only a small portion of these fish return to spawn again after surviving another ocean period (Ward and Slaney 1988, Busby et al. 1996, Seamons and Quinn 2010), with females predominant among repeat spawners (Withler 1966, Leider et al. 1986, Ward and Slaney 1988). In order for steelhead to become repeat-spawners they must successfully recondition and emigrate after their first spawning. The term kelt is used to describe a post-spawn adult steelhead and kelt outmigration occurs over several months, with most individuals moving downstream immediately following spawning (Shapovalov and Taft 1954).

Both steelhead and rainbow trout life history forms display variation in years to maturation and, once at sea, steelhead may spend anywhere from a few months to 5 years before attaining maturity and returning to spawn (Figure 2, Pautzke and Meigs 1940, Burgner et al. 1992, Busby et al. 1996). A small percentage of returning adult steelhead will prematurely enter non-natal streams for maturation and spawning (Pautzke and Meigs 1940, Shapovalov and Taft 1954). Intermixing on the spawning grounds among life history strategies and cohorts is common and a single redd can produce both resident and anadromous offspring (Ruzycki et al. 2003, Marshall et al. 2006). Resident rainbow trout also occur upstream of natural and anthropogenic barriers to steelhead migration and fish from these populations may be able to descend barriers and co-occur with downstream steelhead populations (Marshall et al. 2006). Reproduction among year classes and life history strategies has the potential to dampen the effects of poor freshwater or marine environmental rearing or incubation conditions during a year or series of years (Maher and Larkin 1955, Leider et al. 1986). Male offspring may reach sexual maturity after one or two years in freshwater but it is unclear if these precocious males migrate to sea after spawning (Shapovalov and Taft 1954). Research by Maher and Larkin (1955) in the Chilliwack River British Columbia, noted that there was no obvious correlation between time spent in freshwater or saltwater by fish, and no tendency to return to fresh water at a particular time of the year, regardless of age, length, or sex.

The timing of adult steelhead re-entry into natal streams can vary over an extended period of the year, and within a river system there can be several distinct seasonal runs (Shapovalov and Taft 1954, Leider et al. 1986, WDFW and WWTIT 1994, Busby et al.1996). “Winter-run” steelhead generally return to freshwater from December through May, spawn from March through May, and are the dominant adult life history type in Puget Sound (WDFW and WWTIT 1994). Puget Sound also has “summer-run” steelhead and these adults enter freshwater between April and October in a sexually immature condition and spawn between January and April the following year (WDFW and WWTIT 1994, Busby et al. 1996). Distinct summer-run populations commonly occur upstream of physical features that are migration barriers to winter-run steelhead due to low in-stream flow (Withler 1966, WDFW and WWTIT 1994, Busby et al.1996).

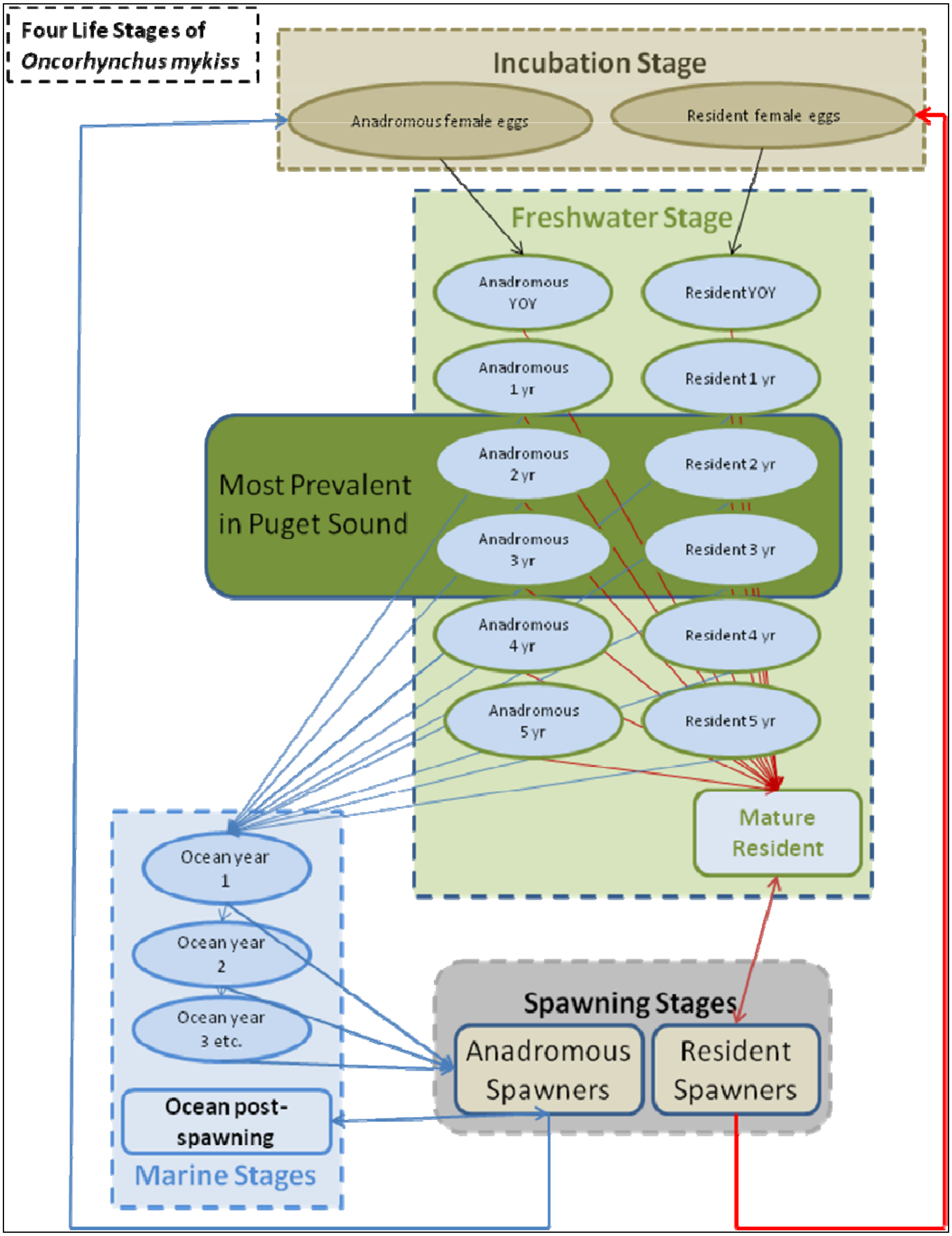


Figure 2. Life history trajectory complexity in steelhead.

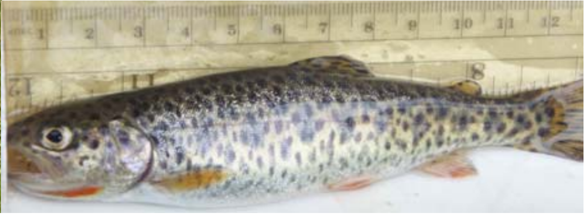
Anatomy and Morphology

Puget Sound steelhead and rainbow trout share physical characteristics typical of their species, such as scale and fin ray counts in an expected range, but achieve different physical forms due to their respective anadromous and freshwater resident life histories. Adult steelhead are typically much larger than adult rainbow trout. In their marine phase steelhead have a silvery coloration, but upon entering freshwater to spawn acquire greenish and reddish coloration, including the distinctive reddish band on their sides, and dark, numerous spots on head, upper body and fins are more visible. Adult resident rainbow trout are expected to have this type of coloration pattern throughout their lives. Resident rainbow trout are similar to cutthroat trout (*Oncorhynchus clarkii*), but can be differentiated by the lack of a red slash on the bottom of the lower jaw (Figures 3-5) and presence of hyoid teeth (Pollard et al. 1997).

Figure 3. Hatchery rainbow trout

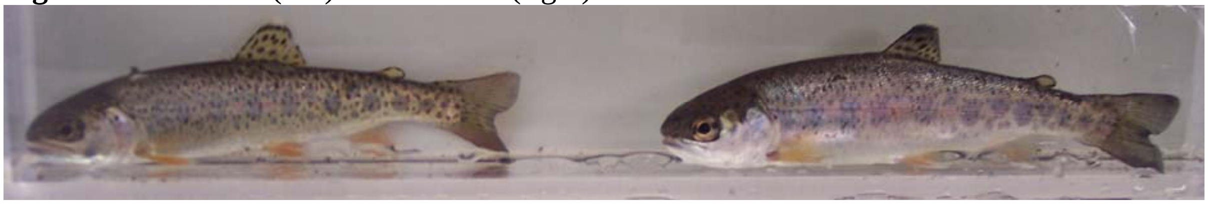
Photograph by Michael L. Blanton

Figure 4. Cutthroat trout (note red slash under jaw)



Photograph by Larry Phillips

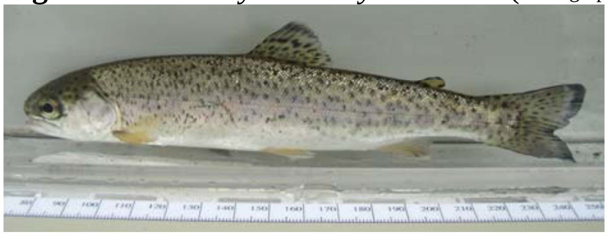
Figure 5. Cutthroat (left) and rainbow (right) trout



Photograph by Cheri Scalf

Juvenile anadromous and resident *O. mykiss* are indistinguishable while rearing in freshwater. Their coloration is extremely variable, with the top of head, back, and upper sides ranging from dark blue to greenish or brown. The lower sides and belly may be silvery white to grayish (Morrow 1980). Juveniles may be heavily spotted with irregularly-shaped spots both above and below lateral line including dorsal and caudal fins (Figure 5). Juveniles may have a rose-red, lateral line band and display 5 – 13 rounded parr marks laterally (Behnke 1992). Rainbow trout parr exhibit white to orange tips on the dorsal and anal fins, and have heavy spotting on the tail. This differs from smolting or marine forms of steelhead, which are a bright silvery color (Figure 6).

Figure 6. *Oncorhynchus mykiss* smolt (Photograph by Cheri Scalf)



Marine phase *O. mykiss* are typically silver, with pink- or orange-tinted pectoral, pelvic and anal fins and a light green dorsal surface (Figure 7). Spotting is common on the dorsal surface and, less so, on the flanks and ventral surface. As with the freshwater form, coloration may vary widely. The common name steelhead derives from the tendency of the dorsal surface of the head to darken to a shiny gray color as the fish approaches the freshwater environment in preparation for spawning. Additional changes that occur as freshwater is approached include darkening of the dorsal surface and a return of the lateral pink or red stripe (Figure 8).

Figure 7. Marine phase *O. mykiss*

Photograph by Michael L. Blanton

Figure 8. Spawning steelhead

Photograph by Michael L. Blanton

Oncorhynchus mykiss fry are approximately 30 mm long and parr are approximately 100 mm long from snout to tale fork (Pollard et al. 1997). Steelhead out migration data from the Nisqually River captured parr ranging in size from 85-145 mm and smolts ranging in size from 150-180 mm (Hiss et al. 1982). Others have reported smolts sizes ranging from 140-160 mm in length (Wydoski and Whitney 1979, Burgner et al. 1992).

The average Washington steelhead adult ranges from eight to eleven pounds. The Washington State sport caught record for winter run steelhead is 32.75 lbs taken from Lewis River in 1980, although steelhead can reach over 40 lbs and over 45 inches in length (Love 1996).

Spawning and Redd Development

Throughout their range along the western coast of North America and around the Pacific rim to southern Japan steelhead are known to spawn in a wide variety of streams, ranging from large mainstem rivers to smaller, even intermittent, streams. In many cases steelhead migrate farther upstream into a river system than other salmonids (WDFW and WWTIT 1994, Quinn

2005), with the possible exception of coho salmon (*Oncorhynchus kisutch*). Steelhead commonly spawn in gravel stream bottoms within the tailout of pools and in riffles (Needham and Taft 1934, Shapovalov and Taft 1954). Visually, this region can be distinguished as being near the point where the smooth surface water transitions into a turbulent riffle (Shapovalov and Taft 1954). If available, overhanging bank cover or complex instream structure (e.g., large woody debris, boulder fields) adjacent to the spawning area are used by spawning steelhead between periods of nest building (Needam and Taft 1934, Shapovalov and Taft 1954).

When spawning, adult female steelhead construct the redd (i.e., series of closely spaced nests) by rolling to their side and using sweeping, powerful tail beats to disturb the benthic sediment, which is displaced downstream by the flow. This process is repeated and a depression or pocket is formed in the streambed. When excavated to a suitable depth and dimension, depending on the size of the fish, eggs are deposited in the depression, fertilized by the male, and then covered by the female with sediment. Only a few seconds are required for the male and female to drop into the depression, complete the synchronized release of gametes, and deposit the eggs (Shapovalov and Taft 1954, Orcutt et al. 1968). The process is then repeated in an upstream direction until the female is spent (Shapovolov and Taft 1954). Fecundity of female steelhead is size dependent and ranges from 3,500- 12,000 eggs for females ranging in size from 508-813 mm in total length on the Alsea River, OR (Bulkley 1967, Busby et al. 1996) to 3,285 eggs/female in 1939 and 2,580 eggs/female in 1940, respectively, on the Green River, WA (Pautzke and Meigs 1940). The process of excavating the redd reduces the fine sediment content of the gravels, improving conditions for water flow through the egg pocket (McNeil and Ahnell 1964).

Egg Incubation and Hatching

Steelhead egg size is, on average, 7.0 mm (range 6.5 – 7.5 mm) (Beacham and Murray 1990) and development duration is dependent upon water temperature. Development time at typical ambient temperatures is approximately 4 to 7 weeks, which is comparable to cutthroat trout but substantially shorter than other salmonids (Table 2) (Quinn 2005). At the time of hatching steelhead are approximately 17 to 18 mm long and weigh about 0.1 gram (Shapovalov and Taft 1954). Newly hatched alevins are inefficient swimmers and do not immediately emerge from their redd (Quinn 2005). Instead they tend to move downward through interstitial spaces, orient toward the water flow, exhibit negative phototaxis, and seek areas of high dissolved oxygen (Quinn 2005). After one to three weeks, dependent on water temperature and dissolved oxygen, alevins absorb their yolk sacs and emerge from the gravels as fry, which most often occurs nocturnally (Quinn 2005). Once fry are free swimming they either take up residence, or relocate to other areas of the stream (Quinn 2005, Pauley et al. 1989).

Table 2. Number of days from fertilization to hatch for Pacific Salmon held at a constant temperature. Adapted from Quinn (2005), pg. 148.

	Temperature (°C)				
Days to Hatch	2°	5°	8°	11°	14°
Steelhead Trout	115	68	42	28	22
Cutthroat Trout	*	61	45	25	*
Chinook Salmon	202	102	67	47	38
Coho Salmon	115	87	63	42	32
Sockeye Salmon	206	120	77	52	47
Chum Salmon	*	97	67	52	46
Pink Salmon	*	99	72	47	40

* = No data

Environmental factors affecting embryo survival

Water quality parameters are primary determinants of steelhead embryo survival. Both developmental rate and survival are positively correlated with dissolved oxygen concentration (Shumway et al. 1964, McNeil 1966) and temperature (Beacham and Murray 1990) of interstitial water. Increased water exchange enables dissolved oxygen to be replenished and remove metabolic waste (McNeil 1966). Embryos subjected to dissolved oxygen levels < 5 mg/l suffer significant mortality (Bjornn and Reiser 1991). Extreme temperature ranges, either too high or low, can also be lethal to embryos. Embryo survival is poor at temperatures < 2°C and > 14°C (Beacham and Murray 1990; Quinn 2005).

Environmental factors, such as the distribution of sediment grain size in spawning gravel and high flow conditions that can result in scour, are also important to the survival of embryos (McNeil and Anell 1964; McNeil 1966). Siltation of redds from fine-grained sediment (particles less than 1 mm in diameter) can fill interstitial spaces, reducing substrate permeability and reducing oxygenated water over the eggs (Bjornn and Reiser 1991). Fine sediments are delivered to stream systems through various sources, including anthropogenic input from logging roads and forest harvest practices (Cederholm et al. 1981). A long term study at Carnation Creek, Vancouver Island, Canada, demonstrated a significant decrease in embryo survival from pre- and post-logging periods that was attributed to an increase of fine materials in the stream bed (Scrivener and Brownlee 1989).

Rearing and Outmigration

Freshly emerged steelhead fry take up residence in shallow, gravel-bottomed areas along the margins of the stream (Shapovalov and Taft 1954, Hartman 1965) or in shallow riffles, among boulders within the channel, or in open water areas landward of boulders and debris (Hartman 1965). Steelhead fry congregate in small schools shortly after emergence. Within weeks, however, they disperse and take up individual feeding territories, which are strongly defended from other fishes (Shapovalov and Taft 1954, Quinn 2005). In tributaries of the Clearwater River, ID, 0+ steelhead ranging from 14.3 - 25.4 mm in length, were found in water less than 20 cm in depth and at velocities of less than 20 cm per second (Johnson and Kucera 1985). With continued growth they then seek territories in higher velocity flows where prey are more abundant (Keeley and McPhail 1998). The body form of juvenile steelhead, and the shape of the median and paired fins, is adapted to maintaining territorial feeding positions in swift portions of the stream (Bisson et al. 1988). Some studies have shown diel patterns of habitat use by steelhead. Steelhead reportedly move from their daytime feeding territories to shallow, lower-velocity areas of the stream at night (Chapman and Bjornn 1969, Reeves et al. 2010).

As steam temperatures rise in spring and summer months and steelhead grow larger there is an increase in energy demand and a concomitant move to territories with a greater abundance of drifting food (Chapman and Bjornn 1969, Smith and Li 1983). An increase in stream velocity from 20 cm per second to 30 cm per second was found to double the available drifting food items (Smith and Li 1983). In the Skagit River, stomach analysis identified chironomid (midge) larvae as the most numerous food item for 0+ steelhead, but as juveniles grew larger Ephemeroptera (mayfly) nymph prey became important (Graybill et al. 1978).

In the fall with the onset of colder water temperatures, 1+ steelhead move to deeper (15-45 cm), lower velocity (< 15 cm/s) areas (Bustard and Narver 1975) and hide within large substrate, roots and woody debris (Hartman 1965, Chapman and Bjornn 1969, Bustard and Narver 1975, Swales et al. 1986, Roni and Quinn 2001). This behavior has not been frequently observed in 0+ steelhead, which tend to use shallow areas of the stream margin and seek shelter in gravel substrates beginning in October as water temperatures approach 7 - 8°C (Hartman 1965, Bustard and Narver 1975, Johnson and Kucera 1985).

Behaviors of over-wintering juvenile steelhead are complex. Some studies indicate that winter rearing steelhead do not enter the substrate, but move throughout pool habitats diurnally (Roni and Fayram 2000, Roni and Quinn 2001). Reeves et al. (2010) observed Cascade steelhead stocks seeking substrate cover during winter daylight hours but dispersing into open water at night. This pattern was reversed in Coastal streams, and laboratory experiments suggest genetic and environmental conditions may be factors influencing winter steelhead rearing behaviors (Reeves et al. 2010). Rainbow trout also tend to seek cover in the interstitial spaces of stream substrate with the onset of winter, with higher densities of rainbow trout juveniles present in more complex configurations of rocks than in widely spaced configurations (Meyer and Griffith 1997). In contrast to steelhead, however, temperature did not appear to be a factor influencing this behavior (Meyer and Griffith 1997).

Throughout their range, steelhead are known to rear in fresh water for a variable number of years before emigration to the marine environment. A high percentage of age 2+ steelhead ocean emigrants appear to be common throughout the southern range of steelhead including California (Shapovalov and Taft 1954), Oregon (Chapman 1958), Idaho (Whitt 1954; BPA 1992), and British Columbia (Maher and Larkin 1954). Conversely, more northern populations tend to have longer freshwater and ocean residence (Withler 1966). One population from Northern Vancouver Island was found to have 60% of seaward migrants rearing in fresh water for three years (Ward and Slaney 1988). Variation in steelhead freshwater rearing life history, both within and among populations, means that downstream migrants are a heterogeneous group consisting of several age classes from various parental sources (Shapovalov and Taft 1954, Christie et al. 2011).

Transition to marine environment

The downstream migration of juvenile steelhead generally takes place from late March through June, with a peak in May (Shapovalov and Taft 1954, Chapman 1958). Juveniles are influenced to begin the parr-smolt metamorphosis and downstream emigration to the marine environment by reaching a threshold size or condition factor, by water temperature, and by lengthening photoperiod (Wagner 1974). Fish size or condition factor is influenced by stream flow, water temperature, water quality, light and food (Wagner 1974). Laboratory studies have demonstrated that photoperiod is the most important factor in initiating the parr-smolt metamorphosis and that temperature also has a significant effect (Zaugg and Wagner 1973, Wagner 1974).

As they reach the threshold size of 160 mm fork length (Scott and Gill 2008), steelhead juveniles become more silvery in appearance, lose their parr marks and begin to form schools (Sharpolov and Taft 1954). They also take on a slimmer body form, reflecting a decrease in condition factor, possibly as a result of a reduction in lipid stores (Fessler and Wagner 1969, Wagner 1974). It has been demonstrated that larger steelhead smolts mature and return from the ocean earlier than smaller smolts (Chapman 1958), and have a higher survival to maturity (Ward et al. 1989).

Oceanic Residence

The behavior and ecology of steelhead is less well known once they emigrate to the marine environment. Upon entering saltwater steelhead smolts make a rather rapid migration to the

Pacific Ocean (Welch et al. 2004, Melnychuk et al. 2007). Steelhead smolt out-migration in freshwater occurs primarily at night, however once smolts enter the sea they move throughout the day and night (Melnychuk et al. 2007). Travel rates in marine waters of approximately 27 km/day have been reported (Melnychuk et al. 2007, Moore et al. 2010). Assuming a body length of 180 mm, these fish were traveling 1.8 body lengths/second. Telemetry work by Ruggerone et al. (1990) found that adult steelhead traveling Dean and Fisher channels, British Columbia, traveled near the surface (72% of the time in the top 1m of water column). Steelhead are typically thought of as occurring in the top few meters of the water column, however Walker et al. (2000) recorded them making moderate descents to depths of 50 m.

Steelhead smolts enter the ocean in spring and are found in the greatest concentration between 42°N and 52°N from the North American coastline westward to approximately 155°W in the Gulf of Alaska (Burgner et al. 1992). Several studies have shown that North American winter steelhead use a broad swath of the central north Pacific Ocean, the Gulf of Alaska, and an area along and south of the Aleutian Island chain (Light et al. 1988, Burgner et al. 1992, Myers et al. 1996). Steelhead are distinctly absent from the colder (northern) regions of the Pacific Ocean that other salmon species occupy, and this phenomena is particularly evident during winter and spring (Welch et al. 1998). Distributions of winter-run fish have generally been similar to those for summer steelhead, though winter fish may have a more western and northern distribution (McKinnell et al. 1997).

Though mortality rates immediately following migration into estuaries, such as Puget Sound, are generally high, daily mortality rates appear to decrease substantially after steelhead enter the open ocean (Moore et al. 2010). Some research suggests that a strong limiting factor on steelhead populations is early marine survival. On the Cheakamus River, Howe Sound, British Columbia both hatchery and wild steelhead populations demonstrated precipitous declines in survival with increasing migration distance, though significant differences in smolt survival rate existed between hatchery (23-36%) and wild (69-72%) fish (Melnychuk et al. 2009).

Ocean conditions influencing the survival of steelhead, and other salmonids, change every several years in an oceanic and climatic phenomenon known as the Pacific Decadal Oscillation (PDO) (Mantua et al. 1997). Periodically coastal upwelling brings cold, nutrient-rich waters towards the ocean surface creating favorable conditions for phytoplankton and zooplankton that ultimately benefit salmonid early marine survival (Smith and Ward 2000, Moore et al. 2010). Steelhead that reach these favorable ocean conditions will ultimately have higher survival rates than those that come before or after this window of ocean stability (Gargett 1997).

In an effort to catalogue variation in steelhead residence time in both freshwater and marine systems, the International North Pacific Fisheries Commission collected scales from 10,668 immature and maturing steelhead collected offshore by research vessels from 1955 through 1985 (Burgner et al.1992). Of these samples 65.7% were 2-4 years old and the following four life history types, shown as years in freshwater followed by years in marine environments, were most prevalent: 3.1, 2.1, 3.2, and 1.1. The oldest fish collected was ten years old, having spent 5 years in freshwater and 5 years in the ocean (i.e., 5.5) (Burgner et al. 1992). The seasonal distributions of sampled steelhead, regardless of age, as measured by catch per unit effort are shown in Figures 9 and 10 below.

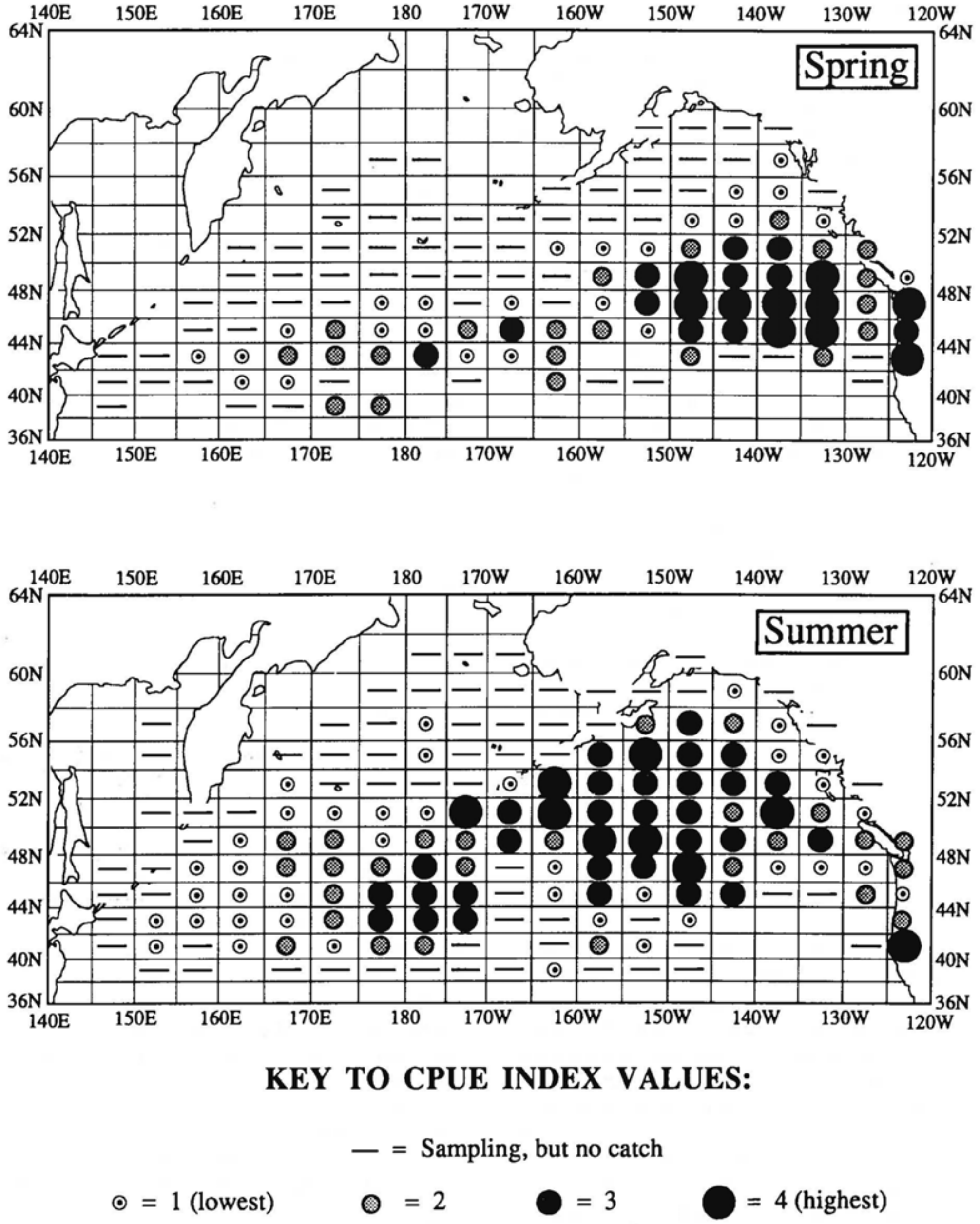


Figure 9. Ocean distribution of steelhead in spring (March-May) and summer (June-August) based on weighted average catch per unit effort (CPUE) data from U.S. and Canadian (1955-1990), U.S.S.R (1983-1990), and Japanese (1981-1989) research vessels fishing with purse seines, gillnets, and longlines. Copied from Burgner et al. (1992). Reproduced with permission from North Pacific Anadromous Fish Commission.

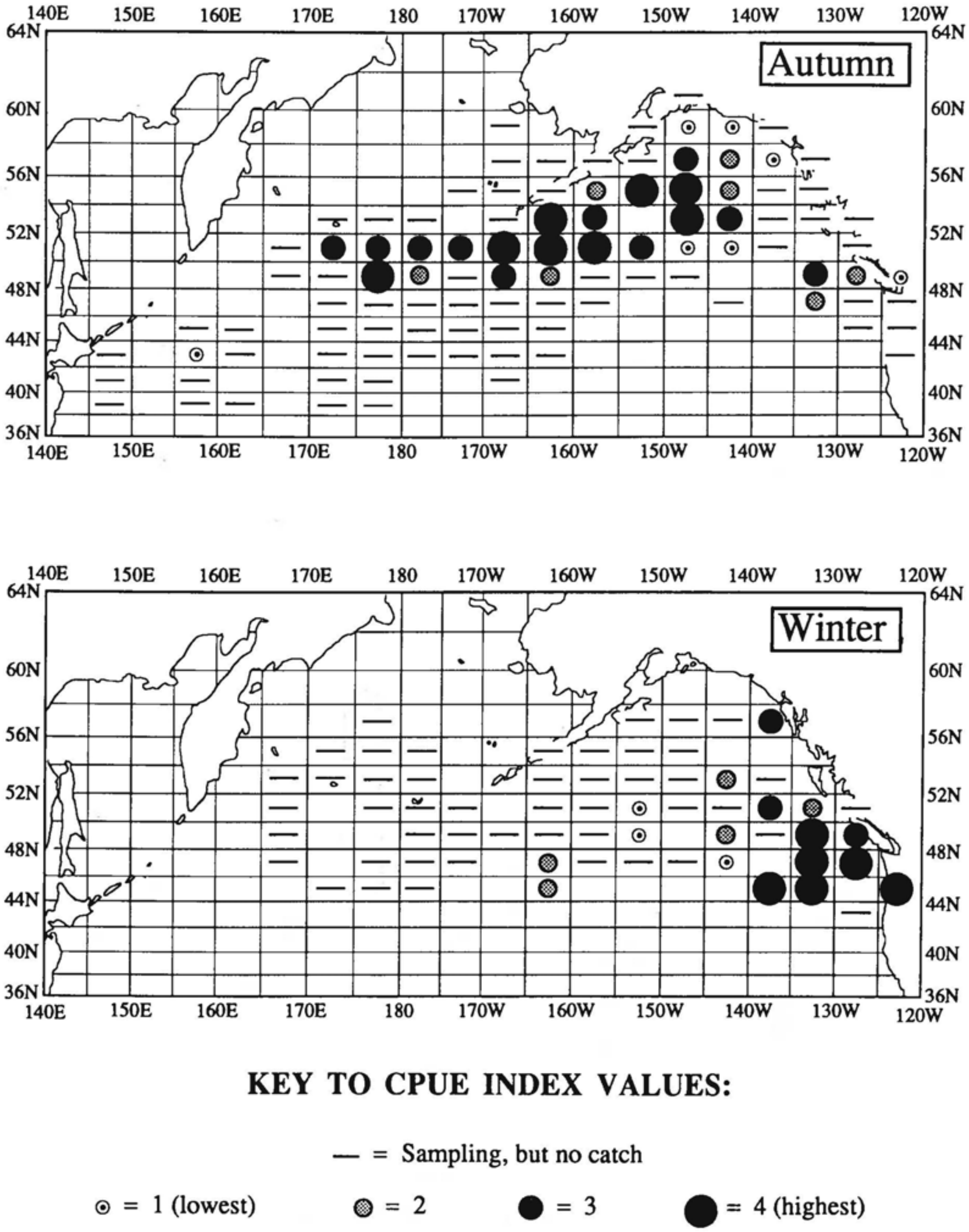


Figure 10. Ocean distribution of steelhead in autumn (September-November) and winter (December-February) based on weighted average catch per-unit-effort (CPUE) data from U.S. and Canadian (1955-1985) and Japanese (1981-1989) research vessels fishing with purse seines, gillnets, and longlines. Copied from Burgner et al. (1992). Reproduced with permission from North Pacific Anadromous Fish Commission.

Steelhead Foundations Open Standards

As the beginning of an Open Standards for the Practice of Conservation for Puget Sound steelhead the first step is to develop a conceptual frame work of the basic parameters for the project, including personal composing the project team, the public entities and stakeholders to be involved, and the project scope and vision.

By definition Open Standards for the Practice of Conservation is public, thus involvement of entities for conservation planning for Puget Sound Steelhead should include federal and state agencies, Native American tribal governments and their salmon co-management programs, local governments, Lead Entities for Salmon Recovery, Regional Enhancement Groups, Environmental Groups, both sport and commercial fishing organizations, and representatives of trade and industry groups.

The geographic scope of the project would include the Puget Sound Steelhead Distinct Population Segment (DPS) area (see Figure 12a+b).

The stated vision for the project will be developed with consensus of the stakeholders involved but should include incorporation of Viable Salmonid Population (VSP) criteria for identified Puget Sound steelhead stocks.

Figure 11 provides the conceptual Open Standard model for Puget Sound Steelhead. The conceptual model includes goals, strategies, assumptions and objectives. These elements provide a portion of step two in the Open Standards Project Management Cycle. The completion of step two would include the development of monitoring and operational plans.

The three final steps in the Open Standards Project Management Cycle are: Implement Actions and Monitoring; Analyze, Use and Adapt; and Capture and Share Learning.

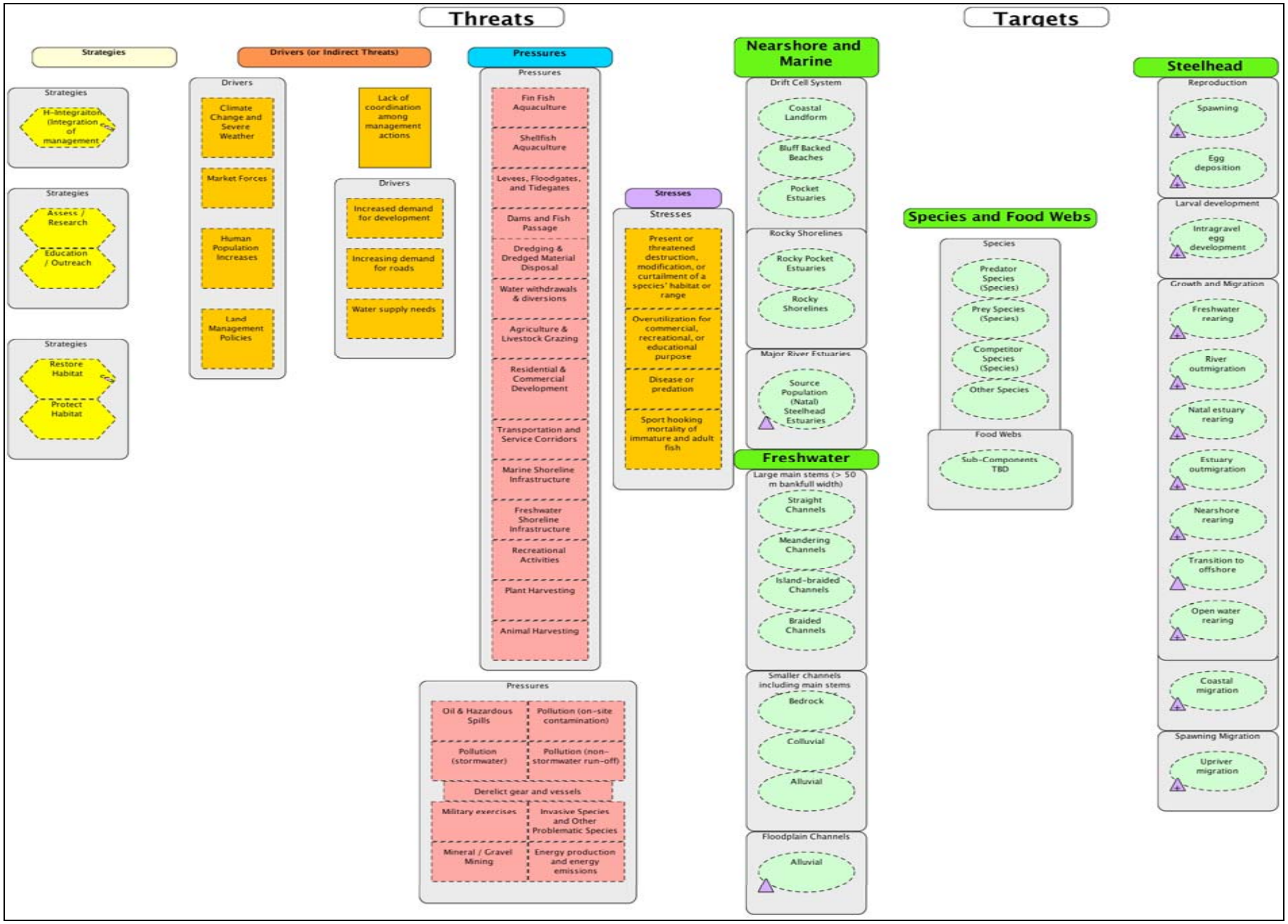


Figure 11. Conceptual open standards model for Puget Sound steelhead recovery.

Puget Sound Steelhead

The Puget Sound Steelhead Distinct Population Segment (DPS) encompasses all known, naturally spawning populations of steelhead occurring in tributaries to Puget Sound east of the Elwha River on the Strait of Juan de Fuca, inclusive, and north to the Canadian border (Figure 12a+b). Additionally, the Green River natural and Hamma Hamma winter-run hatchery steelhead stocks are included. Puget Sound steelhead are predominately winter-run, with summer-run populations typically occurring upstream of physical features, such as water falls, that are migration barriers to winter-run steelhead due to a lack of river flow during the months they return (Figure 12a+b). Summer-run steelhead can ascend these barriers due to high flows from late spring and summer snow melt (WDFW and WWTIT 1994).

Puget Sound steelhead juveniles remain in fresh water on average 2 years (range: 1–5 yrs) before heading to sea as smolts (Pautzke and Meigs 1940, Maher and Larkin 1954, Shapovalov and Taft 1954, Busby et al. 1996). Acoustic tagging studies suggest that Puget Sound steelhead smolts migrate rapidly through estuaries (Moore et al. 2010, Dorn and Small 2011). Puget Sound steelhead spend approximately one or two years at sea before returning for their first spawning migration. Deer Creek (N. F. Stillaguamish) summer-run steelhead are unusual in that most spend only one year at sea prior to their first return (WDFW and WWTIT 1994, Busby 1996).

Spawning migrations in river systems of Puget Sound are relatively short (1 to 100 miles) compared to several hundred miles in the Columbia and Fraser Rivers. Many small independent tributaries, such as those in Hood Canal, have only a few miles of available habitat. Thus, winter-run adults return in a sexually mature condition and spawn relatively soon after entry into fresh water (Busby et al. 1996). Summer-run steelhead in some large Puget Sound rivers, such as the Stillaguamish and the Snohomish, typically use habitat in tributaries that are not available to winter-run fish due to seasonal migration barriers. Summer-run steelhead return to river mouths between April and October as sexually immature fish and hold in freshwater for several months before spawning (Busby et al. 1996). In general, summer steelhead spawn earlier in the spring than winter-run steelhead, but spawn timing can overlap (Busby et al. 1996). Some Puget Sound rivers, such as the Sauk, have summer- and winter-run steelhead that co-occur and are not separated by migration barriers. In these cases, the overlap in spawning habitat and spawn timing suggest that interbreeding may occur between the two run types (WDFW and WWTIT 1994, Busby et al.1996). In addition to run timing, the environment in which gonadal maturation occurs and spawning seasonality are the most divergent characteristics of these stock types (Table 3).

Figure 12a. Boundaries of the Puget Sound Steelhead Distinct Population Segment (DPS) showing winter-run populations.

Figure 12b. Boundaries of the Puget Sound Steelhead Distinct Population Segment (DPS) showing constituent summer-run populations.

Table 3. Puget Sound winter- and summer-run steelhead stock attributes

Characteristic	Winter-run	Summer-run
Number of unique stocks	37	16
Gonadal maturation	Marine environment	Freshwater
Timing of return to freshwater as adult	November - July	May - November
Spawn timing	January to mid-June, peak mid-April through May	January to May, without obvious peak period
Years in ocean prior to first spawn	Range from 1-5 years; variation within stock.	
Years in river prior to out migration	Range from 1-5 years; variation within stock. Range from 2-3 years most common.	

The frequency of iteroparity in Puget Sound steelhead varies among stocks. Estimates from a variety of stocks range from 6 to 9% (Scott and Gill 2008), to 8.3% (Seamons and Quinn 2010), to 7 to 11% (Busby et al. 1996) of adults engaging in their second spawning migration during a given season. A very small percentage of steelhead may make a third spawning migration. Busby et al. (1996) estimated that < 1% of returning Puget Sound steelhead were in their third spawning migration and most of these were females. By comparison, the iteroparity rate for steelhead stocks in the interior Columbia River Basin is relatively low: Hood River (4.6%), Klickitat River (3.3%), Walla Walla River (2 to 9%), and Yakima River (1.6%) (Hatch et al. 2003). Iteroparity among steelhead populations may increase with latitude. For example, iteroparity was estimated at 79% in the Utkholok River of Kamachatka (Savvaitova et al. 1996) and 30% in the Karluk River, Alaska (Van Hulle 1985). Increases in migration distance and the presence of passage barriers may reduce the rate of iteroparity by decreasing survival probability.

Redd Construction and Spawning Behavior

Puget Sound steelhead spawn in a wide variety of streams, from large mainstem rivers, to headwater tributaries of these mainstem rivers, to small independent tributaries to the Sound itself (WDFW and WWTIT 1994). In smaller streams, WDFW field staff have noted that redds are also associated with areas near deep pools, logs, and overhangs, while few redds are located in areas without adjacent cover despite the apparent suitability of depth, velocity and gravel size (Dave Low and Randy Cooper, WDFW – pers. comm.). In mainstem channels where riffles and tailouts are broader and larger, steelhead redds can be less associated with structural cover because, when disturbed, steelhead can use depth, turbidity and surface disturbance for cover.

Female steelhead prefer to construct redds in water depths ranging from 0.3 to 5.0 feet and velocities ranging from approximately 0.9 to 3.3 feet per second (Orcutt et al. 1968, Smith 1973). On the Skagit River, Steelhead were found spawning in water 0.9 – 2.9 feet in depth with a current velocity if 1.5-3.0 ft/sec (Graybill et al. 1979). Gravel size preferences are also apparent and females tend to select gravel ranging from 0.6 to 10.1 centimeters in diameter, and entirely avoid gravel larger than 15centimeters (Reiser and Bjornn 1979). Size of spawners is one of the factors that determine the size and depth of redds and the largest gravel sizes suitable for spawning substrates (Kondolf 2000). Rainbow trout use slightly smaller gravel substrate, ranging from 0.6 to 5.2 centimeters (Orcutt et. al. 1968, Reiser and Bjornn 1979), and generally construct smaller redds in shallower, slower moving water (Table 4; Zimmerman and Reeves 2000). Redds can be constructed over varying time periods ranging from one day to a week (Groot and Margolis 1991).

Table 4. Redd Dimensions and habitat attributes for steelhead and rainbow trout (after Zimmerman and Reeves 2000).

	Redd dimensions		Redd site characteristics		
Life History	Width (m)	Length (m)	Depth (cm)	Velocity (cm/sec)	Gravel (mm)
Rainbow Trout	0.8	1.5	42.6	63.4	25.1
Steelhead	1.2	2.1	54.1	71.4	32.5

Two types of male steelhead mating behavior were described by McMillan et al. (2007) within the Quileute River basin, located on the Olympic Peninsula, Washington. The two tactics, termed “guarding” and “sneaking”, have also been observed in other salmonids. For Quileute River steelhead guarding dominated slightly (53% of observations) over sneaking and the propensity to sneak was determined by the presence, size and aggression of competing males. Both strategies were successful in securing matings for the fish who employed them. Additionally, a shift was observed from male steelhead to male rainbow trout in the population later in the spawning season. This lack of male steelhead meant that late arriving females only had the option of mating with male rainbow trout (McMillan et al. 2007). During this later portion of the spawning season, with absence of a larger dominate male, a third mating tactic, termed group mating, was observed.

Embryo survival, juvenile rearing, and outmigration

Changes in the magnitude and frequency of high and low flow events in Puget Sound streams and rivers have dramatic effects on channel structure, habitat complexity and the exchange and movement of nutrients through various substrate classes (Quinn 2005). High water and flooding events can cause redd scouring (McNeil 1966, Montgomery et al. 1999), as well as changes in stream channel form and streambed gravel composition (Scrivener and Brownlee 1989, Hartman and Scrivener 1990). High water and flood events that occur during times when developing embryos are susceptible to mortality from physical "shock" can have negative impacts on egg survival. The susceptible period is from 2-13 days after fertilization (Jensen and Alderdice 1989).

Provided steelhead larvae survive long enough to emerge from the gravel, emergence time can vary considerably, both within and among populations. In the Skagit River system, including the Cascade and Sauk Rivers and numerous small tributaries, steelhead fry numbers peaked in October of one year but remained low until July the following year (Graybill et al. 1979, Kahler 1999). Despite these peaks, fry were present during both years well into the summer. Fry captured in June were approximately 30 mm in total length, whereas the following December fry averaged 75 mm (Graybill et al. 1979). As mentioned above, from the onset of exogenous feeding fry condition, growth, and, likely, emergence time are dictated by food availability and environmental factors that have the potential to vary dramatically on an annual basis.

Steelhead juveniles originating from Puget Sound streams typically spend 2 years in freshwater. In the Green River, 73% of steelhead emigrated at age 2+, with smaller percentages emigrating at ages 1+ and 3+ (Pautzke and Meigs 1940). The average length was 15.2 cm for age 1+ smolts, 16.6 cm for age 2+ smolts, and 22.7 cm for age 3+ smolts (Pautzke and Meigs 1940). In Snow Creek, a small tributary to Puget Sound, 84.5% of steelhead emigrated at age 2+, with smaller percentages emigrating at ages 1+ and 3+ (WDFW and WWTIT 1994). The average length of ages 1+, 2+, and 3+ smolts were 13.9 cm, 16.4 cm, and 19.5 cm, respectively (WDFW and WWTIT 1994). Emigration at age 2+ and approximately 16 cm is by far the most common life history strategy throughout Puget Sound, with the percentage of age 2+ emigrants ranging from 79-95% of the smolt population (Busby et al. 1996).

Puget Sound steelhead smolts rapidly reach salt water once downstream migration is initiated, generally taking no more than a few weeks (Shapovalov and Taft 1954, Chapman 1958). In the Green River, travel time to exit the river is less than two weeks (Goetz et al. 2008, unpublished data) and migration occurs during both day and night (Chapman 1958, Goetz et al. 2008, unpublished data).

Oceanic Residence

Puget Sound steelhead smolts generally exit the estuary rapidly and do not make extensive use of the nearshore environment. Using acoustic telemetry Moore et al. (2010) demonstrated that migrating steelhead smolts from Hood Canal travel in open water far from the beach and move quickly toward Admiralty Inlet. Additionally, it was estimated that over 58% of the steelhead smolts released in this study perished within 3 to 4 weeks, prior to exiting the Strait of Juan de Fuca and entering the Pacific Ocean proper. A three year nearshore fish utilization assessment along the northern shoreline of the Kitsap Peninsula collected over 230,000 fish of 60 species, including Chinook, chum, pink and coho salmon juveniles. Despite fishing during both the day and night between the months of February-November, 2007-2009 they never encountered a steelhead smolt during beach seining (Dorn and Small 2011).

Little is currently known about the habitats utilized by Puget Sound steelhead between the time they emigrate as smolts and the time they return to spawn as adults. Kovalenko et al. (2005), while investigating the diet of steelhead of the Pacific Kurils islands located between the southern tip of the Kamchatka Peninsula, Japan, the Sea of Okhotsk and the north Pacific Ocean, recovered six fin clipped steelhead. The fish were determined to be from either the Dworshak or Clearwater hatchery on the Snake River in Idaho (Dr. Nancy Davis, North Pacific Anadromous Fish Commission; pers comm).

Homing and Straying

A small percentage of wild steelhead do not return to their natal stream, and instead “stray” making spawning migrations into other rivers. Straying rates of 6.8% for Columbia River steelhead have been demonstrated (Keefer et al. 2005). However, straying rates for native populations of Puget Sound steelhead have not been well described. Hatchery steelhead, as identified by a clipped adipose fin, often do not return to their hatchery of origin and can be found in wild steelhead habitats. While it is possible that most stray hatchery steelhead in a given river are from an in-basin hatchery or nearby river, there are few data to verify this because hatchery-specific tags (e.g., coded wire tags) are not usually applied. In Puget Sound, hatchery steelhead in natural habitats are considered a risk to native populations, because most hatchery programs produce domesticated strains of steelhead that are not ESA-listed and not suitable for recovery purposes. Exceptions to this rule are the experimental Hood Canal rivers program lead by NOAA Fisheries and a White River program conducted by WDFW and Muckleshoot and Puyallup Indian tribes.

Focused Watershed Profiles for Puget Sound Basins – WRIA's 1-18

Nooksack Watershed (WRIA 1)

The Nooksack Basin is the largest salmon-producing system within Water Resource Area Inventory Area (WRIA) 1 (Figure 13) and contains as many as 19 independent salmonid stocks (4 steelhead , 4 possible Chinook, 2 chum, 1 coho, 3 pink, 1 riverine sockeye, 1 cutthroat, and 3 Dolly Varden/bull trout) (Smith 2002). The majority of salmonid spawning habitat in the Nooksack Basin is located in the three forks of the Nooksack River, however much of this area has considerable sedimentation problems resulting from landslides associated with clearcuts and roads (Smith 2002). The North and Middle Fork Nooksack Rivers have naturally high sediment loads due to glacial inputs. Sediment transport is further impaired by a lack of large woody debris (LWD), and excess sedimentation has likely contributed to a lack of adequate pool habitat.

Other habitat problems in the Forks include impacts to riparian, floodplain, water quality and flow conditions, and most of these problems occur in the lower reaches. The lower South Fork Nooksack River has been substantially diked, decreasing channel length and complexity and resulting in a lack of secondary channels (Smith 2002). Riparian conditions are rated "poor" in this same area, as well as in some of the tributaries, and elevated water temperatures are a critical problem in the sub-basin. Warm water temperatures have also been recorded in the lower Middle Fork Nooksack River and Canyon Lake Creek, but temperature data are lacking in other tributaries. The lack of shade, loss of wetlands, and channel changes are probable causes for warm water temperatures (Smith 2002). Riparian conditions are generally poor along the lower Middle Fork Nooksack River and Rankin Creek, but are fair elsewhere in the sub-basin. While the lower North Fork Nooksack River has experienced some warm water temperatures, most of the water quality problems are in the tributaries. Many areas also have degraded riparian and sedimentation conditions, both of which lower water quality. The Nooksack River sub-basin (downstream of the Forks) has a heavily impacted floodplain and very poor riparian conditions. Compared to other rivers in the Puget Sound region, the Nooksack River near Ferndale has among the highest levels of nitrogen (including ammonia and nitrate), phosphorous, turbidity, and suspended solids.

Inadequate stream flows for steelhead are a pervasive problem throughout the Nooksack Watershed, and can exacerbate water quality problems. Many of the lowland streams and tributaries flow through agricultural or urban land, and many reaches are closed to further water allocations in an effort to preserve instream flow (Smith 2002). Land cover vegetation has been greatly altered downstream of the Forks, as well as in watersheds draining to the lower North, South, and Middle Fork Nooksack Rivers.

Independent Drainages

Several smaller, independent drainages in WRIA 1 (the Dakota, California, Terrell, Squalicum, Whatcom, Padden, Chuckanut, Oyster, and Colony Creek sub-basins) provide habitat for steelhead and other salmonids. Low stream flows are also believed to be a problem in many of these streams, prompting closures for further water allocations. Riparian vegetation has also been greatly decreased and altered, increasing the likelihood of water flow impacts. Elevated water temperatures have been documented in Dakota, Squalicum, Whatcom, Padden, and Chuckanut Creeks. Toxins, such as pentachlorophenol, and mercury, lead, zinc, and copper have been documented in Whatcom Creek, with urban and industrial storm water runoff the suspected source.

Floodplain conditions are poor in Dakota, California, and Squalicum Creeks due to wetland loss or bank hardening.

Fraser River Tributaries

Though most of the Fraser River basin lies in Canada, several small tributaries drain across the international border from northern Washington. Habitat conditions in Washington's Fraser River tributaries vary greatly with land ownership, with the upper Chilliwack sub-basin and others found within National Park Service or U.S. Forest Service boundaries being relatively pristine. In contrast, the Sumas River, Saar Creek, and Frost Creek sub-basins are extensive impacted by development. Levels of nitrogen (including ammonia) and phosphorous in the Sumas River are among the highest levels in the Puget Sound region, and low dissolved oxygen levels have been documented in several tributaries. Numerous water rights exist throughout the Sumas River watershed, and the Sumas River and Saar Creek are closed to further water allocations.

Estuarine and Nearshore Environments

Condition of the estuarine and nearshore habitat associated with the Nooksack Watershed varies considerably with location. Estuary habitat loss has been documented in Bellingham, Lummi, and Samish Bays. Overall, Whatcom County ranked 8th out of 14 Puget Sound Counties for the percent of modified (e.g., armored with bulkheads or rip-rap, filled) shoreline miles (Smith 2002). Most of these areas also have poor overhead riparian vegetation. Overwater structures, which can impact eelgrass beds and directly affect steelhead behavior, are also a concern in several areas (Smith 2002).

Water quality (including sediment contamination) is a major problem in inner Bellingham Bay, where numerous toxins (e.g., mercury, arsenic, and PCBs) have been found. These compounds can directly affect the health of steelhead, as well as being lethal to benthic organisms that serve as food. Other water quality issues in the watershed include creosote treated materials and oil spills.

Condition of Steelhead Populations

There are four steelhead stocks in WRIA 1, three winter- and one summer-run, all of which are of unknown status (WDFW and WWTIT 2002). All are of native origin with completely wild production. The winter stocks are: 1) the Mainstem/North Fork Nooksack stock, 2) the Middle Fork Nooksack stock, and 3) the South Fork Nooksack stock (WDFW and WWTIT 1994). Summer steelhead spawn in the upper South Fork Nooksack River including upstream from RM 30.4, but the run has been historically small (WDFW and WWTIT 1994). Native rainbow trout are found in the North Fork Nooksack drainage, and non-native rainbows are cultured at the Whatcom Falls Hatchery for releases throughout North Puget Sound. Steelhead in the Chilliwack River belong to a Canadian stock and enter via the Fraser River.

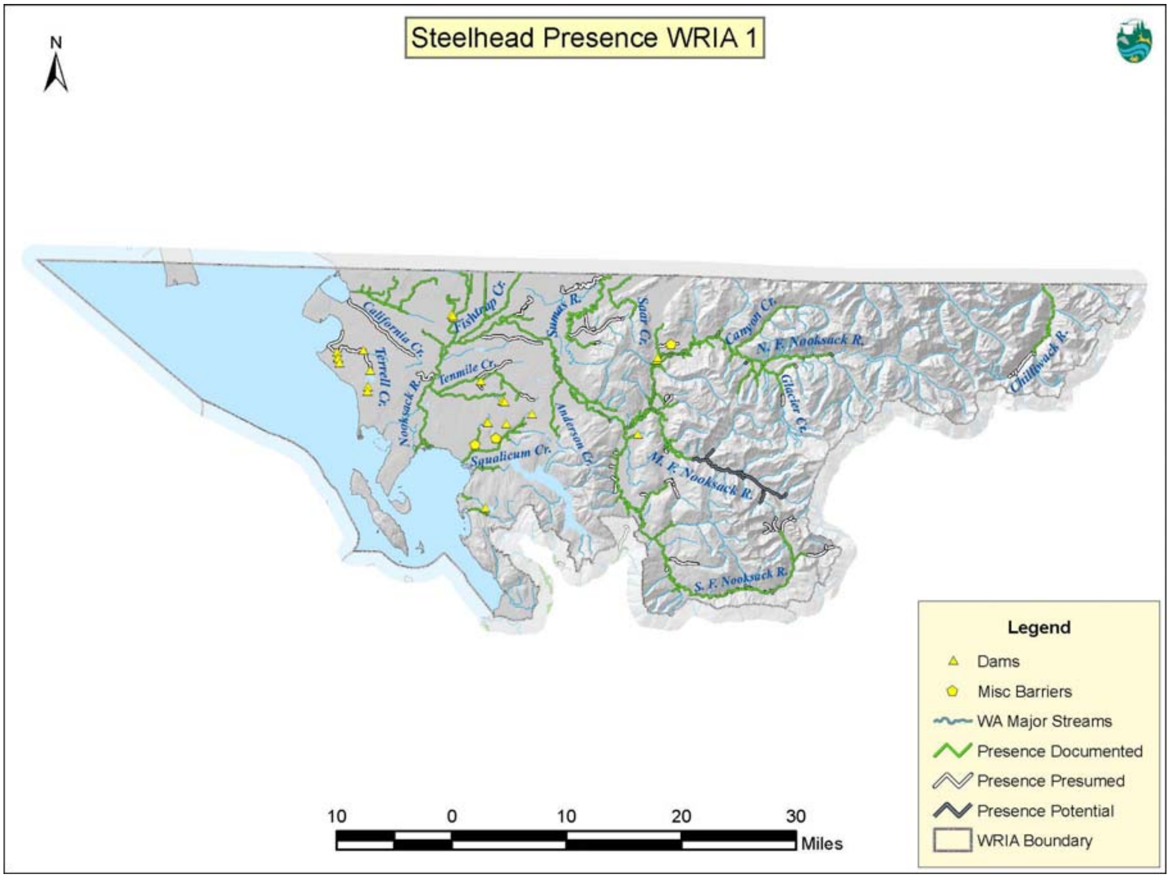


Figure 13. The distribution of steelhead in WRIA 1. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

San Juan Watershed (WRIA 2)

The San Juan Islands (WRIA 2) contain at least 85 identified freshwater streams. Williams et al. (1975) identified approximately 100 miles of stream habitat in the Islands but did not address accessibility issues for anadromous salmonids. The Washington Department of Natural Resources has identified 83 streams on Orcas Island, 64 on San Juan Island, 20 on Lopez Island, 18 on Shaw Island, and 6 on Blakely Island. Together this amounts to an estimated 158 miles of potential habitat. Only a few of these streams are naturally accessible to anadromous salmonids, however, as most streams enter the marine environment from points that are perched or down a gradient too steep for salmonids to ascend. There are no known naturally sustaining populations of anadromous or resident salmonids in the freshwater habitats of the San Juan Watershed.

Value of the San Juan Islands to Salmonids

There are no known naturally reproducing salmonid populations and/or stocks in the San Juan Islands. The value of the San Juan Islands is the diverse nearshore habitats that serve as nursery grounds to migrating juvenile salmonids from other watersheds, and in their production of forage fish utilized by sub-adult and adult salmon on return migrations. Forage fish found within the nearshore marine habitats of the San Juan Watershed include herring, surf smelt, and Pacific sand lance. Within the nearshore of the San Juan Watershed, there are numerous known herring spawning areas and a number of documented surf smelt and Pacific sand lance spawning beaches (Penttila 2007). Continuing studies are documenting additional forage fish spawning areas.

Condition of Steelhead Populations

Resident trout are found in a number of lakes throughout the San Juan Islands but none are believed to be self-sustaining and anadromy is not known to be present.

Skagit and Samish Watersheds (WRIAs 3+4)

The Skagit River Watershed (Figures 14+15) is the largest in Puget Sound and produces the greatest abundance of salmonids belonging to the greatest number (19) of salmonid stocks (WDFW and WWTIT 2002). This includes the most abundant chum and pink salmon populations in the contiguous United States (Beamer et al. 2000; City of Seattle 2001). Most of the salmonid populations within the Skagit Basin are of native origin with relatively little influence from non-native introductions, and are considered healthy (WDFW and WWTIT 1994, WDFW and WWTIT 2002). A notable exception to this trend is the Chinook stocks, which are depressed (WDFW and WWTIT 2002). In contrast, the Samish Basin has had extensive non-native population influences on its salmon populations. The Samish Basin supports coho, chum, and Chinook, one population of steelhead, and one population of cutthroat trout (WDFW and WWTIT 2002).

Estuarine Habitat Conditions

Estuary deltas associated with the Skagit and Samish Watersheds include the Samish, east Padilla, Swinomish Channel, North and South Fork Skagit, central Skagit, and Douglas Slough. The loss (72%) of intertidal habitat in the Skagit delta (including the nearby sloughs) has been considerable (Beamer et al. 2002). Dikes have isolated much of the historic delta habitat, and fish-blocking tide gates associated with the dikes are numerous. While many of the tide gates do not allow salmon access, they also prevent adequate tidal flushing. Further impacts to the isolated delta habitat, such as ditching, channelization, filling, riparian loss, and loss of habitat complexity have highly degraded the isolated habitat.

Lower Skagit Sub-Basin

The lower Skagit sub-basin (all streams downstream of the Sauk River confluence except the Baker River) (Figure 14) contains the most highly degraded freshwater habitat in the basin, and loss of wetlands has been extensive. While the lower Skagit River has the most extensive floodplain area in the basin, at an estimated 108 square miles, degradation as a result of diking an riprap installation has been abundant. An estimated 62% of the Skagit River channel length from Sedro Woolley to the mouth has been modified by diking and bank protection, and only 10% of this length has split channels or island habitat (Duke Engineering 1999; Beamer et al. 2000).

Water quality in the lower Skagit River has been degraded by development. Elevated levels of nutrients and chronic levels of lead and copper, generated by urban and highway runoff, wastewater treatment, failing septic systems, and agriculture/livestock impacts, have been documented in the lower mainstem Skagit River. Water quality in the tributaries to the lower Skagit River is worse than the mainstem. Most of the lower Skagit tributaries have warm water temperatures during summer months. In some tributaries elevated nutrients, low dissolved oxygen levels, toxic organic compounds and heave metals, and increased turbidity are also present. Many of the same sub-basins that have warm water temperatures also have riparian and sediment impacts, and these are likely contributors to at least part of the water quality problems in the lower Skagit tributaries (Beechie and Feist, NMFS, unpublished data). Very few drainages within the Skagit have been thoroughly assessed for sedimentation causes, but for those that have landslides associated with clearcuts and roads are major sources. A lack of large woody debris (LWD) and pool habitat has also been noted in those areas that have been assessed (Beechie and Feist, NMFS, unpublished data). Most lower Skagit tributaries also exhibit impaired flow conditions (Beamer et al. 2000).

Fish access conditions (culverts, small dams, etc.) have been inventoried and prioritized via remote sensing methods to guide future field assessments. Many high and medium priority blockages exist in the Carpenter, Nookachamps, and Hansen Creek sub-basins.

Upper Skagit and Sauk Sub-Basins

Much of the upper Skagit sub-basin (streams upstream of the Sauk River confluence) is within National Forest boundaries or protected in the National Park, a national recreation area, or a designated wilderness area, generally resulting in good habitat conditions. Known impairments include a fairly high road density in the upper Skagit River floodplain and degraded riparian conditions in the Corkindale sub-basin, along the mainstem Skagit River, and in lower Jordan, Shoemaker, and lower Boulder Creeks. Excess sedimentation has been documented in Jordan and Boulder Creeks, accompanied by a loss of habitat complexity. No known water quality problems have been documented in this sub-basin.

The largest habitat alterations in the upper Skagit sub-basin are a result of dams and associated hydroelectric and flood storage activities, which are located upstream of historic steelhead use. Seattle City Light operations have evolved to protect downstream fish resources to a great degree through agreements for appropriate ramping rates and flows. However, the magnitude of peak flows by return period has decreased by 50%, and this has likely impacted the development of side channels (Beamer et al. 2000). Dams have also possibly impaired sediment and LWD transport, though recent off-channel habitat enhancements are offsetting this.

The Sauk River is the largest tributary to the Skagit, and much of the drainage is within National Forest boundaries. Many of the known impacts to salmonid habitat are in the areas that are predominantly private or state owned. Riparian habitat conditions throughout much of the sub-basin are poor. Excess sedimentation has been estimated for portions of the sub-basin, while in other areas it is not an issue (Beamer et al. 2000). Reduced pool habitat and LWD has been noted in some areas, but data are lacking for many tributaries.

Baker Sub-Basin

The greatest impact to steelhead habitat in the Baker River sub-basin is the activity associated with the dams and hydroelectric operations. In the recent past, flow and downramp agreements have not been met, occasionally leading to dewatering of spawning reaches, damaging redds (Brulle 2002). Dams have also directly altered habitat in the Baker sub-basin, including destruction of wetlands and ponds, side-channels, and small tributaries (U.S. Forest Service 2002). Dams, and their operation, have also impacted sedimentation and riparian vegetation. Despite dam-related impacts, habitat in the Baker sub-basin is generally good. Although the number of landslides is low, many are associated with roads, and those have increased sediment delivery to streams by 21 fold in the Baker Lake drainage and 150 fold in the Lake Shannon drainage (U.S. Forest Service 2002). Riparian condition is either generally good or fair in the sub-basin, and water quality conditions are good with the exception of warm water temperatures in Bear Creek.

Samish River Basin

The Samish River is well known for having low gradients throughout much of its mainstem and its largest tributary, Friday Creek, which makes it highly accessible to steelhead. However, most of the land is under private ownership, and habitat impacts are abundant. Much of the lower Samish River is diked, resulting in a loss of estuarine and freshwater habitat. Both the Samish and Friday Creek have generally poor riparian conditions due to conversion to non-forest land uses (Beamer et al. 2000). Water quality is also, with warm water temperatures, increased nitrogen, phosphorus, and turbidity throughout the system. The likely causes of the water quality problems include loss of riparian vegetation, sedimentation, hydrologic alterations (wetland losses), and inputs from agriculture and failing septic systems. The overall sediment supply rates are estimated as high for both the Samish River and Friday Creek.

Condition of Steelhead Populations

Six populations of steelhead were described in the Skagit Basin in 1993 (WDFW and WWTIT 1994): a winter-run stock in the Mainstem Skagit, a summer-run stock in Finney Creek, and both winter- and summer-run stocks in the Sauk and Cascade Rivers. As spawning areas are generally continuous for the three winter-run stocks, they were later combined for status reporting purposes (WDFW and WWTIT 2002). All winter-run steelhead are of native origin with wild production, and the Skagit winter steelhead population has declined from healthy status in 1993 to depressed status in 2002 (WDFW and WWTIT 1994, WDFW and WWTIT 2002). The status of all three summer steelhead stocks is unknown, due to a paucity of data (WDFW and WWTIT 2002). The three populations are greatly separated spatially in spawning distribution. Finney Creek and Sauk River summer steelhead are of native origin with wild production, while the Cascade River stock has an unknown origin and wild production (WDFW and WWTIT 2002). No spawning abundance estimates are available for any of these populations.

A native, wild population of winter steelhead spawns throughout the Samish River and Friday Creek, as well as other small tributaries. The status of this stock changed from depressed in 1992 to healthy in 2002 because run size regularly exceeded the goal of 700 spawners (WDFW and WWTIT 1994, WDFW and WWTIT 2002).

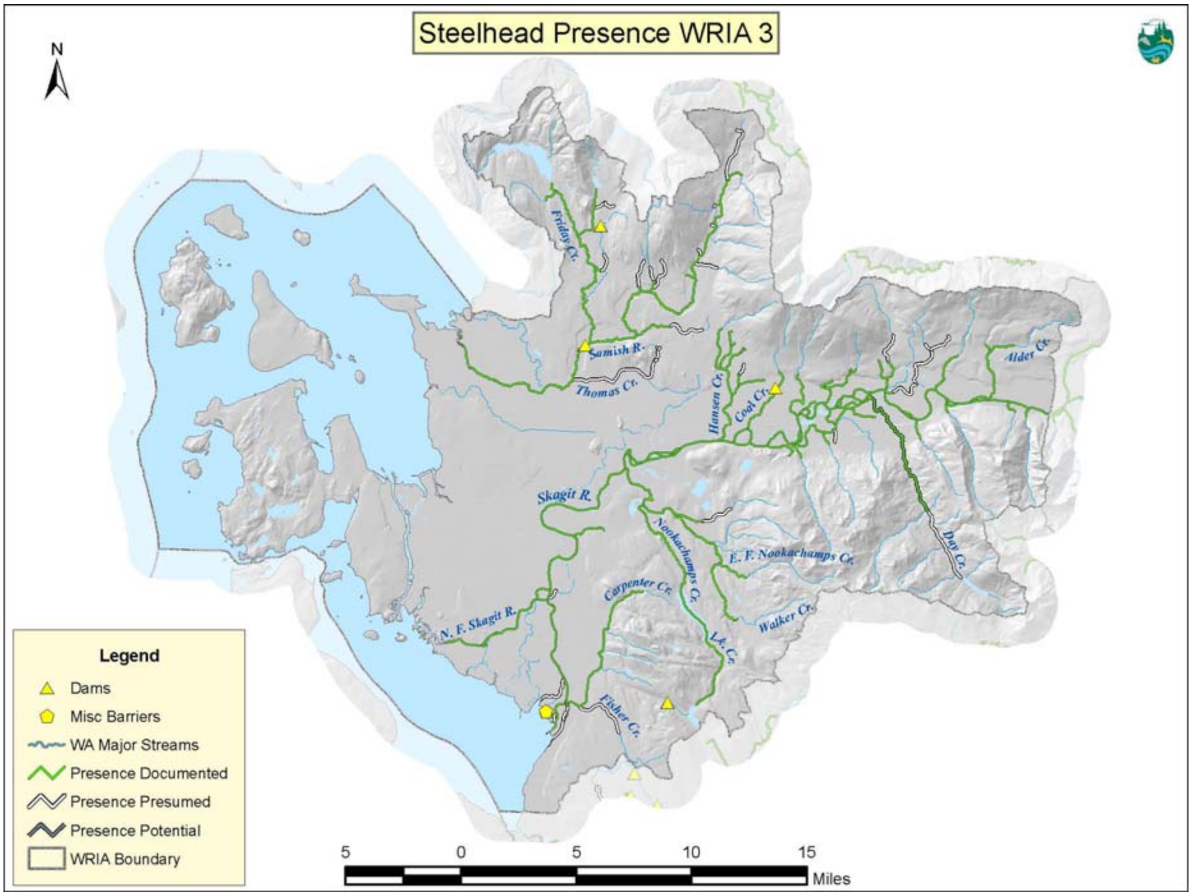


Figure 14. The distribution of steelhead in WRIA 3. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

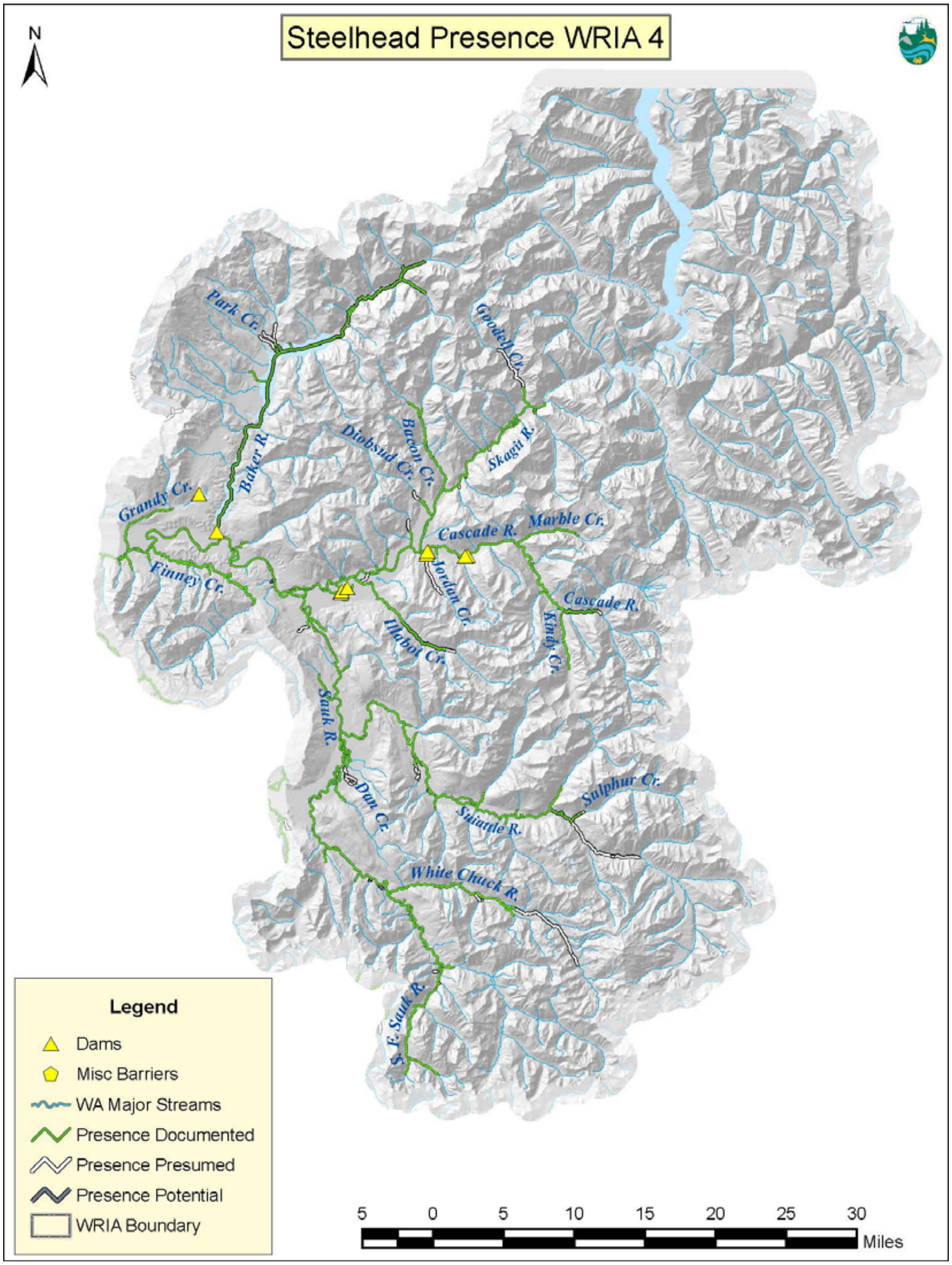


Figure 15. The distribution of steelhead in WRIA 4. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Stillaguamish Watershed (WRIA 5)

The Stillaguamish watershed includes 22 miles of marine shoreline, which is <1% of the total nearshore habitat contained within the watersheds of Puget Sound (Figure 16). Generally speaking, the nearshore habitat associated with the Stillaguamish is in good condition when compared to the urbanized nearshore areas of Puget Sound. Residential development is the primary anthropic threat to shoreline ecological integrity. A severe biological threat to the estuary, however, exists in the form of an invasion of non-native cordgrasses (*Spartina).* Cordgrass invasions eliminate native salt marsh vegetation, displace native plants and animals, raise the elevation of the estuary substrate, and lead to an increase in flooding (Ma et al. 2011). The Stillaguamish estuary provides habitat for juvenile steelhead salmon to make the physiological transition between freshwater and saltwater environments and for adult salmon to transition between saltwater and freshwater.

The upland areas of the Stillaguamish watershed have been considerably more impacted by human development than the shoreline and estuary. From the time that logging of the Stillaguamish watershed (WRIA 5) began in the lower mainstem of the river in the early 1860s, through the 1940s, the entire anadromous channel network, with the exception of a few areas, has been logged (Washington State Conservation Commission 1999). By 1968 approximately 85 % of the Stillaguamish tidal marsh was converted to agriculture, leaving only 3 km^2, though in recent decades the estuary has been increasing in size, possibly as a result of upland sediment impacts. The newly accreted areas (mostly sand and mudflats) are of less value to steelhead and other salmonids than the original salt marsh. It is estimated that 78% of historic wetlands have been impacted or lost in this WRIA (Washington State Conservation Commission 1999).

The Stillaguamish system supports both wild and hatchery stocks of salmonids, including five species of salmon (Chinook, coho, pink, chum, and sockeye), two species of anadromous trout (steelhead and cutthroat), and many non-commercial resident species (including cutthroat and rainbow trout, and native char) (Miller and Somers 1989). The Stillaguamish is managed for wild coho and Chinook stocks, however hatcheries have supplemented wild runs of summer Chinook, chum, and coho on this river since 1939 (US Army Corps of Engineers 1997).

Condition of Steelhead Populations

Four steelhead (*Oncorhynchus mykiss*) stocks have been identified in the Stillaguamish watershed, one winter- and three summer-run stocks. Juvenile steelhead rear between one and three years in freshwater before departing for Puget Sound (Miller and Somers 1989). Smolts migrate out of the river from March through late June.

Winter steelhead enter the river from early November through April to spawn. Spawning occurs mainly in the North Fork and South Fork as well as in tributaries including Pilchuck, Boulder, Squire, Jim and Canyon Creeks. This stock is native in origin and its status is depressed, based on a long-term downward trend in escapement (WDFW and WWTIT 2002). Approximately 100,000 to 130,000 hatchery winter steelhead smolts are annually released into the Stillaguamish River. The potential for the wild stock to interbreed with the returning winter hatchery stock is believed to be small since the hatchery fish spawn in January and February prior to the native spawning season in March and April (WDFW and WWTIT 1994).

The summer steelhead runs include the native Deer Creek stock, a mixed wild/hatchery Canyon Creek stock, and the non-native South Fork stock (Figure 16). Summer steelhead enter the river from May through October and spawn from mid-February through mid-May the following year. The preferred spawning habitat includes the main channels of the North and South Forks and most tributary streams (Miller and Somers 1989). The Deer Creek and Canyon Creek summer stocks are geographically isolated from eachother and the South Fork stock. The Deer Creek stock may have historically numbered between 1,000 to 2,000 fish, but now is believed to be at only about 5 to 10 % of that level. The fishery on this stock has been closed since the late 1930s and the population status is listed as depressed (WDFW and WWTIT 2002). The Canyon Creek stock consists of a small run, and fewer than several dozen fish are harvested annually. Escapement of this stock is not monitored and the status is unknown (WDFW and WWTIT 2002). The South Fork stock originated from hatchery steelhead fry and smolts introduced to the upper South Fork watershed subsequent to the construction of the Granite Falls fishway in the mid1950s (MBSNF 1995). Approximately 80,000 hatchery summer steelhead smolts are annually released into the river. The stock status of the South Fork run is as unknown (WDFW and WWTIT 2002).

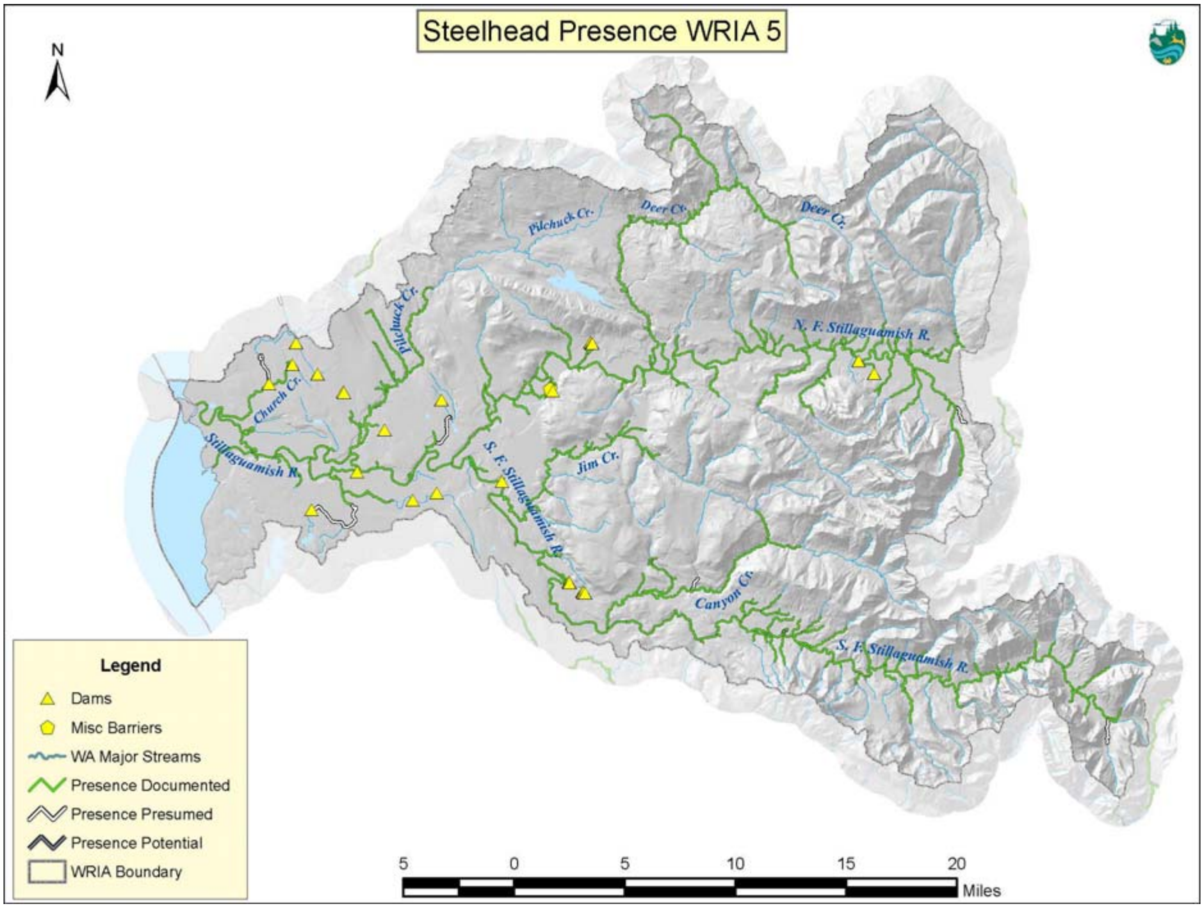


Figure 16. The distribution of steelhead in WRIA 5. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Island Watershed (WRIA 6)

The Island Watershed (WRIA 6) overlaps Island County, including Whidbey, Camano, Ben Sur, Smith and Strawberry Islands. Island County is the second smallest but second fastest growing county in Washington State. Between 1980 and 1990, the County's population grew by 37 %, the highest in the state. Residential development encompasses much of the shoreline and is expanding into rural and forested areas.

Condition of Steelhead Populations

Steelhead do not occur in any streams in the Island Watershed. The streams are of insufficient size and typically exhibit intermittent or ephemeral flow, thus they provide no steelhead habitat. It is assumed that steelhead utilize the nearshore, but to an unknown degree. The islands making up the watershed are located at the junction to Puget Sound and in front of some of the most productive salmon-producing rivers (Snohomish, Stillaguamish, Skagit) in western Washington. From a regional standpoint, the Island Watershed's major contribution to steelhead productivity is from its nearshore habitats. The Island Watershed nearshore environment includes numerous estuaries and salt marshes and provides important habitat for spawning herring and other species that are food for salmonids, including steelhead.

Snohomish Watershed (WRIA 7)

The Snohomish River watershed (WRIA 7) is the second largest river basin draining to Puget Sound, with a total area of 1,980 square miles (Pentec 1999). Elevations in the watershed range from sea level to 8,000 feet (Gersib et al. 1999) and a large portion of the watershed drains high elevation areas of the Cascade Mountains, with spring and early summer snowmelt strongly influencing streamflow patterns (Pentec 1999). The watershed includes ~25 miles of marine shoreline that supports local anadromous salmonid stocks, as well as salmonid stocks from other Puget Sound Watersheds. Three major rivers, the Skykomish, the Snoqualmie, and the Snohomish, make up the watershed (Figure 17). There are 720 miles of streams in the Snohomish Watershed that are known to support anadromous salmonids, including coho, Chinook, chum, and pink salmon, steelhead, bull trout, and Dolly Varden.

Adult and juvenile salmonid access to historic spawning and rearing habitats is significantly impaired in many areas of the watershed by a variety of fish passage barriers (e.g., culverts, dams, dikes/levees, and water quality). In addition, dikes and levees preclude or inhibit access to floodplain wetland habitats that could support rearing. Some of the effects of lost salmonid production due to access constraints are masked by the establishment of anadromous access (July-December) beginning in 1958 to the entire SF Skykomish upstream of Sunset Falls. Sunset Falls was historically a natural anadromous barrier; anadromous passage has resulted in known/presumed anadromous salmonid utilization of 72.9 miles (roughly 10% of the Snohomish basin-wide distribution) of historically inaccessible habitat. However, the intent of providing anadromous passage at Sunset Falls was to provide additional salmonid production, rather than to mitigate for losses elsewhere in the watershed.

Floodplain Modifications

Perhaps the most profound impact to salmonid habitat in the Snohomish Watershed has been the loss or impairment of floodplain function. Much of the historic production capacity is thought to have been associated with the presence of vast floodplain and estuarine wetlands. Bortelson et al. (1980) estimate there has been a 74% reduction in presence of floodplain wetlands, and a 32% loss of intertidal wetlands for the Snohomish River. Diking and bank armoring have also contributed to a 2-km decrease in total length of side channels and a 55% reduction in the area of side channel sloughs on the Snohomish River. Extensive historical floodplain wetlands at Marshland and lower French Creek (Figure 17) have been diked and drained, and no longer provide rearing habitat.

Floodplain function has also been severely impaired or lost further upstream on the mainstem rivers and on tributaries by conversion of historical stream associated wetlands to agriculture, and increasing recent conversion of these areas to commercial/residential development. In addition, floodplain function has been severely impaired by ditching and channelization, particularly in agricultural areas and along roads, to improve drainage of naturally wet areas.

Inland Habitat Conditions

The loss of channel complexity, cover, bank stability, and pools has adversely affected spawning and rearing habitat in much of the watershed. Dramatic alterations due to channelization, loss of large woody debris (LWD) and associated pools, and loss of bank stability and complexity are due to a variety of land use practices. LWD is generally absent from most low floodplain areas of mainstem rivers and tributaries, particularly where the streams have been extensively managed through agricultural areas and along roads. LWD presence is also poor in streams in forested areas, particularly where there has been active forest management. Although current LWD condition may be poor in many of these streams, there is potential for future recruitment potential due to recent changes in federal and non-federal forest management.

Spawning gravel quality is adversely affected by increased presence of fines (< 0.85 mm), which reduce spawning success and benthic productivity. Gravel substrates utilized by steelhead and other salmonids are impaired in many areas of the watershed by significant fine sediment deposition, typically as a result of development, agricultural, and forestry land uses (Haring 2002).

Impaired riparian function throughout much of the watershed has resulted in increased water temperature, loss of bank stability, loss of instream cover, and loss of LWD recruitment to streams. Riparian function has been severely impaired throughout much of the basin by removal of riparian vegetation; construction that precludes riparian vegetation growth; channel incision and channelization that lower the water table in riparian areas; and altered hydrology (Haring 2002).

Condition of Steelhead Populations

In the Snohomish River watershed, three summer steelhead stocks and three winter steelhead stocks have been identified (WDFW and WWTIT 1994, 2002). Wild summer stocks occur in the forks of the Tolt River, the upper North Fork (NF) Skykomish River, and the upper South Fork Skykomish River. The summer steelhead stocks in the Tolt and NF Skykomish rivers are native, and the SF Skykomish summer steelhead stock was developed by colonization of non-native steelhead, and is maintained by trap and haul of adults over Sunset Falls. Wild winter steelhead include the Snohomish/Skykomish, Snoqualmie, and Pilchuck river stocks, all of which are native. There is little information indicating these stocks are genetically distinct and designations are based on geographic isolation of spawning populations and biological characteristics.

Adult return timing of summer steelhead stocks is generally May through October, while winter stocks return from November through April. Spawn timing for summer steelhead stocks may be similar to other steelhead stocks in the Puget Sound area, typically February through April. Native summer stocks were historically limited in their abundance by the extent of their habitat. Spawn timing for winter steelhead stocks is generally from early March to early June. In the Snohomish River watershed, this separation occurs upstream of waterfalls that were probable migration barriers except during the low flows of summer and early fall.

The status of the Tolt River summer steelhead stock is healthy due to a consistent increase in escapements and escapement estimates, which have exceeded the escapement goal of 121 adults in every year since 1992 (WDFW and WWTIT 2002). The status of summer steelhead in the NF Skykomish River and tributaries, which is a distinct stock due to the largely impassable Bear Creek Falls (WDFW and WWTIT 1994), is unknown due to a lack of survey effort (WDFW and WWTIT 2002). The SF Skykomish summer steelhead stock spawns throughout the SF Skykomish and tributaries upstream of Sunset Falls (WFDW and WWTIT 1994) and is designated as having healthy status, in large part due to hatchery supplementation.

The Snohomish/Skykomish winter steelhead stock spawns in the mainstems of the Snohomish, Skykomish, Sultan, and Wallace Rivers and associated tributaries (Figure 17), and stock status is depressed due to a severe short-term decline in total escapements since 1999 (WDFW and WWTIT 2002). The Pilchuck winter steelhead stock spawns in the Pilchuck River and tributaries and is designated as a distinct stock based on the geographic isolation of spawning and its slightly older age structure than other steelhead in the watershed (WDFW and WWTIT 1994). The percentage of three-salt adults (fish that spend three years in saltwater) returning to the Pilchuck River appears to be higher than elsewhere in the basin. The status of this stock status is also depressed because of a short-term severe decline in total escapement since 1999. The Snoqualmie winter steelhead stock spawns in the mainstems of the Snoqualmie, Tolt, and Raging rivers, and associated tributaries, and is also depressed.

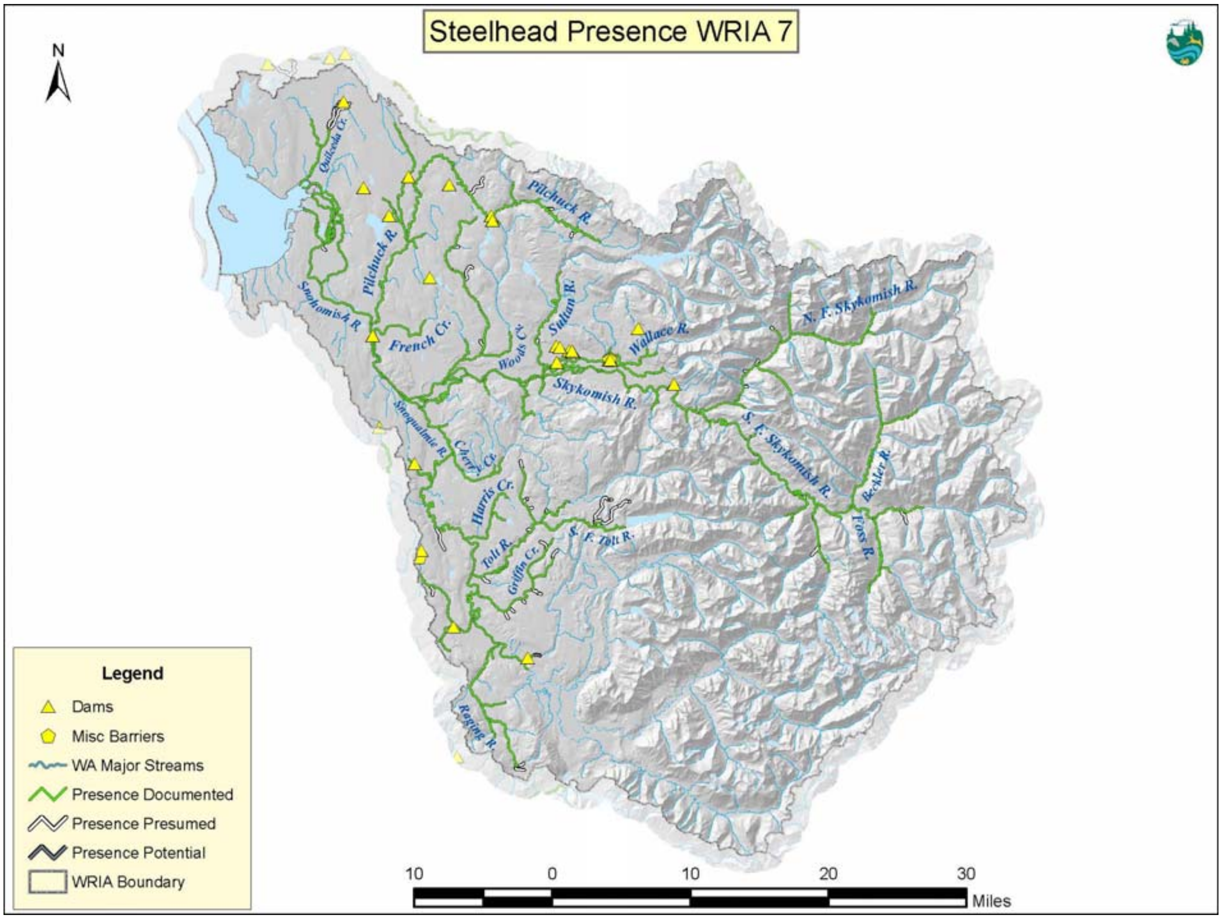


Figure 17. The distribution of steelhead in WRIA 7. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Cedar-Sammamish Watershed (WRIA 8)

Of the nearly 700 mi^2 in the Cedar-Sammamish Watershed (WRIA 8), 607 are in the Cedar-Sammamish basin, which contains three large lakes, Union, Washington and Sammamish, in addition to the two major rivers (Figure 18). The remainder of the watershed consists of numerous small basin that drain directly to Puget Sound between Elliott Bay and Mukilteo (Figure 18). Lake Washington is the second largest natural lake in the state, with about 80 miles of shoreline and a surface area of over 35.6 mi^2 (Kerwin 2001). The Cedar-Sammamish Watershed has the largest human population in the state, with approximately 1.4 million people; more than twice the human population of any other watershed despite its being geographically smaller than most. Based on projections by the Puget Sound Regional Council, this population is expected to increase more than 10 percent in each of the next two decades, bringing it to more than 1.7 million in 2020.

Historic Hydrography Changes

The Lake Washington watershed has been dramatically altered by heavy logging of old growth forest in the 19th Century and, at the turn of the 20th Century, use of the Cedar River as the main water supply for the city of Seattle. Another major alteration of the watershed occurred between 1910 and 1920 when the Lake Washington Ship Canal and Hiram M. Chittenden Locks were completed. The ecological consequences of this last alteration were profound and included: 1) redirection of the outlet of Lake Washington from its south end, at the Black River, producing a migratory corridor and rearing habitat that did not resemble the natural estuary; and 2) a 9-ft reduction in the water level of Lake Washington, and a resultant lowering of Lake Sammamish, which drained wetlands along much of the shoreline of both lakes and dramatically changed the confluences with Lake Washington's tributaries (Kerwin 2001). In the same decade, the Cedar River was redirected from its normal connection with the Black River, which had fed the Duwamish, and was channelized to flow into Lake Washington. This provided the basis for a major expansion of farming in that corridor, which led to channelization of the Sammamish River in the early 1920s, establishing the general hydrogeography of the present watershed.

Current Habitat Conditions

The most important recent/current cause of physical change to the watershed has been the expansion of urban and suburban development. In particular, changes in land cover and increases in water withdrawals have dramatically changed the extent and nature of the seasonal flow regime. The removal of forest cover for urban and suburban development has increased the size and frequency of high flows from stormwater in lowland creeks and has reduced low flows in the summer and early fall. Following significant floods in the 1950s, countywide flood control efforts led to a dramatic expansion of levees on the Cedar River and local sponsorship of major dredging and levee construction on the Sammamish River by the Corps of Engineers (Kerwin 2001). This, in turn, supported development within the floodplains of both rivers.

Beside the changes in physical habitat noted above, the introduction of non-native fauna and flora have significantly changed the biology of the Lake Washington ecosystem. There have been upwards of 40 non-native fish introduced into the watershed, though today there are 24 known non-native fish species in the watershed (Kerwin 2001). Additionally, Eurasian milfoil, an invasive plant, now dominates much of the shorelines of Lakes Washington and Sammamish. Himalayan blackberry is ubiquitous in riparian areas throughout the watershed, and Japanese knotweed and reed canary grass are increasingly common.

Condition of Steelhead Populations

The Lake Washington system supports one native winter steelhead stock of critical status (WDFW and WWTIT 2002). Since 1997 the escapement estimate for the stock has not exceeded 600 fish, and since 2000 the escapement has been under 50 (WDFW and WWTIT 2002). A limited hatchery program utilizing the native winter steelhead stock was initiated in 1997 as a supplementation type program to assist in recovery of winter steelhead populations in the north Lake Washington tributaries. The sharp decline in Lake Washington winter steelhead was noted as a reason for concern by NMFS in their stock status review (Busby et al. 1996). The vast majority of juvenile steelhead in the Lake Washington Basin smolt and migrate to saltwater, rather than remaining in the lake. These steelhead usually spend 1 to 3 years in freshwater, with the greatest proportion spending two years (Busby et al. 1996).

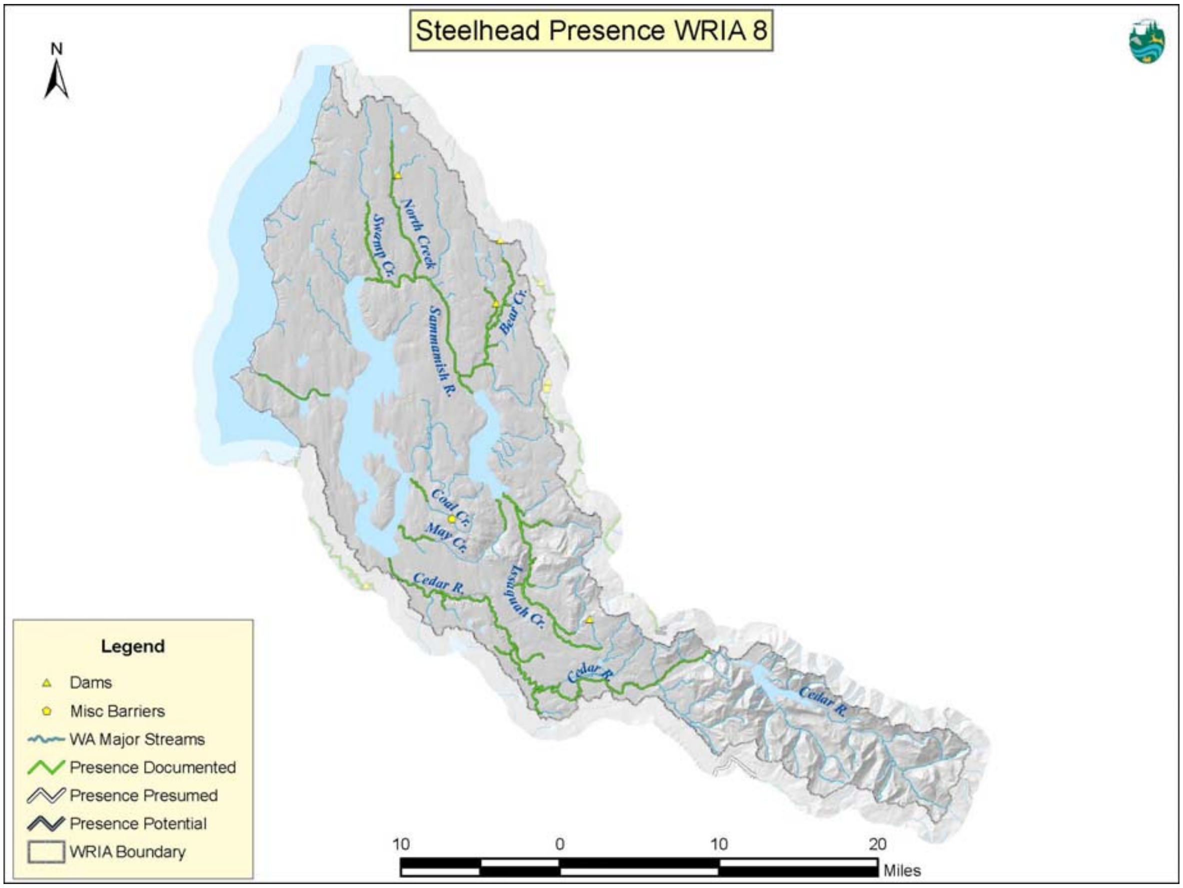


Figure 18. The distribution of steelhead in WRIA 8. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Green/Duwamish and Central Puget Sound Watershed (WRIA 9)

The Green/Duwamish (WRIA 9) river basin begins in the Cascade Mountains and flows into Puget Sound at Elliott Bay in Seattle (Figure 19). Historically, the White, Green, and Cedar (via the Black) Rivers flowed into the Duwamish River, and the system drained an area of over 1,600 mi^2. Because of the diversion of the White River in 1911 and the Cedar River in 1916, the Green/Duwamish drainage area has been reduced to 556 mi^2 (Kerwin and Nelson 2000). Land uses differ considerably across the watershed. In the Upper Green River sub-basin, land is devoted almost entirely to forest production. The Middle Green River sub-basin is characterized by a mix of residential, commercial forestry, and agricultural land uses. Residential, industrial, and commercial uses prevail in the Lower Green River sub-basin. The Green/Duwamish River sub-basin is split between residential and industrial uses (Kerwin and Nelson 2000).

Anadromous fish access to the upper reaches of the Green/Duwamish River has been blocked at River Mile (RM) 61 since 1911 when the City of Tacoma started construction on a water diversion dam (Headworks). While the City of Tacoma has limited public access in a portion of the upper sub-watershed to protect the potable water supply, commercial timber harvest occurs throughout this portion of the watershed and has altered many ecological processes and degraded much habitat. In 1962, Howard Hanson Dam (HHD), a flood control construct, was completed at RM 64.5, creating a complete barrier to upstream and downstream adult migration. The large flood control dam and associated reservoir interrupts the natural flow of sediments and large woody debris to lower mainstem reaches of the Green River. It also chronically floods upstream habitat.

In the Middle Green River sub-basin (RM 64.5 to 32.0), the construction and operation of Howard Hanson Dam has reduced the recruitment of sediments. Because HHD serves to limit floods, the natural flow regime of the mainstem Green River has been altered, destroying habitat. Currently Chinook, steelhead, coastal cutthroat, coho, and chum utilize the reach up to the Headworks for spawning and rearing (Kerwin and Nelson 2000, WDFW and WWTIT 2002).

In the Lower Green River sub-basin (RM 32.0 to 11.0), the diversion of the White River in 1911 has led to a decrease in flow and sediment and a lowering of the floodplain. Additionally, the two dams mentioned above have led to an unnatural flow regime. One of the most significant habitat alterations has been the construction of a series of revetments that has resulted in the disconnection of off- and side-channel habitats such as sloughs and adjacent wetlands. In the Duwamish estuary, over 97% of historic estuarine mudflats, marshes, and forested riparian swamps have been eliminated by channel straightening, draining, dredging, and filling. The remaining shortened channel has been simplified and suffers from polluted sediments along with stormwater and wastewater effluent.

Condition of Steelhead Populations

There are two winter steelhead stocks in the Green/Duwamish River basin (WDFW and WWTIT 1994, 2002), one of which is a native, wild-spawning population, and the other of which is an early-run hatchery stock. The status of the native stock is healthy while that of the hatchery stock is depressed, based on a downturn in harvest during 1999 and 2000 (WDFW and WWTIT 2002). An historic native wild summer steelhead stock in the Green River Basin may have existed. Prior to 1966, sport angler punch cards indicated an annual summer steelhead harvest of small numbers (<12) fish per year (1962-66). The Salmonid Stock Inventory (SaSI) (WDFW and WWTIT 2002) concluded that adult summer steelhead caught in the Green River basin were the result of strays from other systems or the result of adult winter steelhead caught during the summer steelhead management period (May 1 to October 31).

The current summer steelhead in the Green River Basin are the result of non-native (hatchery introduced) origin fish from the Skamania summer steelhead stock initially introduced in 1965. Escapement goals are not set for this stock as it is thought to be entirely hatchery supported and managed for the recreational sport fishery.

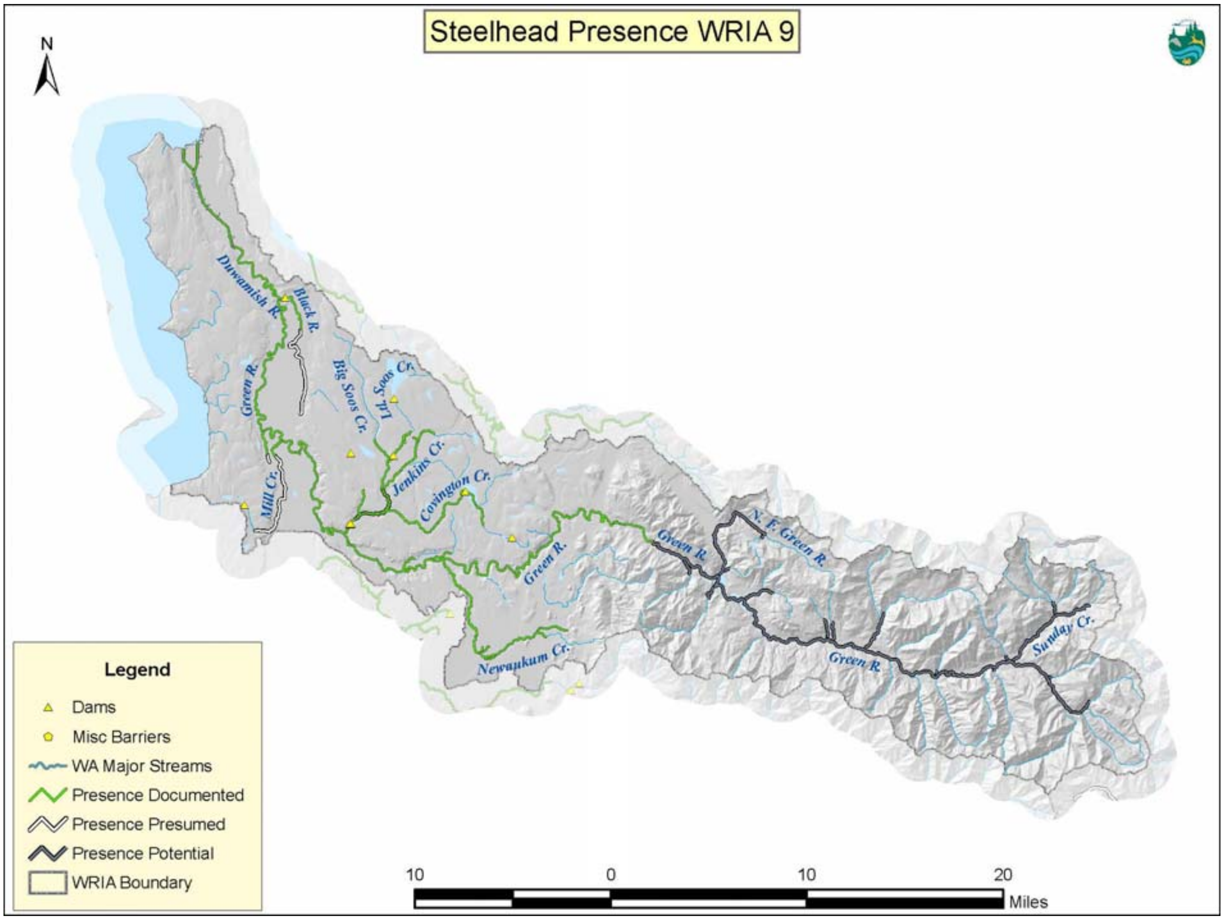


Figure 19. The distribution of steelhead in WRIA 9. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Puyallup Watershed (WRIA 10)

The Puyallup (WRIA 10) River Basin was one of the earliest areas settled in the Puget Sound area. Dredging and filing of the estuary started in the 1800s and was largely completed by 1930. Two hydroelectric dams that are impassable to salmonids were completed shortly after 1900. An extensive system of levees, dikes and revetments were started in the early 1900s and continue to be maintained today. These channel containment structures have removed the natural sinuosity of the rivers and the spawning and rearing habitats that were once present. In 1906 the White River was diverted into the Puyallup River Basin, almost doubling the flows in the lower Puyallup River (Kerwin 1999a). All of these actions have impacted the biological processes necessary for the natural production of steelhead in the Puyallup River Basin.

The headwaters of the Puyallup, Carbon and White Rivers originate inside Mt. Rainier National Park (Williams et al. 1975) and habitat in this area is considered quite pristine (Figure 20). The Mt. Baker–Snoqualmie National Forest forms a ring around the national park. Outside this ring lies another ring of large private commercial timber landholdings (Champion and Plum Creek timber companies) and state owned timber lands that is managed for timber production, recreation and other uses. Westward in the basin, nearer Tacoma, there is a mix of agricultural, residential, urban and industrial areas. Over 357 individual culverts have been identified in the watershed and approximately 70% are partial barriers to anadromous salmon upstream and downstream migration. Approximately 40% were determined to be complete barriers to salmonid migration (Kerwin 1999a).

The White River subbasin originates on the slopes of Mt. Rainier and drains an area of approximately 494 square miles (Williams et al. 1975) before joining the mainstem Puyallup River (Figure 20). Early in the 1900s the majority of the White River flow was directed north into the Green and Duwamish Rivers. A small overflow channel, called the Stuck River, flowed south into the Puyallup River. A flood on November 14, 1906 creating a debris dam in the White River and the entire flow was redirected into the Stuck River and the former White River channel into the Green River went dry (Chittenden 1907). A permanent diversion wall was constructed at Auburn in 1915 and the White River remains a tributary of the Puyallup today.

Commencement Bay and Nearshore

Commencement Bay is a natural, deep-water embayment approximately 5,700 acres in size into which the Puyallup River flows. Surrounded on three sides, the Bay has extensive areas of industrial, commercial and residential influences (US Fish and Wildlife Service and NOAA 1997). Development in the Bay began in the late 19th Century and has fragmented the remaining estuarine habitats (US Army Corps of Engineers et al. 1993). Altered shorelines and/or industrial development consisting of vertical or steeply sloping bulkheads and/or overwater piers of lowered habitat value separate the remaining estuarine habitats. Historical steelhead migration routes through into off-channel habitats and sloughs have largely been eliminated and historical saltwater transition zones are lacking. In addition, chemical contamination of sediments has compromised the effectiveness of the remaining habitat in many areas (US Army Corps of Engineers et al. 1993; US Fish and Wildlife Service and NOAA, 1997; Collier 1998). It has been estimated that of the original 2,100 acres of historical intertidal mudflat within the Bay only 180 acres remain (Commencement Bay Cumulative Impact Study 1992). Extensive anthropogenic activity such as dredging and filling is responsible for the decline of these habitats.

Inland Habitat Conditions

The Carbon River is a glacially fed tributary of the Puyallup River Basin that contributes approximately 30 % of the Puyallup River flow (Williams et al. 1975). The Carbon River has nineteen tributary streams and represents the largest, most productive habitat available for natural salmonid production in the Puyallup River basin. The lower Carbon River reach is heavily confined and levied within what was once a broad, relatively flat floodplain. The river's glacial source delivers large volumes of pulsed sediment to the system. The vegetation along the lower Carbon River consists primarily of mixed hardwoods along with grasses and dense patches of blackberry vines. There are only limited patches of second growth conifer with heavy concentrations of hardwoods occupying the immediate riparian corridors (Kerwin 1999a).

South Prairie Creek is the backbone of natural salmonid production in the Lower Carbon River sub-basin and Puyallup watershed. As the major tributary to the Carbon River, South Prairie Creek produces nearly half of all wild steelhead in the Puyallup River system.

The upper White River is inherently unstable because it cuts through a series of glacial and mudflow deposits, causing it to transport tremendous amounts of sediment annually. Sediment transport has been estimated to range from 440,000 to 1,400,000 tons annually, with the majority of these sediments characterized as fines that are transported out of the upper reaches and deposited into lower gradient reaches and Commencement Bay (Kerwin 1999a), resulting in aggradation and flooding problems. Critical to the natural production of steelhead within this basin are two impassable dams. Puget Sound Energy operates the Lake Tapps diversion dam at RM 24.3 and the U.S. Army Corps of Engineers operates a flood control dam (Mud Mountain Dam) at RM 29.6 (Williams et al. 1975). Returning adult salmon are trapped at the diversion dam (R.M. 24.3) and trucked upstream of the Mud Mountain Dam impoundment where they are released back into the White River. The operation of these two projects essentially eliminates 9.6 miles of mainstem spawning and rearing habitat. Tributaries accessible to anadromous fish are very limited in this reach of the

White River.

The Upper Puyallup River sub-basin is a glacially fed system, the majority of which lies in a rain-on-snow zone between 1000 and 4000 feet in elevation. With a drainage basin of approximately 110,000 acres this sub-basin is about five times larger than the lower Puyallup River sub-basin (Kerwin 1999a). There are 11 tributaries accessible for anadromous fish within this sub-basin. Winter steelhead production does occur in tributaries to the Puyallup River in the diversion reach between the dams mentioned above. Adult steelhead migrate into this section because at the time of adult migration flows are sufficient. One of the most defining features in the Upper Puyallup sub-basin is the Electron Hydroelectric Project. Puget Sound Energy Corporation operates this project on the mainstem Puyallup River with a diversion dam at RM 41.8 and an associated powerhouse at RM 31.2. Initially constructed in 1904, the dam completely blocked anadromous salmonid access to 26 miles of mainstem river habitat and 10 miles of tributary streams above the dam. In addition, water diverted from the main channel bypasses and partially dewaters 10.5 miles of mainstem channel, impacting both upstream and downstream fish passage, rearing, and spawning habitats.

Condition of Steelhead Populations

Three winter-run steelhead stocks exist in the Puyallup Watershed, and they spawn in the mainstem Puyallup, White, and Carbon Rivers (WDFW and WWTIT 1994, 2002). All are native, and the status of all three stocks is depressed based on long-term negative trends in escapement since the early 1990s. Winter steelhead production also occurs in tributaries to the Puyallup River in the diversion reach. The production is almost entirely from three tributaries (Nieson, Kellogg, and LeDout Creeks).

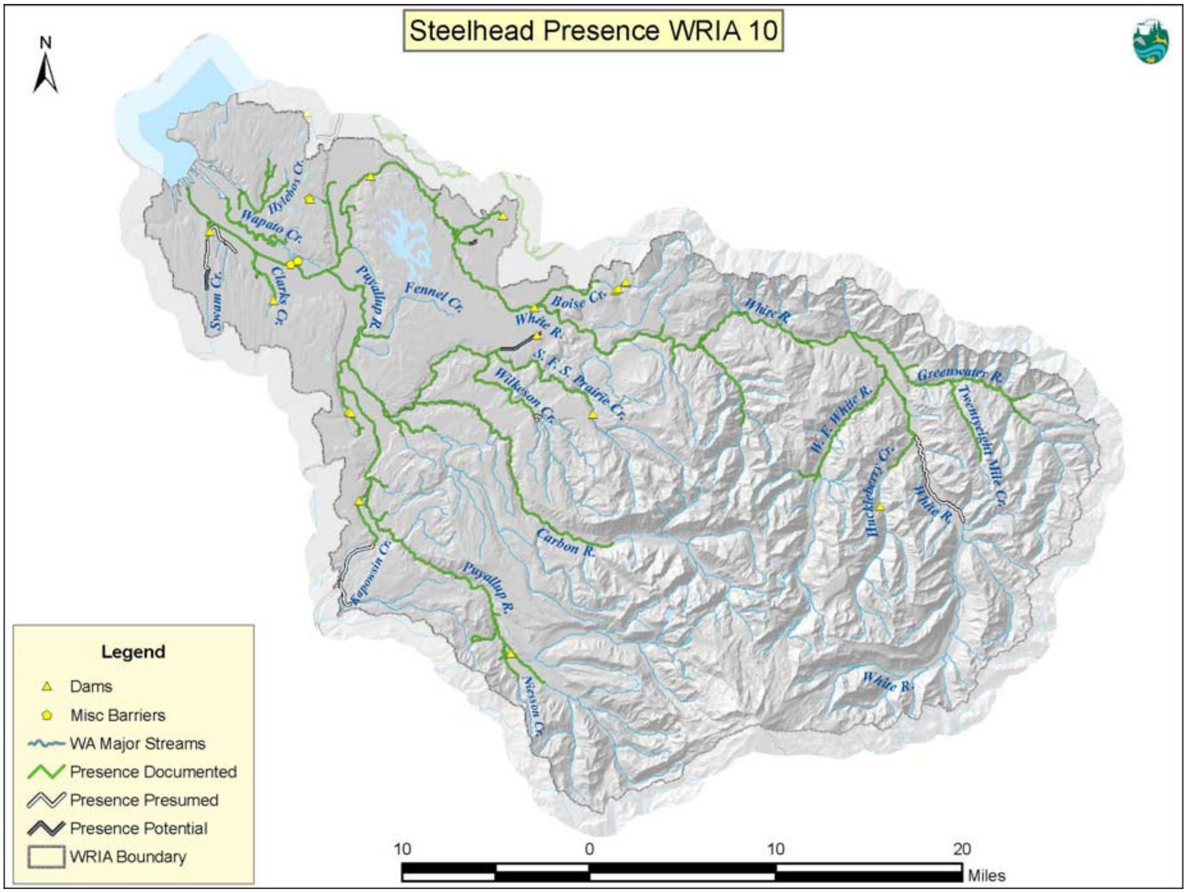


Figure 20. The distribution of steelhead in WRIA 10. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Nisqually Watershed (WRIA 11)

The Nisqually Watershed (WRIA 11) consists of the Nisqually River, which originates on Mount Rainier (Figure 21), and three independent tributaries (McAllister Creek, an unnamed creek, and Red Salmon Creek) draining directly into Puget Sound. The entire basin encompasses 720 mi^2 (Williams et al. 1975) and annual average rainfall in the basin ranges from approximately 40-140 inches (Kerwin 1999b). Approximately sixty percent of this precipitation occurs in the fall and winter months (September through March), and nearly 60% of the Nisqually basin lies at an elevation between 1,000 and 4,000 feet, which leads to the generation of substantial runoff and frequent winter floods. Substantial, glacially derived turbidity within the Nisqually River makes spawning surveys for all anadromous salmonids problematic, especially during the fall.

Diking of the Nisqually estuary has been extensive, and continues today. Additionally, two hydroelectric projects have been constructed in the watershed. The Yelm Hydroelectric Project consists of a diversion dam located at RM 26.2 and a canal that transports water to a powerhouse where the water is returned to the mainstem Nisqually River. The LaGrande Hydroelectric Project also serves as a barrier to anadromy, as does LaGrande Canyon. The hydroelectric projects in the Nisqually River are not intended to provide flood control but the LaGrande Project does provide some flood tempering. Operations of the hydroelectric projects do not provide a naturalized flow regime to the mainstem Nisqually River.

The Nisqually River Basin has been adversely impacted by a variety of land use practices. Commercial timber activities have increased sediment loads, reduced large woody debris input and recruitment potential, and altered precipitation run-off patterns (Kerwin 1999b). The conversion of valley bottom lands and wetlands to agricultural purposes has reduced the natural biological processes necessary for production of salmonids in the basin. The Nisqually River estuary had lost about 30% of its historical intertidal and subtidal habitat prior to extensive restoration efforts conducted by the Nisqually Tribe and the National Wildlife Refuge. Of critical importance to the natural production of salmonids was the 54% reduction in intertidal emergent marsh habitats (Kerwin 1999b). Heroic restoration efforts are currently reversing this pattern of loss.

Lower Nisqually River

Significant bank armoring is present in the lower portions of this reach and The Burlington Northern–Santa Fe Railroad grade limits lateral channel migration in the area of RM 3.7. These have resulted in a reduction of lateral channel migration, available side channel rearing habitats, and site specific riparian cover (Kerwin 1999b). Upstream to RM 12.7, the Nisqually River meanders freely and has several important side channels that provide overwinter rearing habitat for steelhead. The riparian zone is largely forested with conifers and hardwoods. Because of the freedom of the river to move laterally the riparian forests are in various stages of maturity throughout this reach. This reach represents the least impacted reach within the lower basin and LWD is present in large amounts.

Middle Nisqually River

This reach differs significantly from the lower Nisqually River in several respects. The majority of this reach is contained within a shallow, narrow canyon and fairly steep gradient river channel bordered on each side by flat prairie habitats. Instream habitat consists of deep pools with some boulder stretches and spawning gravel patch pockets. The presence of spawning gravel increases in the lower two miles of this reach (EDT Workgroup, In Press). Riparian habitat varies considerably throughout the reach from intact and mature to substantially degraded, in the area of rural housing developments. Several flood control dikes are present, which limit lateral channel migration and reduce available off channel rearing opportunities.

Upper Nisqually River

This reach stretches from the Diversion Dam upstream to the City of Tacoma LaGrande Hydroelectric Dam. Flood control dikes exist in the lower portions of the reach along the left bank and limit lateral channel migration, eliminating off-channel rearing and overwintering opportunities. There are single family residences, hobby farms, and larger agricultural facilities in this reach that negatively impact riparian habitat quality, particularly in the lower portions of the reach. Riparian habitat consists of second growth coniferous and hardwood trees with some pockets of old growth conifers. These pockets of old growth trees are important in the recruitment of LWD into this section of the river. In the middle portion of the reach the mainstem Nisqually River meanders freely and off-channel rearing and overwintering habitats are abundant.

Upstream of Ohop Creek (Figure 21), the mainstem Nisqually River is characterized by deep pools between narrow bedrock cliffs. The gradient of the river increases as one moves upstream and in spite of several actively eroding sand/gravel bluffs there are only limited areas of appropriately sized and sorted spawning gravel. The few gravel pockets available assume a greater importance due to their relatively low number. The only channel constriction in this reach is an abandoned wood/log bridge that was part of a road system maintained by the Weyerhaeuser Company. This bridge is located just above the confluence of the Mashel and Nisqually Rivers (Figure 21) and is being allowed to fall into the river.

Condition of Steelhead Populations

A single stock of native, winter-run steelhead exists in WRIA 11, and spawning occurs in the mainstem Nisqually River, several tributaries of the Nisqually River, and the independent

McAllister Creek. Since 1970, run sizes have been highly variable. Winter steelhead run sizes decreased throughout the 1990's and have not recovered (WDFW and WWTIT 1994). Based on this long-term negative trend the status of the stock is depressed (WDFW and WWTIT 2002).

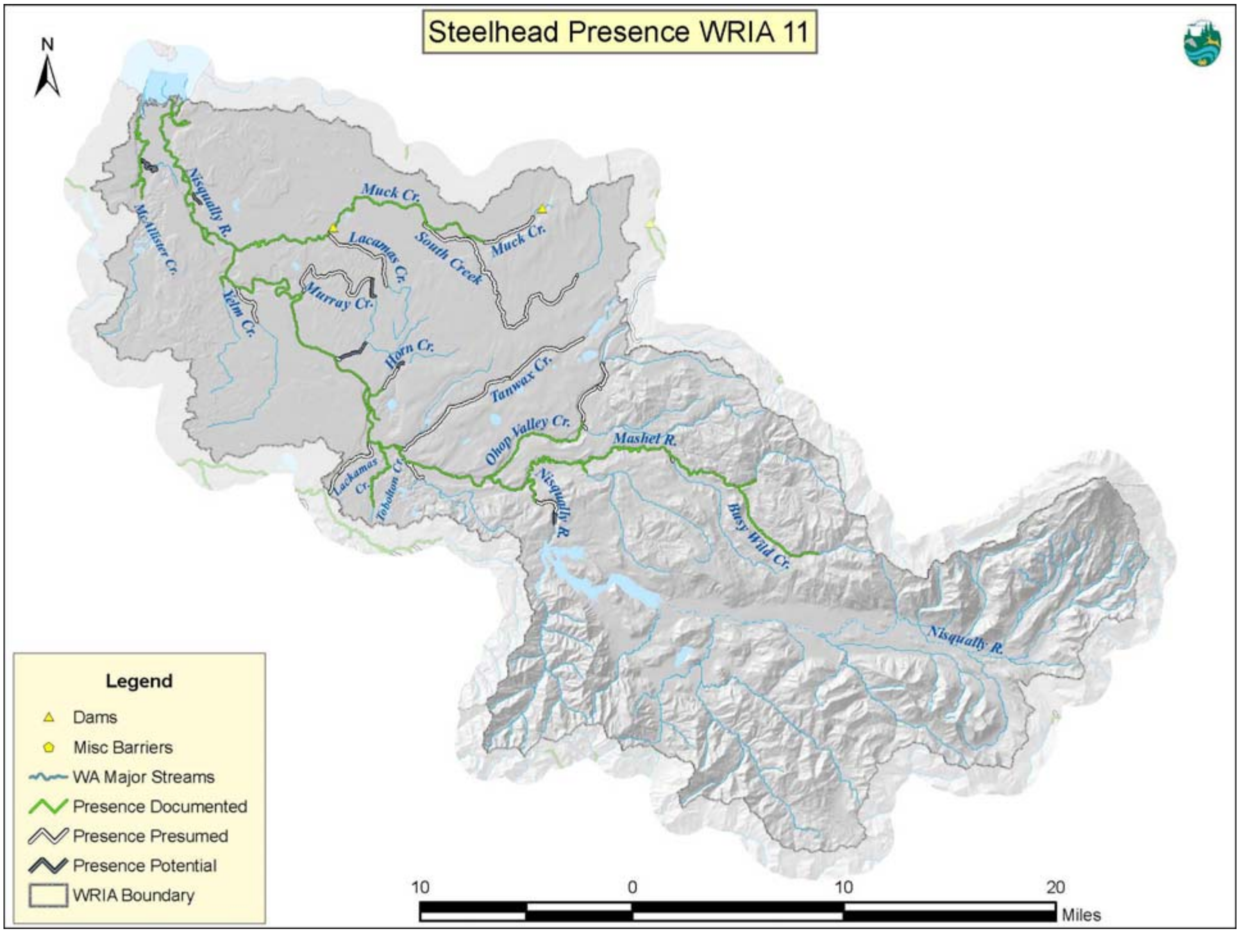


Figure 21. The distribution of steelhead in WRIA 11. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Chambers/Clover Watershed (WRIA 12)

The Chamber/Clover Watershed (WRIA 12) lies between WRIA 10 and WRIA 11, is roughly triangular in shape, and covers approximately 180 mi^2 (Clothier et al. 2003) (Figure 22). While no major rivers lie within this WRIA it encompasses the Chambers-Clover Creek Basin and the neighboring small drainages of Sequalitchew and Puget Creeks. It also encompasses several independent stream drainages, including Crystal Springs Creek and several unnamed creeks draining directly into Puget Sound. Several substantial lakes are found within the watershed (Clothier et al. 2003). Overall topography is flat and elevations range from sea level to 600 feet (Pierce County Public Works and Utilities 1996).

The steady pace of urbanization in this watershed has led to declining fisheries resources for over a century. Many alterations have been made to the streams and overall watershed, beginning as early as 1853 and accelerating in the late 1800s (Consoer and Townsend 1977). Trends in fisheries production/escapement appear to be linked to stream flow, water quality, human harvest, and natural predation. Human use and development have been major contributors to the current conditions and impervious surfaces, runoff, pollution, and water consumption have taken their toll (Clothier et al. 2003).

Chambers-Clover Creek

Of the three largest sub-basins in the watershed, the Chambers-Clover Creek watershed is the largest. Steilacoom Lake was created when a dam was built at RM 4.1 on Chambers Creek (Lakewood Community Plan 1991, cited in PCPWU 1997). The dam at the outlet controls lake elevation and fish ladders facilitate passage for spawning salmon (Tetra Tech/KCM 2002). Dense residential, commercial, and military development encroaches upon most of the Clover Creek main stem from Steilacoom Lake to the confluence with the North Fork (Tetra Tech/KCM 2002). Encroaching development is also a problem on the North Fork of Clover Creek and low-density residential development and agricultural practices frequently encroach upon the banks of Clover Creek upstream of the North Fork confluence. In addition, dredging and channeling of the creek throughout this sub-basin have contributed to intermittent flows and water loss (Tetra Tech/KCM 2002). A dam with a spillway and fish ladder forms the head of Chambers Bay, the beginning of the tidal influence. The outlet of Chambers Bay to Puget Sound is very narrow and restricted due to a railroad dike and bridge across the mouth of the bay.

Sequalitchew Creek

The Sequalitchew Creek sub-basin lies south of Tacoma and drains an area of 38.4 mi^2 (Clothier et al. 2003). Habitat conditions in the creek are typified by reduced flow, relative to historic levels, and invasive plant species have overrun it (Pierce County Public Works and Utilities 1997). The overflow from American Lake historically drained into

Sequalitchew Lake (Wolcott 1973). Sequalitchew Lake has its own overflow outlet that forms the beginning of Sequalitchew Creek. The water level of both lakes is maintained year round by springs and water table seepage (Pierce County Public Works and Utilities 1997). A diversion dam for overflow water from the lake lies near the outflow of Sequalitchew Lake and directs water through a canal east of the creek. There is disagreement as to the effect of this canal system upon the Creek. Andrews and Swint (1994) reported that the diversion dam and canal structure is a tangled arrangement and the effects of this structure on the creek are significant. Fort Lewis officials report that the effects of this structure on Sequalitchew Creek are not significant, and that the structure was constructed to maintain the lake level and flow to Sequalitchew Creek. Little natural estuary is present near the mouth of the creek, but the extensive Nisqually Flats lie immediately to the south and provide estuarial rearing for smolts from this system (Williams et al. 1975).

Condition of Steelhead Populations

No steelhead stocks are recognized in either Chambers or Sequalitchew creek, or any of the small tributaries in WRIA 12 (WDFW and WWTIT 2002). However, a handful of winter steelhead have been observed passing through the Chambers Creek trap (WDFW, unpublished data). Historically, steelhead were the first salmonids to be captured in the Chambers Creek trap when first operated in 1945 (Crawford 1979), indicating presence of a natural run. It is possible that steelhead returning to Chambers Creek may pass the dam (trap site) after the trap is opened in early February, and would therefore be undocumented and uncounted. No steelhead stock assessment work has been done in the Clover/Chambers Watershed streams.

The Lakewood Hatchery complex on Chambers Creek was historically used as the primary steelhead spawning site and egg source for the western Washington hatchery steelhead program. Adult steelhead were collected at hatchery sites and adult salmonid collection racks throughout western Washington, transferred to the Lakewood Hatchery complex, spawned, and the resulting juveniles transported to streams throughout western Washington.

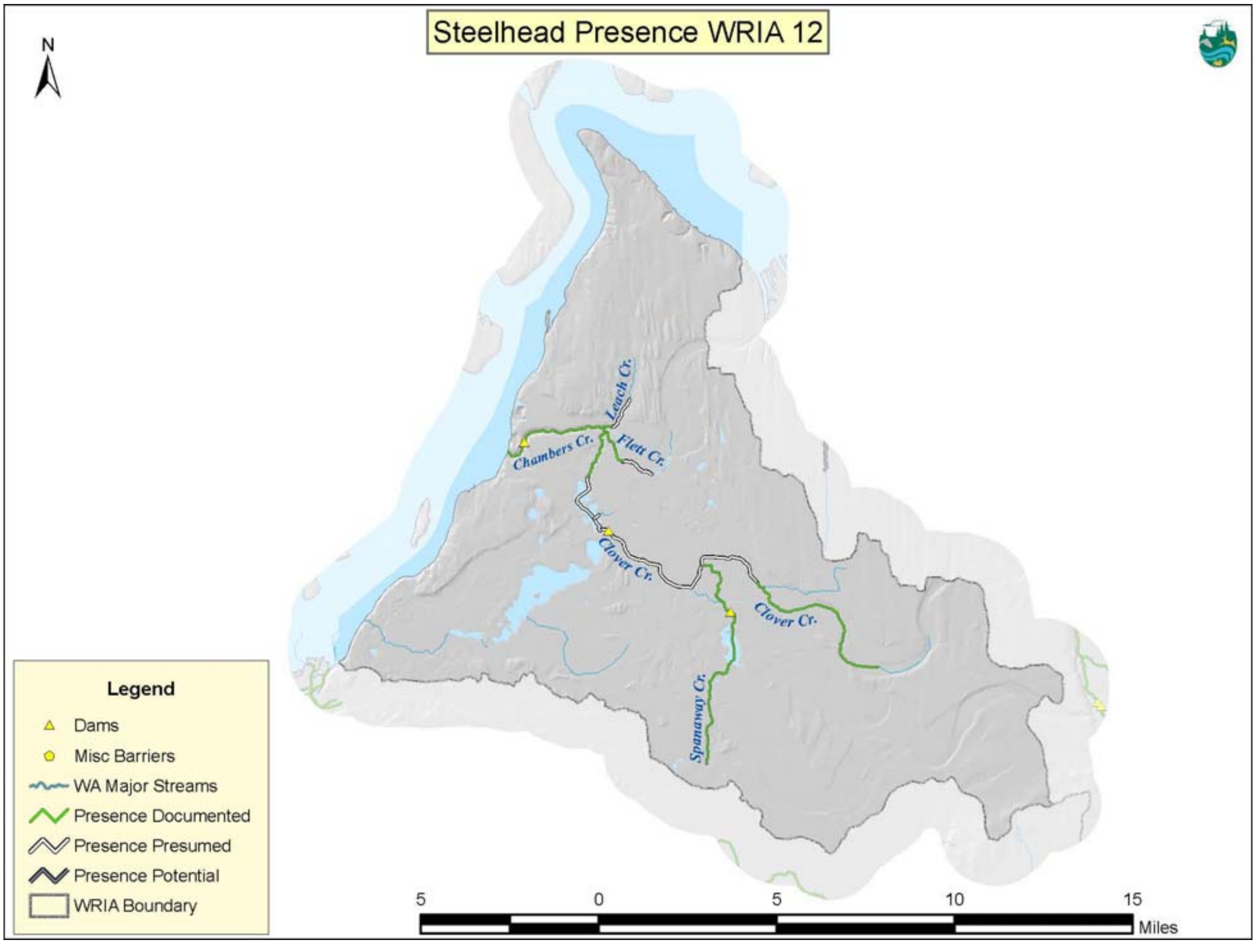


Figure 22. The distribution of steelhead in WRIA 12. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Deschutes Watershed (WRIA 13)

Located at the southern end of Puget Sound, the Deschutes Watershed (WRIA 13) consists of sub-basins that empty into three saltwater inlets (Henderson Inlet to the east, centrally located Budd Inlet, and Eld Inlet to the west) (Figure 23). The Deschutes River is the major hydrologic basin in the watershed, with a number of other smaller independent tributaries to salt water.

Henderson Inlet Sub-Basin

The Henderson Inlet basin lies in the northeast section of the watershed and has a total drainage area of nearly 30,000 acres (Thurston County 1989). The topography of the watershed is divided into three parts: the Dickerson Point peninsula, the Johnson Point peninsula, and the Woodland Creek Basin. Most of the basin lies at an elevation of less than 200 feet above sea level. The southern head of the inlet forms an estuary at the mouth of Woodland Creek and reveals large mudflats at low tide. Dickerson Point peninsula, to the west, is characterized by high, bluff-backed beaches bisected by steep, narrow ravines with intermittent streams that drain into the many small coves along the shoreline. The largest stream on Dickerson Point peninsula is Woodard Creek. The highest point of the peninsula is 177 feet, just southeast of Woodard Bay (Thurston County 1989). Johnson Point peninsula is similar in topography to Dickerson Point. The Woodland Creek basin flows through a series of lakes to its terminus at the southernmost point of Henderson Inlet. Drainage is slow and the areas between them are peat bogs, marshes, and beaver ponds. Woodland and Woodard Creeks are the largest of the major tributaries to Henderson Inlet and drain about 80% of the watershed. The other streams in the basin drain small areas of the Dickerson Point and Johnson Point peninsulas to the north of Woodard Creek and Woodland Creek basin. The Henderson Inlet Basin includes rural, unincorporated areas as well as the city of Lacey and portions of the city of Olympia and between 1979 and 1989, over 41% of the new housing in Thurston County was built in the Henderson Inlet Basin.

Budd Inlet/Deschutes Sub-Basin

Budd Inlet is 7 mi long and has an average depth of 27 ft, with a maximum depth of 110 ft near its mouth. The inlet is classified as a shallow, poorly mixing estuary. A variety of land uses occur along the shoreline at the south end of the inlet, including undeveloped park shoreline, marinas, residences, and industrial facilities. This urbanized portion of the shoreline accounts for about one-third of the total shoreline. The upper portion (northern end) of the inlet is largely suburban in nature (Thurston County Advance Planning and Historic Preservation 1995). Land use in the middle third of the basin consists of commercial and non-commercial agriculture production with rural residences found throughout the mid-basin and the outer peninsulas. Land use in the lower basin, near the mouth of the Deschutes

River and inner Budd Inlet, is mostly urban in character (Turner 1993). The Budd Inlet/Deschutes Basin is composed of 143 identified streams that provide over 256 linear miles of drainage. Total area of the basin is 118,773 acres.

The Deschutes River with its associated tributaries is the largest drainage system within the basin, draining ~84% of the total basin. The drainage basin of the Deschutes River drops from the highest point within the watershed, at an elevation of 3,870 ft, to the river's mouth at Capitol Lake. The upper extent of the river has a moderately steep gradient and the river then drops rapidly over Deschutes Falls at river mile 41, forming a total barrier to fish passage (Williams et al. 1975). The lower portion of the drainage consists of a broad prairie valley and open farmland interspersed with dense stands of mixed deciduous and coniferous growth.

Eld Inlet Sub-Basin

Eld Inlet has about 30 mi of total shoreline and the highest point on the peninsula is 243 ft in elevation. The land rises steeply from Puget Sound, with banks often reaching a height of 100 ft within 500 ft of the beach. The steep slopes are indented in many places by draws, ravines and gullies holding small seasonal streams. The one exception to this topography is the estuarine area at the southwest corner of the peninsula where the land adjacent to Mud Bay is very low and flat, rising only a few feet above high tide level. The primary stream in the sub-basin is McLane Creek, which drains 7,360 acres and terminates at the estuary of Mud Bay.

Condition of Steelhead Populations

Two distinct stocks of winter steelhead have been identified in WRIA 13; Deschutes winter steelhead and Eld Inlet winter steelhead. Wild winter steelhead in the Deschutes River and tributaries are a distinct non-native stock based on the geographical isolation of the spawning population. Run timing is generally from November to mid-March and spawn timing is generally from early January to early April (WDFW and WWTIT 1994, 2002). Eld Inlet wild winter steelhead are native to the drainages and the primary spawning tributary for the stock is McLane Creek. Run timing is generally from December through mid-March, with spawning generally from early February to early April. The status of the stock is unknown but historic run sizes have been small. Little recent data regarding the status of either stock is available and escapement is not monitored. Other streams in the Deschutes Watershed that have identified winter steelhead escapement not specifically associated with either of the designated stocks include Woodland and Woodard creeks.

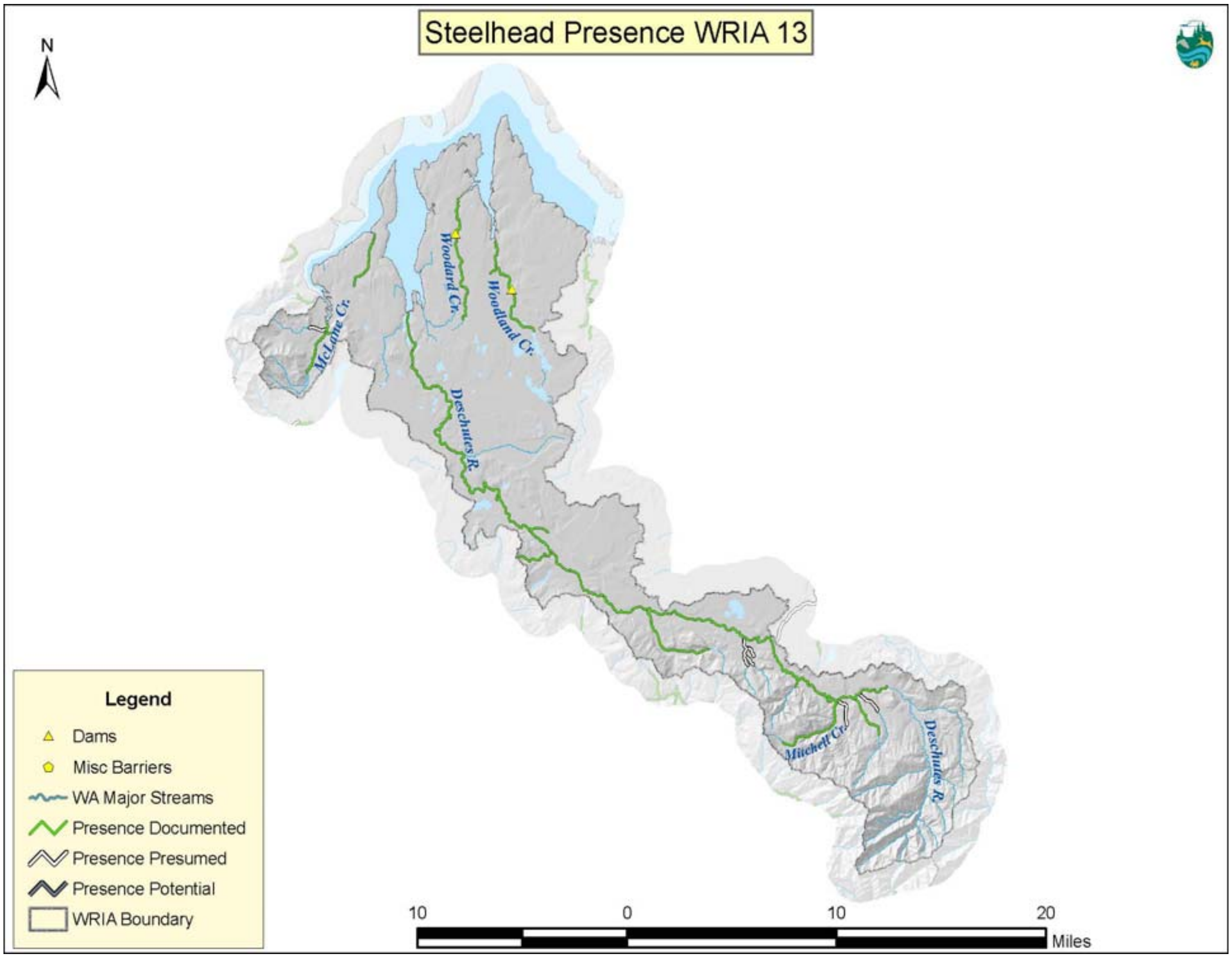


Figure 23. The distribution of steelhead in WRIA 13. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Kennedy-Goldsborough Watershed (WRIA 14)

The Kennedy-Goldsborough Watershed (WRIA 14) encompasses the extreme southwest terminus of Puget Sound, including a portion of Eld Inlet, the entirety of Totten Inlet, Oakland Bay and Hammersley Inlet, and a portion of Case Inlet (Figure 24). The watershed covers approximately 380 mi^2 and is characterized by numerous independent tributary streams that drain directly into Puget Sound. No major river system is present but lakes and wetlands are widespread throughout the area (Washington Department of Fisheries 1975). The majority of the area is characterized by low elevation hills and valleys and streams are rainfall-dominated and subject to low summer flows because of the lack of snow pack. Porosity of widespread glacial soils allow groundwater, wetlands, and beaver ponds all contribute to maintaining summer stream flows (Molenaar and Noble 1970).

Logging has been the dominant industry in the area since the 1850s and the vast majority of the watershed is dominated by early and mid-seral forests (Washington Department of Fish and Wildlife 1996). Riparian canopy closure throughout the watershed is generally inadequate to maintain state water quality temperature and dissolved oxygen standards (Schuett-Hames et al. 1996, Squaxin Island Tribe 2002, unpublished work), and streambank condition is generally poor. Pool frequency varies, but pools are typically moderately abundant. Although pools are generally shallow, they often make up a large proportion of stream surface area (Schuett-Hames et al. 1996). Disruptions of floodplain connectivity have occurred on some streams, but in general floodplain connectivity is fair to good. Wetlands, lakes, and beaver ponds provide off-channel habitat throughout the watershed (Taylor et al. 2000). Eroding streambanks and runoff from logging roads, etc. have contributed fine sediment to streams throughout the watershed. Total LWD abundance is moderate to low and LWD abundance is generally below state standards (Schuett-Hames et al. 1996).

Damming of wetlands to create man-made lakes and shoreline modifications have been a common practice in the watershed. These activities along with conversion of forestland to agricultural or residential uses have altered the natural flow regime of many streams. Additionally, exotic warm water fish have been introduced to many of the lakes causing competition and predation problems with native salmonids.

Condition of Steelhead Populations

Winter steelhead in the Kennedy-Goldsborough Watershed typically enter freshwater from December through mid-March and spawn from early February to early April. Stock status throughout the watershed (four stocks) was characterized as “unknown” because escapement is not monitored (WDFW and WWTIT 1994, 2002). Low summer flows in many creeks limit the ability to produce a two-year-old steelhead smolt.

Sport fishing regulations vary among streams but, where present, provide most of the available knowledge for the abundance of these stocks. Wild steelhead release is required on all streams. Perry and McLane Creeks are the two winter steelhead streams that drain into Eld Inlet (Figure 24). No tribal or sport fisheries target these fish. Totten Inlet winter steelhead spawn in Skookum, Kennedy, and Schneider Creeks. Steelhead are also present in Mill, Goldsborough, Johns, Cranberry, Deer, Spring, Malaney, Uncle John, and Campbell Creeks. Sherwood, Coulter, and Rocky Creeks are home to Case Inlet winter steelhead.

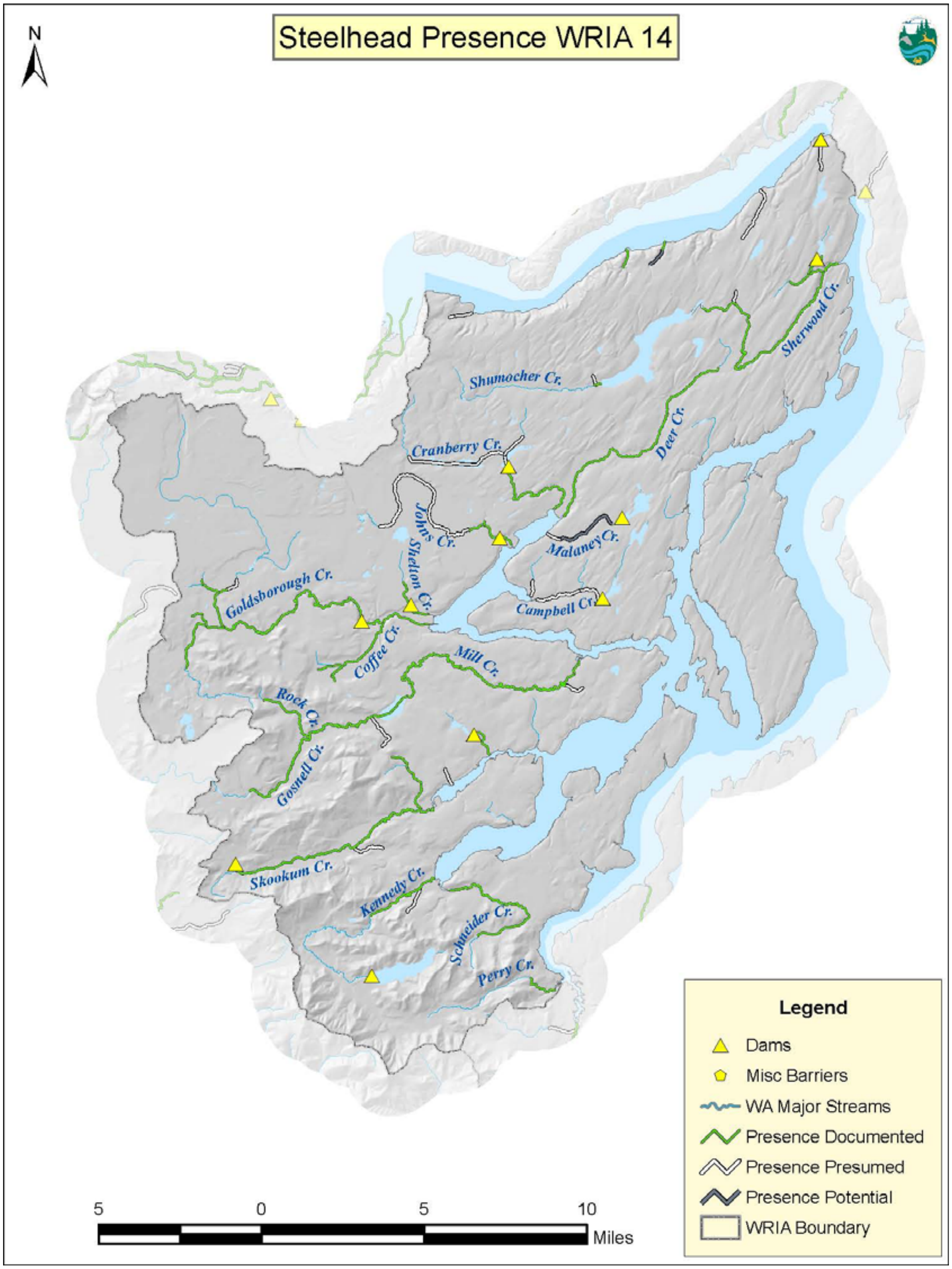


Figure 24. The distribution of steelhead in WRIA 14. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Kitsap Peninsula Watershed (WRIA 15)

The Kitsap Peninsula and Bainbridge Island Watershed includes many freshwater streams that drain into inlets in southern Puget Sound, the east side of central Puget Sound, and various locations along Hood Canal (Figure 25). Streams draining into Puget Sound from the east half of the Kitsap Peninsula are numerous, but rather small in comparison to those of the west half. They represent typical lowland type streams with generally moderate gradients. Considerable deciduous growth, interspersed with stands of conifers, farmland, and urban development is common on all streams. Many of the streams originate from lakes, ground water run-off, or swamp-like headwater wetlands (Williams et al. 1975), which in several instances drain to both Puget Sound and Hood Canal tributaries. None of the streams are supported by snow runoff, as the maximum elevation in WRIA 15 is < 500 m.

Numerous low elevation, low-gradient streams drains the eastern sides of peninsulas and islands within WRIA 15. Of these, 125 streams are known to support salmonids, with an estimated 215 linear miles of total utilization (Haring 2000). This level of utilization rivals that of most large river basins and production potential of the streams is very high due to low stream gradients, lack of natural passage barriers, and extensive wetland complexes. Although the upper portions of some watersheds may not be accessible to anadromous salmonids, many support resident populations, including rainbow trout, and warrant protection. Numerous steelhead-bearing streams drain from the east side of WRIA 15 (Figure 25). In addition, there are 320 miles of marine shoreline and nearshore habitat in East Kitsap, which provides juvenile rearing and migration habitat for salmonids from throughout Puget Sound. Land management practices and direct actions within the stream corridor have degraded habitat in many of the east Kitsap streams. Chief among these are substantial timber harvest, stream channelization and nearshore armoring, agricultural practices, urbanization and development of headwater areas, and the construction of large number of culverts/screens/dams that preclude unrestricted upstream or downstream access of juvenile and adult salmonids (Haring 2000).

Most of the stream and rivers on the western side of WRIA 15 drain into Hood Canal, rather than into Puget Sound proper (Figure 25). These streams and rivers are generally larger than those on the east side of the WRIA and support more abundant salmonid populations. While many of the same upland habitat factors influencing streams in the eastern half of the WRIA also impact western streams, the effects are often less pronounced as a result of less prevalent urbanization.

Condition of Steelhead Populations

No summer-run steelhead stocks exist in the Kitsap Peninsula Watershed, but 5 winter-run stocks have been identified. Two stocks utilize the east/southeast aspect of the peninsula while three utilize the Hood Canal (western) side. In the east, Case/Carr Inlet steelhead and

East Kitsap steelhead are native and run from December through mid-March. They generally spawn from early-February to early-April. Both stocks are composed of an historically small number of individuals, with insufficient information to classify status due to a lack of monitoring. As small stocks, they could be especially vulnerable to any negative impacts. In the west, distinct stocks utilize the Dewatto, Tahuya, and Union Rivers. Spawning in these stocks occurs from February through June, and little else in known about Union River Steelhead. The status of both Dewatto and Tahuya steelhead stocks is depressed based on chronically low escapement estimate (WDFW and WWTIT 2002).

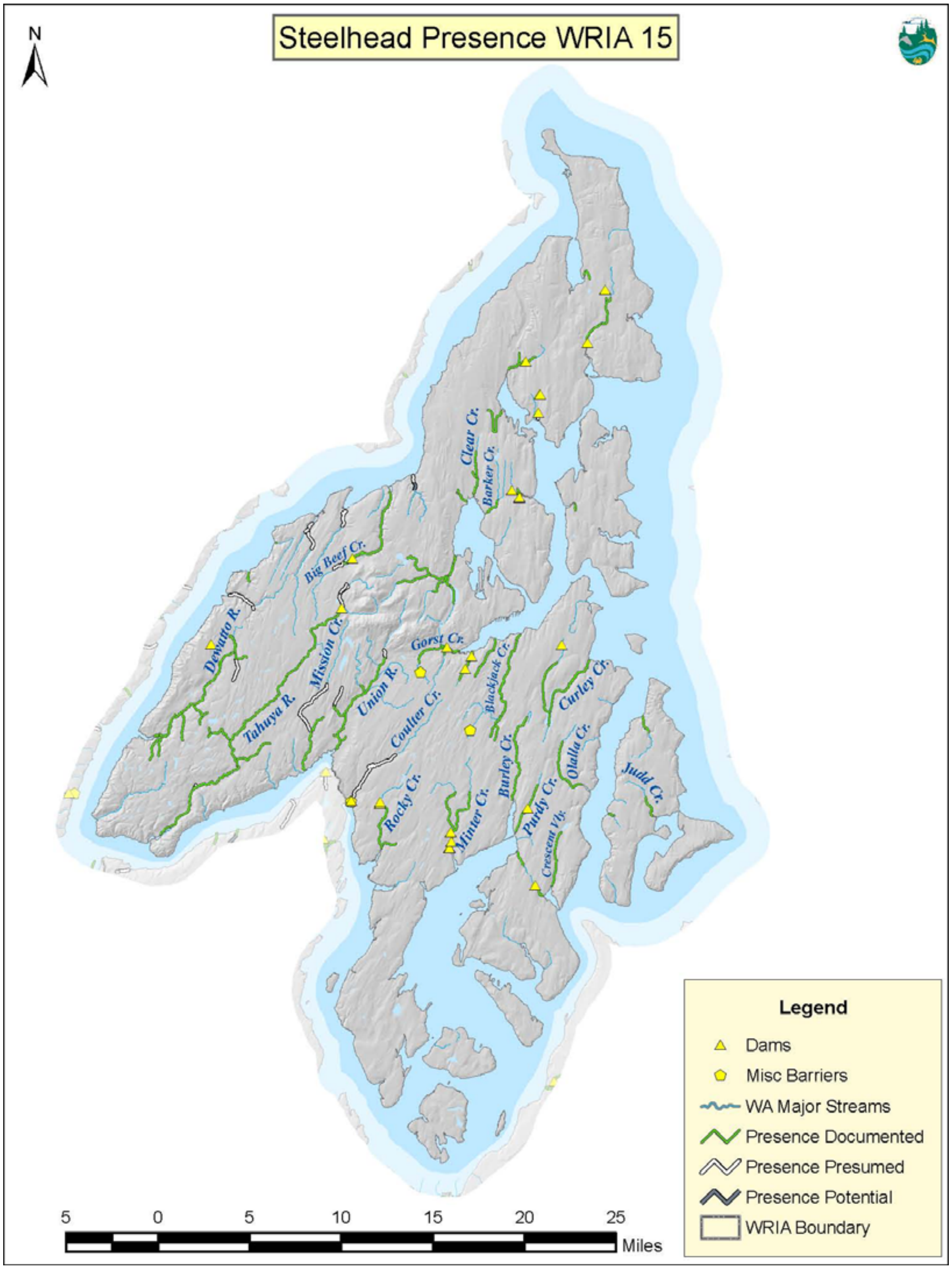


Figure 25. The distribution of steelhead in WRIA 15. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Hood Canal and Northeast Olympic Peninsula Watershed (WRIAs 16+17)

The Hood Canal Basin is located between the eastern slope of the Olympic Mountains and the Kitsap Peninsula and is made up of WRIA 16 (Figure 26), much of WRIA 17 (Figure 27), the western portion of WRIA 15 (Figure 24), and the northern portion of WRIA 14 (Figure 24). As the portions of basin fed by rivers from WRIAs 14+15 have already been discussed, the text bellow focuses on rivers draining into Hood Canal on the western shore (WRIAs 16+17) and rivers draining into several prominent bays on the northeast Olympic Peninsula (WRIA 17). The five principal rivers draining into the western side of Hood Canal are the Big Quilcene, the Dosewallips, the Duckabush, the Hamma Hamma, and the Skokomish. Interspersed among the large rivers are numerous smaller, independent lowland streams with headwaters in the low foothills of the Olympic Mountains. The Dosewallips, Duckabush, and Hamma Hamma Rivers are characterized by two annual runoff peaks, one associated with winter rains between November and February and the other associated with snowmelt between May and June (U.S. Forest Service 1999).

Hood Canal and Northeast Olympic Peninsula Nearshore

The Strait of Juan de Fuca/Admiralty Inlet portion of WRIA 17 contrasts markedly with the portion inside Hood Canal itself. The Strait is a wind-dominated system, with currents changing dramatically in response to regional and larger scale oceanic winds (Strickland 1983, Shaffer 2001). A submarine sill at Admiralty Inlet obstructs the continuous flow of deep water and diverts surface water back to the Sound, producing one of the dominant areas of mixing in Puget Sound (Nightingale 2000). In contrast, the sill located between the mouth of Hood Canal and Admiralty Inlet restricts circulation of ocean water and it takes months to a year for a full exchange of Hood Canal with ocean water. Poor circulation results in periods of hypoxia in the southern reaches of Hood Canal (Newton et al. 2007).

Within Hood Canal the nearshore environment consists of a complex network of mudflats, tidal channels, lagoons, marshes, vegetative beds, beaches, bluffs, and riparian vegetation. These nearshore habitat components provide shallow water migration corridors for juvenile and adult salmonids. Development along the Hood Canal shoreline has substantially altered nearshore habitat characteristics throughout the watershed (Washington Department of Ecology 2000). Activities associated with shoreline development including filling of intertidal mudflat, salt marsh and lagoon habitats, shoreline armoring, removal of riparian vegetation, and installation of boat ramps, docks and piers, have all altered natural shoreline process, particularly recruitment of sediment and woody debris from eroding bluffs and sediment transport and deposition along the shoreline.

Numerous roads and highways are located along the Hood Canal shoreline (Washington Department of Ecology 2000). In many cases, road crossings at stream mouths have constrained stream and tidal channels, altering tidal processes and sediment transport and, in some cases, interfering with fish migration. Shoreline roads have also reduced the width of riparian buffers throughout much of the Hood Canal shoreline, particularly along the east arm of the Canal (Washington Department of Ecology 2000).

Big Quilcene River Basin

The Big Quilcene basin covers ~70 mi^2, drains to Quilcene Bay in northwest Hood Canal (Figure 27). The Big Quilcene has a total mainstem length of 19 mi and a combined tributary length of 80 mi (Ames et al. 2000). The terrain is generally steep (GeoEngineers, Inc. et al. 1998), and 1% of the basin lies within the Olympic National Park while 30% is contained in the Buckhorn Wilderness Area. Below the Buckhorn, the Forest Service, state, and private forestland owners manage most of the remaining basin for timber production. The basin experiences an average annual precipitation of 61 inches and above 4,000 feet snow is the principal form of precipitation, with rainfall dominating below 2000 feet (GeoEngineers, Inc. et al. 1998). The average low-flow is less than 60 cfs in September while maximum flows range from 1500 to 3050 cfs (GeoEngineers, Inc. et al. 1998). Most high flow events result from intense rainstorms, rain-on-snow events or sudden snow melt.

The Quilcene National Fish Hatchery, which produces coho, utilizes water from both the Big Quilcene and from nearby Penny Creek (Ames et al. 2000). Upstream passage is restricted on the Big Quilcene between September and December by an electric weir operated by the fish hatchery. The channel below river mile 0.8 is diked, and portions of the channel between river mile 0.8 and 4.8 have been dredged, diked or the bank armored.

Dosewallips River Basin

The Dosewallips basin, located in southeast Jefferson County, lies in the northern portion of WRIA 16 (Figure 26) and covers ~122 mi^2 (U.S. Forest Service 1999). The Dosewallips basin includes a total of 172.8 stream miles (Williams et al. 1975). The Dosewallips River originates in the Olympic Mountains and is dominated by alluvial and glacial valley bottoms and relatively gentle slopes in the lowlands. The western headwaters are wide glacial valleys with an average slope of 4% (U.S. Forest Service 1999). The Dosewallips River mainstem is ~28 mi long with many tributaries. The upper 60% of the basin is protected in Olympic National Park, the middle 30% lies within Olympic National Forest, and the lower 10% is dominated by residential development, pastureland, and clearcut logging (Ames et al. 2000).

Duckabush River Basin

The Duckabush River originates in the Olympic Mountains and, together with its tributaries, consists of ~120 linear miles of river (Williams et al. 1975) covering 75 mi^2 (U.S. Forest

Service 1999). Valley walls are steep throughout all but the lower two miles of the mainstem river (Williams et al. 1975). Sandstone, siltstone and slate bedrock formations dominate the headwaters while the lower two-thirds of the watershed is basaltic. The upper 75% of the watershed is protected within Olympic National Park boundaries and the USFS Brothers Wilderness.

Timber harvest is the dominant land use in the lower watershed, both on National Forest lands and private lands, and began in the early 1900s. The Washington Department of Fisheries Stream Improvement Division removed logjams and blasted impassable falls between 1955 and 1970 to improve fish passage (Ames et al. 2000). The lower river fluctuates in width, which appears to expand in association with large riparian disturbance such as fire and railroad logging (U.S. Forest Service 1999).

Hamma Hamma River Basin

The Hamma Hamma River originates in the Olympic Mountains within the Olympic National Park and, with its tributaries, consists of nearly 230 mi of waterways. Limited sandstone, siltstone and slate bedrock formations are within the headwaters, with the remainder of the watershed underlain by basalt, as well as glacial and alluvial deposits, along the mainstem (Williams et al. 1975). An impassable falls is at river mile 2.5 with a long series of cascades at approximately river mile 2.0 (U.S. Forest Service 1997). The lower 0.6 miles is tidally influenced (Williams et al. 1975) and at high tide at least one small secondary channel connects the mainstem with a large tidal marsh, just north of the main channel (Ames et al. 2000). Nearly 95% of the basin is in public ownership with 60% in managed forest and 34% protected within Olympic National Park or designated wilderness areas. WDNR owns 261 acres, or 23%, of the watershed. Private lands (5%) are concentrated in the productive lower anadromous reach near the river mouth and are managed primarily for timber harvest, with aquaculture within the estuary and adjacent nearshore (Ames et al. 2000).

Anadromous salmon use the lower reach of the mainstem Hamma Hamma River in September and late fall chum spawn in the mainstem, and intertidally in Hamma Hamma Slough, during December. Steelhead have been observed all the way to the falls at approximately river mile 2.5 and spawn between mid-February and mid-June (WDFW, unpublished data).

Skokomish River Basin

The Skokomish River is the largest river system draining into Hood Canal, with a basin area of ~240 mi^2 covered by 80 mi of mainstem and over 260 mi of tributaries (Ames et al. 2000) (Figure 26). The South Fork originates in the southern Olympic Mountains, as does the North Fork, which also contains Cushman Reservoir. The lower South Fork drains a broad fertile, valley with rural home/hobby farm development (Williams et al. 1975). The Skokomish River enters the southwest end of Hood Canal known as the Great Bend between the rural towns of Potlatch and Union, creating the largest sub-estuary and intertidal delta in the Hood Canal Basin (Ames et al. 2000).

Historically the Skokomish River system produced the largest runs of salmon and steelhead in Hood Canal, most of which were produced in the North Fork. The North Fork basin has been managed primarily for hydropower production, timber and agriculture and, as a result, has suffered from severely reduced flows. The South Fork has experienced extensive timber harvest and the mainstem has been channelized with levees to reduce flooding. Aggradation is a serious condition resulting from these land use activities. Past logging practices in the South Fork, including road failures, have increased the sediment supply much beyond natural levels. The loss of historic flows in the North Fork Skokomish River have reduced sediment transport capabilities. Channelization and diking further contribute to sediment accumulation. The resulting habitat conditions overall are poor as a results of these factors (Ames et al. 2000).

Condition of Steelhead Populations

Populations of both summer- and winter-run steelhead are present throughout the drainages in the Hood Canal Watershed, but the five principal rivers (Big Quilcene, Dosewallips, Duckabush, Hamma Hamma, and Skokomish) are the main production areas. Adult steelhead enter freshwater from December through May and spawn from mid-February to early June. Resident rainbow trout populations have been observed in the Dosewallips, Duckabush, Hamma Hamma, Lilliwaup and Skokomish Rivers but their contributions to steelhead abundance are unknown.

Little is known about summer-run steelhead in the Hood Canal basin. Specific spawning locations for summer steelhead on the Dosewallips, Duckabush, and Skokomish rivers are unknown, but are believed to be in the upper reaches of the watershed. Spawn timing is also unknown but is believed to be from February through April. Adequate abundance trends do not exist for these stocks, nor have genetic analyses been conducted. The status of all three summer steelhead stocks in the basin remains unknown (WDFW and WWTIT 1994, 2002).

Considerably more is known about winter-run steelhead stocks in the basin. Spawn timing is generally from mid-February to mid-June. Dosewallips winter steelhead spawn mostly in the lower 12 mi of the mainstem river. Allozyme analysis indicates that Dosewallips steelhead are distinct from other Hood Canal steelhead stocks (Reisenbichler and Phelps 1989). Duckabush winter steelhead spawn in the lower 4 mi of the mainstem river. Hamma Hamma winter steelhead generally spawn in the lower 2 mi of the mainstem. Genetic samples from this stock have shown significant differences between resident rainbow parr and anadromous parr within the watershed (Berejikian et al. 2002), but comparisons have not been made with other Hood Canal basin stocks. Skokomish winter steelhead spawn in the mainstem Skokomish and South Fork Skokomish with a smaller number in the North Fork Skokomish and Vance Creek. Allozyme analysis indicates that this stock is distinct from other Hood Canal steelhead stocks (Reisenbichler and Phelps 1989). The status of Dosewallips, Duckabush, and Hamma Hamma winter steelhead stocks is depressed because escapement is lower than expected based on available habitat (WDFW and WWTIT 1994, 2002). The same is true for Skokomish winter steelhead but, additionally, there has been a long-term negative trend in abundance for this stock.

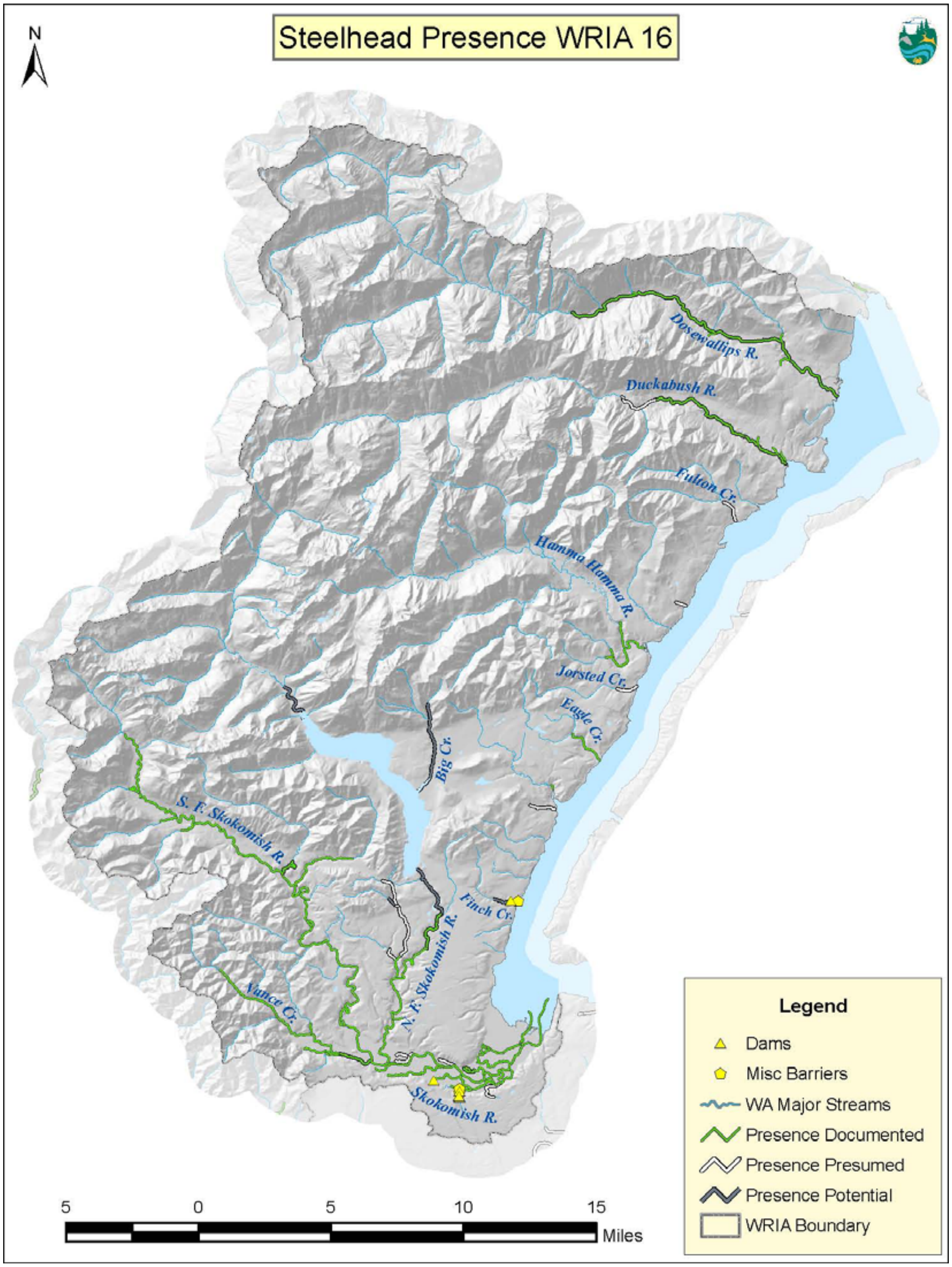


Figure 26. The distribution of steelhead in WRIA 16. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

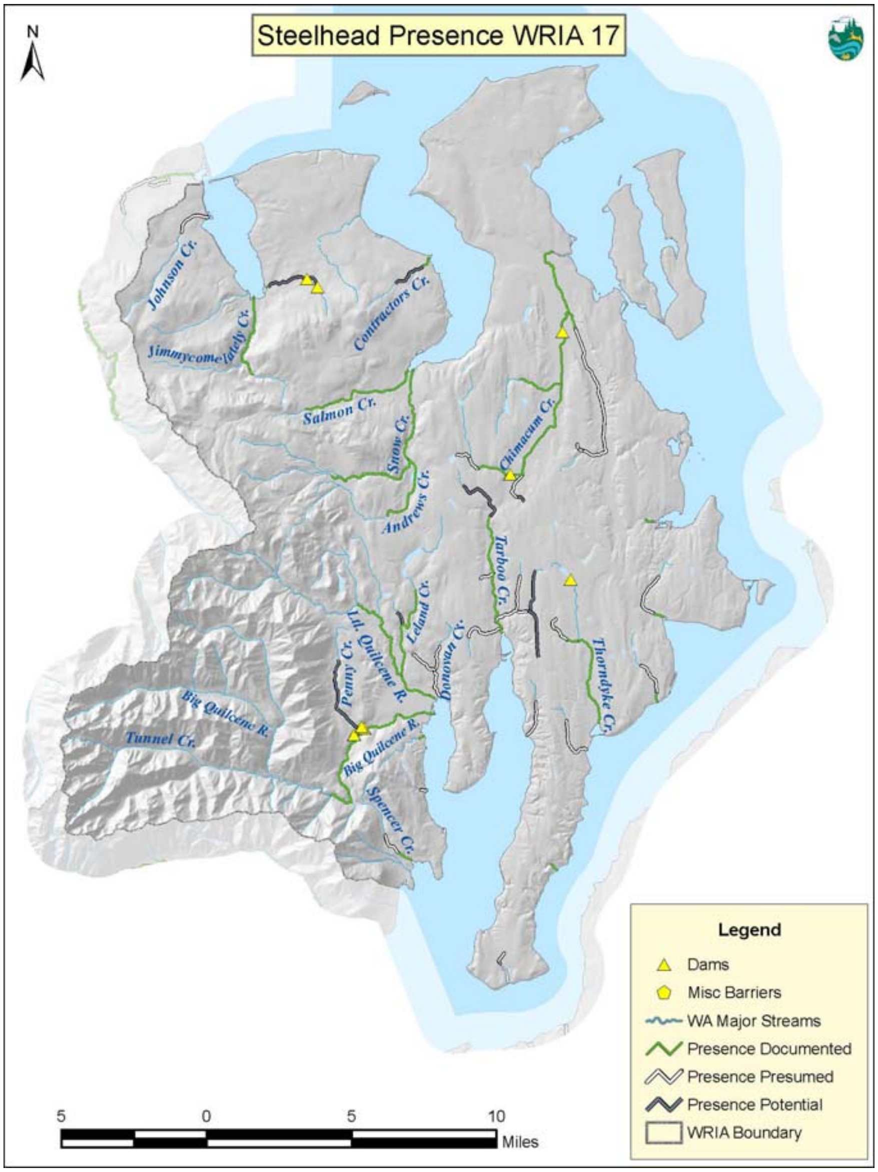


Figure 27. The distribution of steelhead in WRIA 17. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

North Olympic Peninsula Watersheds - Dungeness River, Morse Creek and Elwha River Watersheds (WRIA 18)

Several independent drainage basins make up WRIA 18, which lies along the northern edge of the Olympic Peninsula (Figure 28). The largest of these are the Dungeness and Elwha River basins. The WRIA drains 172,517 acres and the topography includes three distinct areas: mountains; foothills; and the alluvial fan adjoining the Strait of Juan de Fuca. The mountainous area includes lands within Olympic National Park and Olympic National Forest. The foothill areas range from flat valley bottom to moderate 40% slopes. The agricultural and residential areas in the northern portion are gently rolling to nearly flat. Public and private forestlands total 74,624 acres (43% of the watershed) (Puget Sound Cooperative River Basin Team 1991). Very steep bluffs dominate the marine shoreline west of the Dungeness River. A total of 33 mi of shoreline make up the northern edge of the watershed.

An extensive Dungeness River irrigation system has been constructed to serve municipal and agricultural needs of the area. This system contains approximately 62 miles of main ditch canal and another 111 miles of secondary ditches and laterals (Montgomery et al. 1999). Irrigation ditches play an important role in groundwater recharge in the lower watershed.

Dungeness River Watershed

The largest contributor of nonpoint pollution in the Dungeness watershed was identified as agricultural activities, including irrigation diversions and laterals, direct animal access to waterways, and chemical application (Puget Sound Cooperative River Basin Team 1991). Rural residential areas and agricultural lands near the Strait of Juan de Fuca account for over 90% of the watershed’s population. In the past, most of this land was farmed but now is being held either for recreational or investment purposes. Private woodlots, which are not intensively managed for timber production, make up another five percent of the watershed. As a large portion of the middle and upper sections of this watershed are protected and/or undeveloped the Dungeness River basin offer substantially quantities of excellent steelhead habitat.

Elwha River Area Watershed

The Elwha River is the largest and historically most productive salmonid river within WRIA 18, and possibly on the Olympic Peninsula. It originates from Mt. Olympus, deep in the Olympic National Park, and flows northward to the Strait of Juan de Fuca. Most of the tributary headwaters originate at ~4,000-ft in elevation and the watershed drains over 300 mi^2, 83% of which is located within the Olympic National Park. The mainstem is ~45 miles in length, with 100 miles of tributary streams (Williams et al. 1975). Annual precipitation in the upper watershed averages 200+ inches, while that of the lower drainages averages 56 inches. Because the river is snow-field-fed, stream flows have a bimodal discharge pattern with peaks occur during winter freshets and in late spring or early summer (Munn et al. 1998).

The Elwha supported legendary runs of at least ten species-runs of anadromous salmonids, including winter- and summer-run steelhead. Hydroelectric dams were constructed in the early part of the 20th century at RM 4.9 and 13.2 without fish passage facilities, preventing salmon from reaching historic spawning and rearing areas. This immediately eliminated up-river production of winter- and summer-run steelhead, as well as several other salmonids. Some lower river spawners, such as pinks and chums, remained at relatively high abundance into the mid 1960s. However, ecological changes associated with the dams, including the truncation of gravel recruitment in combination with channelization, ultimately led to the collapse of these stocks by the 1970s. Today, natural production of salmon is limited to just a few areas in the lower river, however dam removal began in September 2011 and is expected to ultimately restore access to substantial spawning habitat in the central and upper basin.

Independent Watersheds

Although several rivers within WRIA 18 drain independently into the Strait of Juan de Fuca (Figure 28), they are jointly discussed here due to the connectivity of these systems through the irrigation distribution network associated with the Dungeness River.

McDonald Creek is 13.6 mi long, draining a watershed area of 23 mi^2. The headwaters originate at 4,700 feet and flow through a deeply incised coastal upland and marine bluff before entering the Strait of Juan de Fuca. Land in the upper watershed is managed for commercial forestry, with the extreme headwaters located in the Olympic National Park. The lower reaches contain both moderate- and low-gradient habitat, with land uses including commercial forestry, agriculture, and suburban development.

Siebert Creek is 12.4 mi long and drains an area of 19.5 mi^2 before emptying directly to the Strait of Juan de Fuca (Williams et al. 1975). Siebert Creek drains the low hills paralleling the Strait of Jan de Fuca, and the upper reaches of the watershed are typically steep and incised at elevations up to 3,800 feet. Land uses are similar to those described for McDonald Creek, however, agricultural impacts, including water withdrawals, are considered less significant.

Morse Creek is the largest of the independent drainages to salt water between the Dungeness and Elwha Rivers, draining over 57 mi^2. Morse Creek drains steep headwaters of Olympic National Park including Hurricane Ridge, Mt. Angeles, and Deer Park. Over 75% of the area of the watershed lies within the Olympic National Park. Like other watersheds on the North Olympic Peninsula that accumulate significant snowpack, Morse Creek exhibits two peaks in annual discharge (one associated with winter rainstorms and one resulting from spring snowmelt). Morse Creek is known to have produced a high diversity of salmon species in greater numbers than expected for a stream of its size, but steelhead usage is confined to the lower reaches.

The mouth of Lees Creek is a “closed channel” through the summer, isolated from the Strait of Juan de Fuca by a natural sand spit during low flow periods. Ingress or egress access for anadromous salmon is only provided when flows and tides increase to the extent that the sand spit is overtopped. Historically, closed streams may have had fewer anadromous fish as compared to streams with fully developed estuaries; however it is difficult to assess the historic populations of salmon in Lees Creek because the watershed was already largely degraded by the 1920s**.** There is a perched culvert close to the mouth, with a significant drop at the outlet, which is a complete barrier to anadromous fish. In 1998 a fishway was installed in the culvert beneath Highway 101, which was a barrier since approximately 1940. Other upstream culverts (e.g., Marsden Road) remain as total fish passage barriers. Passage barriers and habitat degradation also limit steelhead use to the lower sections of Ennis, Tumwater, and Dry Creeks.

Condition of Steelhead Populations

Two stocks of summer-run and three stocks of winter-run steelhead exist in WRIA 18. Both the Dungeness and Elwha Rivers support both summer and winter stocks, and a third stock spawns in Morse Creek and various independent tributaries. Some evidence suggest there is also a summer steelhead run in Morse Cr., but whether this “stock” is composed of stray hatchery fish from the Elwha or Dungeness or a true Morse Creek population that should be considered for designation as a separate stock based on geographic separation remains in debate.

Little is known about summer steelhead in WRIA 18 but on the Dungeness River summer steelhead adult presence has been documented to the impassable falls on the mainstem (RM 18.7), and to at least 3-Forks on the Gray Wolf River (RM 9.6). The lowermost extent of spawning is unknown as summer and winter steelhead cannot be distinguished at spawning time, but they are thought to spawn in the upper reaches of the river. As of 2002 the status of this stock was designated as unknown, but a re-designation to critical is currently under review (R. Cooper, WDFW, personal communication). The status of summer steelhead in the Elwha River is also unknown, due to a lack of monitoring effort in recent years, but re-designation to critical is currently under review (D. Goin, personal communication). Summer steelhead have been observed annually in the “upper” pool below the dam throughout the late 1990s (perhaps a dozen fish present in latest survey in mid-October, 1999) during Chinook surveys conducted by WDFW (Ray Johnson/Ken Gilliam). Spawning occurs upstream as far as the dam, with the lowermost extent of spawning unknown. The Elwha has been regularly planted by WDFW with 10,000 Skamania-origin summer steelhead, with past plantings as high as 25,000 (Mike McHenry, personal communication).

More is known about winter steelhead in WRIA 18, though recent survey efforts have been hampered by high stream flows and disagreement about escapement estimation methodology. Dungeness River winter steelhead spawning distribution is thought to be similar to that of coho, extending from the upper extent of tidewater to RM 18.7. Winter steelhead distribution is also presumed to match that of coho salmon in all Dungeness River tributaries, including the Gray Wolf River. In the Elwha River steelhead spawning is limited to the 4.9 mi below the dam and historic abundance is considerably below historic levels. Stock status for both Dungeness and Elwha winter steelhead is depressed due to a long-term negative trend in abundance, but re-designation to critical is possible (R. Cooper, WDFW, personal communication). Dramatic changes in abundance are expected on the Elwha River in response to removal of the hydropower dam.

The Morse Creek/Independents winter steelhead stock includes steelhead in Morse, Siebert, and McDonald creeks and its status is rates as depressed. In Morse Creek, spawning is limited by an impassable falls at RM 4.7. Although designated as depressed, there is some optimism in response to escapements in recent years (B. Freymond, WDFW, personal communication). Regular plantings of 5,000 Bogachiel-origin winter steelhead have been made in Morse Creek.

Additional winter steelhead streams include Lees, Ennis, Valley, Tumwater, and Dry creeks. The status of winter steelhead in these streams is unknown, with little current or historic data available. The spawning distribution in Lees Cr. extends from the mouth to approximately RM 3.8 in the mainstem, and to approximately RM 3.2 in the East Fork. The spawning distribution in Ennis Cr. is from approximately RM 0.2 upstream to the impassable cascade at RM 5.0. The spawning distribution in Valley and Tumwater Creeks is thought to be the same as for coho, up to Highway 101 at RM 1.2 and the power line crossing at RM 2.3, respectively. Steelhead spawning has been observed in Dry Creek to approximately 100 yards below the road at the falls (RM 1.0). Dry Creek has limited over-summer habitat and steelhead presence may be influenced by attraction of Elwha River water which leaks from a pipeline into Dry Creek (M. McHenry, personal communication).

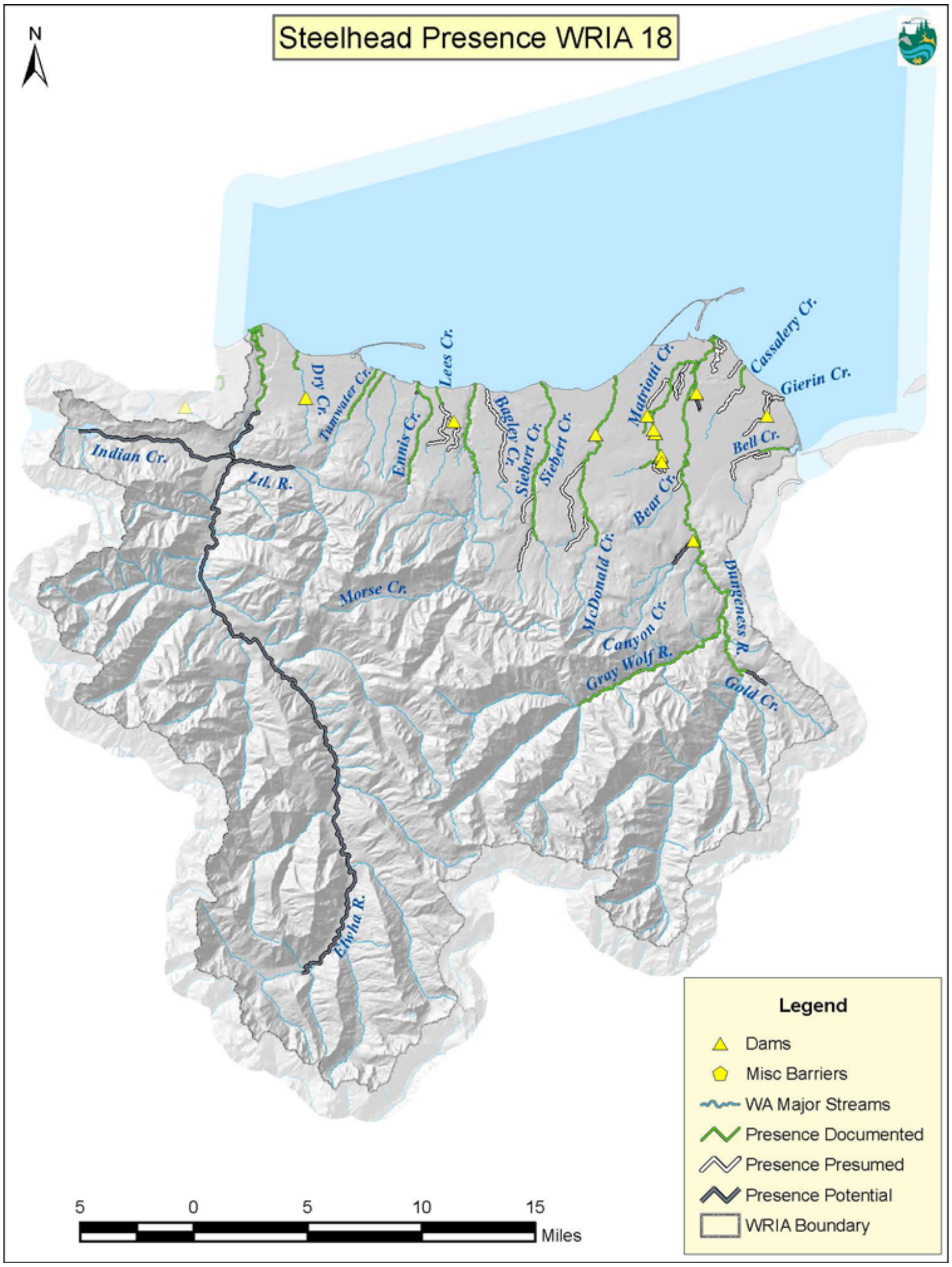


Figure 28. The distribution of steelhead in WRIA 18. Documented = survey records exist that confirm presence; Presumed = surveys have not verified occurrence, but presence is a reasonable assumption based on habitat and documentation elsewhere; Potential = current lack of presence due to artificial obstructions, poor habitat quality, or extirpation of local stocks.

Recovery Gap Analysis

Within the Puget Sound recovery domain, recovery plans have been written for Puget Sound Chinook (NMFS 2007), Hood Canal summer chum (Brewer et al. 2005), and bull trout (USFWS 2004). We analyzed these documents to identify possible recovery planning gaps that should be considered in planning for Puget Sound steelhead recovery.

The habitat requirements of salmonids identified in the above recovery plans overlap to varying degrees. Thus, habitat recovery actions identified in the plans will provide various levels of direct, and possibly indirect, benefit to Puget Sound steelhead. For example the Chinook salmon recovery plan (NMFS 2007) lists the "Top Ten Actions needed for salmon recovery," which at this coarse scale, overlaps the recovery needs of steelhead:

1. Protect and restore estuaries
2. Restore and reconnect floodplain areas
3. Protect and restore riparian areas
4. Set, achieve, and maintain goals for instream flow (water quantity)
5. Reduce both non-point and point source pollution (water quality)
6. Remove/revise barriers to increase fish access
7. Protect and restore Puget Sound shoreline and nearshore marine areas
8. Ensure sustainable harvest management
9. Manage hatcheries to preserve the integrity of wild stocks
10. Integrate harvest, hatchery, habitat, and hydropower management

Although there are common habitat needs and stressors among salmonids, steelhead possess some distinct life history traits that require additional consideration. We have attempted to lay the foundation for the identification and consideration of these differences, as well as acknowledge the areas of greatest uncertainty, concerns, and confounding factors for steelhead recovery planning.

Summary of Findings

After review of the recovery plans listed above, the following potential habitat-specific gaps were identified:

- Steelhead commonly penetrate farther into watersheds than Chinook or chum salmon. Impairment of fish passage, particularly upstream adult fish passage at dams and road crossings, will need stronger consideration in steelhead recovery planning.

- Juvenile steelhead reside longer in freshwater systems (2 -3 years) than Chinook or chum salmon. Water quality and flow conditions play an increasingly important role for steelhead survival. For example, while most chum and Chinook salmon have migrated to the sea by summer of their first year of life, steelhead may need to endure elevated stream temperatures and low dissolved oxygen conditions for one to two years. Streams with water withdrawals for municipal or commercial purposes may influence low flow conditions during summer, further limited steelhead rearing habitat.

- As spring spawners, steelhead are especially vulnerable to elevated temperature regimes during late spring/early summer, when eggs are still in gravel nests. As planning for Chinook and chum primarily considers embryo and alevin presence in the late summer and fall, when these species spawn, there is a temporal gap in the consideration of habitat effects on early life history stages.

- Upon their return to natal streams in spring, adult summer steelhead "hold" in headwater habitats for almost a year. During this period, they are especially vulnerable to predation mortality and stress-related mortality from habitat disturbance or illegal fishing activity. Adult steelhead require cool water refugia during summer months, and adequate in-stream cover from predators.

- Steelhead populations exist in streams that do not have listed chum or Chinook salmon. Habitat protection and restoration strategies may need further consideration in these streams.

- Recent information on early marine survival of steelhead in Puget Sound and the Strait of Juan de Fuca indicates a source of relatively high mortality. Although principle reasons for this mortality are unclear, steelhead recovery planning should address this uncertainty and population sink.

- Climate change may disproportionately affect steelhead. Climate change may affect ocean-rearing species (such as chum, pink, and fall Chinook populations) less than species, like steelhead, with lengthy freshwater rearing. Steelhead recovery planning should include protection strategies for cool-water refugia reaches, intact stream and riparian reaches, and reaches where climate models predict adequate flow.

- Freshwater productivity is a key indicator in the adequacy of protection/restoration strategies of salmon. Although tools vary by watershed and population, freshwater productivity trends can be measured by comparing adult returns to a watershed and corresponding smolt migrations out of the watershed. Although freshwater productivity is measured in several watersheds of Puget Sound for salmon, these estimates are less available for steelhead, providing less information to indicate how recovery actions are working. Recovery planning for steelhead should address increased monitoring needs of freshwater productivity for steelhead to help in detecting population trends.

Other recovery planning gaps identified for steelhead that were unrelated to habitat were largely beyond the scope of this review. However, some non-habitat gaps were apparent after review of existing recovery plans, including, but not necessarily limited to:

- A lack of knowledge about the prevalence of hooking mortality for juvenile steelhead during freshwater sport fishing seasons.
- Ambiguity surrounding the potential for marine predation on young steelhead smolts by other fish species and/or birds, especially during the current decline of forage fish stocks (herring, smelt, sand lance, etc.).
- A lack of stock-specific life history and productivity information, particularly for summer-run steelhead.
- Little information regarding the extent to which smaller, independent drainages are used by winter-run steelhead.
- Limited data on the effects of reduced nutrients on steelhead, which result from decreasing availability salmonid carcasses throughout Puget Sound.
- A lack of information regarding the adverse effects on steelhead development and survival from hazardous and toxic chemical pollutants entering rivers and Puget Sound.
- An incomplete understanding of the impacts of rainbow trout stocking and fishing in Puget Sound lakes and streams.
- An absence of studies quantifying potential impacts associated with production, straying, and interbreeding of hatchery and wild steelhead.

Unique Steelhead Attributes

Freshwater Residency

Steelhead freshwater residency prior to smoltification and emigration is longer than Chinook or chum salmon, but can be comparable bull trout. However, unlike bull trout, steelhead have a greater range of temperature tolerance and, therefore, a wider geographic distribution throughout Puget Sound. In addition, unlike Chinook and chum salmon in a given stream, multiple age classes of steelhead rear at the same time. Habitat conditions within a given stream are extremely important to steelhead survival because juvenile steelhead must endure those conditions for an average of two years, and possibly as long as four to five years.

Puget Sound summer-run steelhead have a relatively long freshwater residency as adults. Summer-run steelhead return to freshwater during early summer in an immature condition and do not spawn until the following spring. This ‘holding’ period prior to spawning means their adult habitat requirements differ from those of salmon and winter-run steelhead. Adult summer steelhead require deep pools, cool summer stream temperatures, and/or abundant cover. Most Puget Sound steelhead are winter-run, typically returning in a mature condition during winter or early spring. Winter-run steelhead spawn within 2-3 months after returning from the ocean. Both summer- and winter- run-types move downstream shortly after spawning and many survive to return and spawn in subsequent years. Downstream passage at dams and other obstructions, as well as cover from predators are important factors in the survival of these fish.

Due to their protracted freshwater life history stage, steelhead must endure habitat constraints for multiple years. The multi-year residency increases the likelihood of cumulative negative effects from degraded watershed habitats and processes. Cumulative effects on steelhead could result in a reduced condition factor (weight to length relationship), which influences successful competition for food, susceptibility to diseases and parasites, predator evasion, and early ocean entry of juveniles. Both size and condition at ocean entry are important factors in determining survival.

Contrasting Bull Trout and Steelhead Recovery Planning

As previously indicated, bull trout have more specific habitat requirements than other salmonids and their distribution is limited within the range of Puget Sound steelhead. The most important of the specific habitat requirements for bull trout is cold water temperatures, which are important for spawning, incubation and early rearing. However, for rearing, foraging, migration and maturation of certain bull trout, older individuals utilize warmer stream segments within their drainages (USFWS 2004, Brenkman and Corbertt 2005).

Bull trout and steelhead can express a long freshwater resident life history (Behnke 2002). Within the cold water spawning and rearing portions of known bull trout habitat, including migration and foraging habitats, bull trout and steelhead have similar requirements. Therefore, recovery efforts focused on bull trout will also benefit steelhead. The protection and restoration strategies for bull trout, if expanded into steelhead habitat outside the range of bull trout, will directly benefit steelhead stocks. Improvements to fish passage, channel complexity, in-stream structure, floodplain connectivity, riparian width and species composition, stream temperature, pool riffle ratios, in-channel large woody material, stream substrate, and sediment composition and quality, will also benefit steelhead rearing in streams.

Steelhead and bull trout are both migratory and iteroparous species (Behnke 2002). As such, both will benefit from improvements to fish passage at dams, road crossings, and diversion structures. Improvements to the thermal regimes in stream segments, acting as migration barriers for bull trout, will also improve freshwater rearing conditions for steelhead.

Contrasting Chum and Steelhead Recovery Planning

Recovery planning for summer chum salmon is limited to the portion of the Puget Sound Steelhead DPS in Hood Canal and the eastern Strait of Juan de Fuca (Ames et al. 2000). The Hood Canal and Eastern Strait of Juan de Fuca Summer Chum Salmon Recovery Plan (Brewer et al. 2005) embraces a watershed-process based approach, which includes consideration of all freshwater habitat characteristics important to steelhead life histories. The plan also considers the near-shore and estuary habitat elements important to chum salmon, though these are less important for steelhead. Both the freshwater and marine protection and restoration strategies for chum salmon listed in the plan can be expected to provide benefit to steelhead stocks.

Since the distribution of summer chum is limited to the lower portions of tributaries and their estuaries, fish passage and connectivity, outside of near shore dikes and lower river bank armoring impacting floodplain connectivity and access, were not discussed in detail in the plan. With their use of the entire accessible watershed for spawning and rearing, a gap remains for detailed steelhead fish passage inventory and prioritization within the planning area for summer chum recovery.

Contrasting Chinook and Steelhead Recovery Planning

Because Chinook salmon do not occur as self sustaining natural populations within the Kennedy – Goldsborough and East Kitsap watersheds, the Chinook recovery planning for these watersheds focused on the near-shore and marine environment. A steelhead recovery planning gap exists in this region for freshwater habitat protection and restoration elements important for steelhead life history. A complete steelhead fish passage inventory and prioritization also remains as a gap for these watersheds.

Within the remainder of the Puget Sound Chinook Recovery planning area there is significant overlap of the protection and recovery planning for Chinook and steelhead. As is the case for summer chum recovery planning, Chinook planning is predicated on the protection and restoration of watershed processes and it extends upstream of Chinook utilization into steelhead habitat areas. The protection and restoration of watershed processes, and Chinook life history specific habitat types, will also result in benefits to steelhead. Chinook planning includes significant consideration for estuary and near-shore habitats. Although the estuary and nearshore appears to be far more important for Chinook than for steelhead, some degree of benefit to steelhead can be expected from protection and recovery efforts in these areas. Although significant information on steelhead fish passage exists for some watersheds, a gap remains for a complete inventory and prioritization of steelhead fish passage within all basins.

Summary of Differences between Steelhead and Other Salmonids

Unlike other salmonids that are semalparous (spawn once in a lifetime), have high fecundity, and can return as adults in large numbers, steelhead are iteroparous, have a multitude of life history types, and may not exhibit large extremes in adult returns. While most salmonids generally return and spawn over relatively short time periods, Puget Sound steelhead return to spawn throughout the year. In addition, most other salmonid species have one, or potentially two, life history strategies while steelhead have over thirty, including precocial freshwater maturation in males and life-long freshwater residency (i.e., rainbow trout). Finally, while other salmonid species tend to make use of the nearshore during their seaward migrations, steelhead tend to pass through estuarine and nearshore areas quickly and use off-shore migration pathways.

Puget Sound Habitat Stressors

By understanding the habitat needs of steelhead it is possible to focus recovery efforts on physical stressors that adversely impact steelhead populations throughout Puget Sound. For stressor categorization purposes, steelhead life history can be viewed in 5 discrete stages: 1) adult migration and pre-spawn holding; 2) spawning; 3) egg incubation and fry emergence; 4) juvenile rearing; and 5) juvenile out-migration. Furthermore, the physical habitats used by steelhead can be broken down into three discrete environments that can be influenced by anthropogenic stressors: 1) riverine; 2) coastal marine (Puget Sound, Hood Canal, and Straits of Juan de Fuca); and 3) oceanic (Pacific Ocean). Of these three, the influence of directed recovery actions is most profound in the first two. While humans influence the oceanic environment with regards to ocean acidification, sea temperatures, and pollutants, the following Habitat Stressors analysis by basin will focus on riverine and estuary habitat stressors. Our understanding of the types of stressors that can be detrimental to steelhead is relatively mature; however, our ability to specifically quantify the relative degree to which a given stressor is contributing to the decline of steelhead is still developing. Declines in Puget Sound Steelhead abundance, like Chinook and chum salmon, is not the result of one specific stressor but a multitude of stressors affecting riverine, coastal, and oceanic environments.

NOAA has defined a viable salmonid population (VSP) as "*an independent population of any Pacific salmonid (genus Oncorhynchus) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100- year time frame*" (McElhany et al. 2000). An "independent population" is defined as "*any collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period are not substantially altered by exchanges of individuals with other populations*" (McElhany et al. 2000). Four key parameters were identified for use in evaluating population viability status. They are abundance, population growth rate, population spatial structure, and diversity (McElhany et al. 2000). Below is a series of tables that identify habitat viability stressors, with specific focus upon the VSP parameters. Each of the eighteen WRIAs profiled above is dealt with in an independent table. In addition to identifying general habitat stressors by basin, suggestions for addressing these stressors are provided. Viability stressors were compiled from existing salmon limiting factors analysis reports produced by the Washington Conservation Commission and with input from WDFW watershed stewardship biologists, and tribal biologists. They were reviewed and revised with the assistance of participants from Lead Entity or salmon recovery planning technical teams as well as members of WDFW's Steelhead and Cutthroat Policy Advisory Group. Alternative solutions, which have been identified in the Puget Sound

Chinook Recovery plan were included here as a foundation for additional steelhead recovery planning.

More thorough discussions will need to take place at the watershed level to develop a *complete* list of critical viability stressors and alternative solutions as part of the Puget Sound Steelhead Recovery Planning process. The recovery planning process should include elected officials from counties and cities, as well as federal and state agency representatives with management authorities that affect steelhead (e.g., the U.S. Forest Service, U.S. Army Corps of Engineers, Washington State Department of Natural Resources), non-governmental organizations and other private interests. Countering all the threats currently degrading steelhead VSP parameters will require significant coordination and commitment from the appropriate government agencies, along with societal willingness to accept changes in behavior and lifestyle to promote steelhead recovery. Discussions must involve those with decision-making authority within these organizations.

Stressor tables for each WRIA address the following habitat factors:

A. Loss of access to historical habitat
B. Loss and degradation of side channels and floodplain
C. Loss of large woody debris
D. Loss of pool habitat
E. Degradation of riparian habitat
F. Reduction in degradation of riparian habitat
G. Loss of summer rearing habitat
H. Loss of winter rearing habitat

Nooksack Watershed

1. **Viability Stressor:** **Loss of access to historical habitat**

    a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity; Spatial Structure

    b. **Impact Analyses**

- Man-made obstructions block fish access to 389,800 m^2 of spawning and 1,793,500 m^2 of rearing habitat (may not include MF above diversion)
- Whatcom DPW 1999, 2006
- WRIA 1 Salmon Recovery Board 2005
- Currence 2000
- Collins and Shiekh 2004

    c. **Alternative Solutions**

- Restore upstream and downstream access to the full range of historic habitat types and locations.
- Remove/replace undersized, overly steep or perched culverts, diversion dams, flood gates, tidegates
- Adequately maintain all fishways
- Promote bottomless pipes or bridges over culverts in gravel bedded streams
- Replace floodgates and tidegates with structures that restore passage while addressing seasonal or diurnal flooding
- Incorporate fish habitat needs into long-term transportation planning
- Manage growth wisely to reduce need for new roads; construct new or relocate existing roads to minimize overlap with most productive fish habitats

2. **Viability Stressor:** **Loss and Degradation of Side Channels and Floodplain**

    a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

    b. **Impact Analyses**

- Stream and river reaches have been disconnected from the floodplain by levees, dikes, and riprap, thereby reducing availability and connectivity of floodplain habitats. Floodplain habitats have been degraded by removal of riparian vegetation and draining and channelization of wetlands to promote drainage of stream banks due to loss of root cohesion and bank roughness.
- Whatcom DPW 1999
- WRIA 1 Salmon Recovery Board, 2005
- Collins 2004
- Smith 2002
- Maudlin et al. 2002
- Hyatt 2005

- Indrebo 1998
- GeoEngineers 2001

c. Alternative Solutions

- Restore and connect wetlands and floodplains to the riverine system in order to promote restoration of habitat forming processes and functions.
    - Set back levees and dikes
    - Relocating infrastructure out of channel migration areas
- Restore floodplain habitats through riparian restoration and wood placement
- Encourage land use activities that will not require extensive flood protection or that will tolerate local climate and soil conditions, including seasonal inundation
- Integrated sub-basin restoration and flood hazard reduction planning
- Replace bridges, culverts and other crossing structures to not interrupt routing of wood, water and sediment

3. Viability Stressor: <u>Loss of Large Woody Debris Habitat Diversity</u>

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Historic removal of riparian forests and LWD coupled with increases in anthropogenic sediment sources and flood control activities (channel straightening and bank armoring) has reduced habitat diversity/complexity
- WRIA 1 Salmon Recovery Board 2005a, 2005b
- Maudlin, 2007
- USFS 1995
- Collins 2004
- Smith 2002
- Maudlin et al. 2002
- Hyatt 2005
- Indrebo 1998
- GeoEngineers 2001
- Coe 2001

c. Alternative Solutions

- Construct wood jams to increase short term wood loading and complexity in reach
- Restore and connect wetlands and floodplains to the riverine system
- Replant degraded riparian zones by reestablishing native vegetation appropriate for habitat formation
- Selectively thin, remove and prune nonnative and invasive vegetation

- Remove or setback levees or riprap
- Protect channel migration corridors and restore large woody debris and recruitment potential to provide for on-going and future restoration of habitat forming processes
- Improve routing of wood by addressing channel constrictions caused by bridges, culverts

4. Viability Stressor: Loss of Key Habitat (pools, winter and summer rearing)

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Channel stability (including delivery and routing of coarse sediment) High bed shear stress causes bed scour; low spatial variation of bed shear stress reduces availability of refugia; increased erodibility of stream banks
- WRIA 1 Salmon Recovery Board 2005a, 2005b
- Maudlin 2007
- USFS 1995
- Collins 2004
- Smith 2002
- Maudlin et al. 2002
- Hyatt 2005
- Indrebo 1998
- GeoEngineers 2001
- Coe 2001

c. Alternative Solutions

- Increase channel roughness through increased wood loading
- Reduce artificial channel confinement
- Increase diversity of channel pattern
- Increase availability and connectivity of refugia (more stable habitats)
- Place wood jams; remove or setback levees or riprap
- Restore or encourage formation of floodplain channels (especially side channels)
- Restore degraded riparian zones by removing non-native vegetation and/or establishing native vegetation appropriate for habitat formation
- Reconnect channels to floodplain
- Reduce anthropogenic sources of coarse sediment input by reducing mass-wasting potential
- Increase wood supply through improved riparian function in tributaries
- Increase flood storage
- Improve LWD routing

5. Viability Stressor: Degradation of Riparian Habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Land use activities have degraded riparian function, including stream temperature moderation, bank stability, wood recruitment, detritus inputs, and fine sediment and nutrient filtration
- WRIA 1 Salmon Recovery Board 2005a, 2005b
- Collins 2004
- Smith 2002
- Coe 2001

c. **Alternative Solutions**

- Restore riparian functions within channel migration areas
- Restore recruitment zones and processes by relocating manmade structures and related infrastructure to restore channel migration opportunities
- Replant degraded riparian zones by reestablishing native vegetation that will provide LWD of a size proportionate to the stream size (including conifers for large streams and rivers)
- Selectively thin, remove and prune non-native and invasive vegetation
- Install and maintain fencing or fish friendly stream crossing structures to prevent livestock access to riparian zones and streams
- Discourage landowner use of non-native plant species with invasive tendencies
- Provide education about the need for controlling invasive species on private property
- Support landowner incentive programs
- Restore hedgerows along all agricultural drainages

6. Viability Stressor: High Water Temperatures

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- High temperatures stress, kill, elicit avoidance or otherwise modify behavior, and/or increase incidence to disease, thereby decreasing growth and survival. Low spatial variation of temperature due to lack of habitat diversity reduces thermal refugia. See also *Withdrawals*, which contribute to high temperature

c. **Alternative Solutions**

- Restore groundwater/hyporheic recharge

- Increase shading in known or presumed fish bearing streams (including wetlands, small/slow channels), agricultural drainage and road side ditches
- Increase shading of small upslope streams that may not bear fish, but contribute stream flow to fish bearing waters
- Reconnect floodplain wetlands and off-channel habitats including groundwater fed side channels, to riverine system
- Restore floodplain wetlands (especially forested wetlands, where appropriate)
- Minimize sub-basin scale increases of impervious surface. Protect and restore groundwater (aquifer) recharge areas
- Reduce anthropogenic sources of coarse sediment that can widen channels and reduce stream shading in debris flow paths
- Implement storm water standards
- Reduce mass wasting potential

7. Viability Stressor: <u>Low Flow</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of habitat connectivity and access; reduced habitat volume; adult and juvenile stranding; increase water temperatures; decreased general water quality

c. **Alternative Solutions**

- Ensure flow levels necessary to meet ecological needs during low flow periods
- Reduce/avoid out-of-stream diversions in important reaches affected by low flows
- Utilize sub basin direct tools identified at right
- Enhance/restore wetland storage to increase base flows
- Reduce upslope sediment inputs that cause stream reach aggradation and subsurface flows
- Restore historic hydrograph of the sub-basin; reduce/restore “natural” variability of flows
- Put or keep water in stream using innovative tools, such as water banking, water rights lease or purchase, trust water donation, water conservation and reuse, water storage and groundwater recharge

8. Viability Stressor: <u>Sediment load (fine)</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Fine sediment can infiltrate gravel bedded streams resulting in egg mortality, entombment of alevins and fry, reduced availability of overwinter interstitial refugia, and/or reduced macroinvertebrate production and diversity; high suspended sediment levels (i.e. turbidity) reduces feeding opportunities, causes gill damage, and/or elicits avoidance or otherwise modifies behavior by adult and juvenile salmonids
- Zander 1996,1997,1998
- Watts 1996, 1997
- Schuett-Hames 1984

c. Alternative Solutions

- Reduce delivery of fine sediments to streams
- Implement in-channel projects that address geologic process i.e. deep-seated slope failure, landslide toe erosion, bank erosion
- Employ relay crops and appropriate buffers to prevent surface erosion at its source or trap soil eroded from agricultural lands
- Improve floodplain connectivity through dike removal or breaching
- Revegetate riparian zones and floodplains
- Install frequent cross drains for ditch relief (including on non-forestry roads) rather than routing ditch waters substantial distances then directly delivering to streams
- Install adequate construction phase erosion control
- Fence livestock out of riparian areas.
- Remove roads, reduce road drainage to streams
- Provide frequent ditch relief so water can infiltrate
- Prevent overgrazing, plant cover crops, disconnect ditches from fallow fields during wet periods
- Reduce road drainage to streams, establish hedgerows along road side ditches
- Side cast removal or reduction
- Avoid land management activities on unstable slopes

Skagit Watershed

1. **Viability Stressor: Loss of access to historical habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**

- *Lower Skagit:*
- Loss of up to 19% of historical distribution for winter and up to 17% of summer steelhead (Scott and Gill 2008)
- *Upper Skagit:*
- Loss of 11-31% of historical distribution of winter steelhead and 0-16% of summer steelhead (Scott and Gill 2008)
- Downramping from the Baker dams may cause water levels to drop, stranding fry along river edge (SRSC & WDFW 2005)
- Dam operations cause dewatering of off channel habitat and worsen temperature, predation, rearing habitat ssues. (SRSC & WDFW 2005)
- High temperatures block tributary access (SRSC & WDFW 2005)
- Baker Dam blocks access to habitat in the Baker River. (SRSC & WDFW 2005)
- Existing flows in the Skagit are often below optimum for Chinook (SRSC & WDFW 2005)

   c. **Alternative Solutions**

- Address passage problems that pose considerable impacts to salmonids in WRIAs 3 and 4
- Finish collecting field data to verify habitat quantity and quality as well as type of blockage for passage problems in WRIAs 3 and 4 Begin with blockages in the top prioritization tier
- Install turbines in the Skagit and Baker dams that allow greater flexibility in flow regime
- Restore natural riparian structure and processes. Restore/replant riparian areas, fence off farm animals, and leave adequate un-logged buffers
- Address hydromodification including removing or relocating dikes and riprap (SRSC & WDFW 2005)
- Continue to enforce the 1996 MOU, the 2001 instream flow rule, and existing water code provisions. Issue permits only in accordance with these rules. Investigate evidence of illegal withdrawals. (SRSC & WDFW 2005)
- A Baker Summer steelhead population may have existed historically but is now believed to be extirpated

2. **Viability Stressor: Loss and Degradation of Side Channels and Floodplain**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Hydromodification has resulting in a loss of preferred spawning habitat. (SRSC & WDFW 2005)
- With the amelioration of major flood events due to the flow regulation of the dams, there is less new channel formation (SRSC & WDFW 2005)

c. **Alternative Solutions**

- Preserve functioning floodplain habitat, such as edge habitat associated with the mainstem Skagit River, wetted off-channel habitat, and connected functional riparian. (Smith 2003)
- Remove hydromodifications that would lead to a significant increase in the quality and quantity of off-channel habitat. . (Smith 2003)
- Restrict development and hydromodifications in the geomorphic floodplain. (Smith 2003)
- Create appropriate off-channel habitat in the upper Skagit Basin. (Smith 2003)
- Continue to use “mitigation funds” from Seattle City Light to reconstruct side channel habitat

3. Viability Stressor: <u>Loss of Large Woody Debris</u>

a. **Primary VSP Parameter(s) Affected** Abundance and Productivity

b. **Impact Analyses**

- Wood has been lost because of heavy logging and ongoing agricultural practices. (SRSC & WDFW 2005)
- The loss of large wood has contributed to the disruption of natural processes that create and sustain floodplain habitat, (Smith 2003)

c. **Alternative Solutions**

- Improve LWD transport from dams and around bridges. (Smith 2003)
- Restore natural riparian structure and processes
- Install instream LWD as an interim measure while natural riparian structure and processes are being re-established (SRSC & WDFW 2005)

4. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected :** Abundance and Productivity

b. **Impact Analyses**

- Decreased levels of LWD have resulted in reduced pool habitat. (Smith 2003)
- Increases in coarse sediment can create channel instability and reduce the frequency and volume of pools. (Smith 2003)
- Increases in fine sediment fill pools, lower the survival rate of eggs deposited in the gravel (through suffocation), and lower the production of benthic invertebrates. (Smith 2003)

c. Alternative Solutions

- Restore natural riparian structure and processes
- Install instream LWD as an interim measure while natural riparian structure and processes are being re-established (SRSC & WDFW 2005)
- Improve LWD transport from dams and around bridges. (Smith 2003)
- Decommission or treat road segments that are at a high risk of delivering sediment to streams after a risk assessment is conducted.
- Focus on road segments that pose a greater threat to salmonid habitat. (Smith 2003)
- Monitor and evaluate the effectiveness of sediment reduction efforts on state and private lands. (Smith 2003)

5. Viability Stressor: <u>Degradation of Riparian Habitat</u>

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Areas throughout the Skagit basin have significantly degraded riparian areas. (SRSC & WDFW 2005)

c. Alternative Solutions

- Restore natural riparian structure and processes
- Reduce impact of hydromodifications (dikes) on riparian processes 9Smith 2003)
- Eliminate non-native plants (Japanese knotweed, blackberry, etc.) from riparian zones
- Install instream LWD as an interim measure while natural riparian structure and processes are being re-established (SRSC & WDFW 2005)
- Conduct a basin-wide analysis of riparian conditions that include shade, hazards, and LWD recruitment potential, incorporating previous assessments where possible. (Smith 2003)
- Encourage volunteer riparian restoration and fencing along salmonid streams. (Smith 2003)

6. Viability Stressor: <u>Loss of summer rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Low summer flows limit habitat and result in warm water temperatures
- Dam operations can change the temperature regime in the river and may affect emergence timing or food availability for juvenile salmon

c. **Alternative Solutions**

- Improve water quality throughout the Skagit Basin by addressing riparian, sedimentation, flow, and wetland loss conditions as well as inputs from agriculture, urban, and forestry land uses
- Reduce livestock waste, livestock access, and failing septic systems
- Encourage local groups to implement TMDLs for water temperature and dissolved oxygen. (Smith 2005)
- Install turbines in the Skagit and Baker dams that allow greater flexibility in flow regime
- Apply stormwater quality and quantity controls to existing impervious infrastructure
- Encourage low impact development techniques for new construction
- Monitor low flow conditions in the tributaries to the lower Skagit River
- Assess surface water withdrawals associated with the lower Skagit River and tributaries
- Monitor water temperatures in the Sauk River and tributaries. Spot checks have detected warm water temperatures in the mainstem Sauk River, making this action a high priority
- Monitor water temperatures in the tributaries to the upper Skagit sub-basin

7. Viability Stressors: <u>Loss of winter rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- High winter flows reduce overwinter survival rates (Smith 2003)

c. **Alternative Solutions**

- Analyze the impacts of high flow to salmonid production in the mainstem Skagit River and larger tributaries

8. Viability Stressors: Sedimentation

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Estimated sediment supply rates suggest that excess sedimentation is a major problem in many of the watersheds within the lower Skagit sub-basin and in limited areas of the Sauk River sub-basin (Smith 2003)
- Increases in coarse sediment can create channel instability and reduce the frequency and volume of pools while decreases can limit the availability of spawning gravel (Smith 2003)

c. Alternative Solutions

- Decommission or treat road segments that are at a high risk of delivering sediment to streams
- Identify and prioritize sediment sources in “poor” rated watersheds for possible future restoration projects, focusing primarily on roads
- Conduct assessments on stream stability, gravel quality, and instream LWD quantities in a prioritized manner. Identify potential project areas. (Smith 2003)
- Monitor and evaluate the effectiveness of sediment reduction efforts on state and private lands. (Smith 2003)
- Examine the possibility of re-establishing sediment supply and transport downstream of dams. (Smith 2003)
- Decrease sedimentation impacts to salmonids from diking, such as reduced gravel recruitment and potentially increased scour. (Smith 2003)

Stillaguamish/ Snohomish Watershed

1. **Viability Stressors: <u>Loss of Access to Historical Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**
   - Loss of 0-24% of historical distribution of winter steelhead and 0-23% of summer steelhead (Scott and Gill 2006)
   - Majority of streams have lost more than 20% of habitat historically accessible (Haring 2002)

   c. **Alternative Solutions**
   - Remove or replace undersized, overly steep, or perched culverts as well as diversion dams, flood gates, and tidegates. Replace culverts with bridges or arched culverts that have natural streambed material
   - Adequately maintain all fishways
   - Accomplish better oversight and enforcement of instream work; especially culvert replacements, road building, and bank hardening.
   - Accomplish better enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings. Ensure municipalities and local governments require HPA permits
   - Decommission some USFS roads in the upper watershed and replace or remove culverts that are barriers
   - Provide passage at the Sultan River Diversion Dam and improve temperature conditions
   - Increase forest cover and reduce effective impervious surface to address altered flow and sediment regimes that contribute to fish passage problems
   - Initiate streamlined permitting for restoration projects dealing with listed species, coordinating activities of local governments, WDFW, ACOE, USFWS, WSDOE, and NOAA
   - Ensure coordination of all efforts to list and map manmade barriers, and ensure the overall effort is complete

2. **Viability Stressor: <u>Loss of Large Woody Debris</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Loss of large woody debris (Haring 2002)

   c. **Alternative Solutions**
   - Remove or setback levees and riprap. Encourage riparian acquisition and conservation easements

- Accomplish better enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to better protect channel migration zones including erosion hazard zones
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD
- Protect channel migration corridors to restore large woody debris and recruitment potential. Modify and enforce Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to accomplish this
- Conduct public relations campaigns to educate about the impacts of wood removal from channels and gravel bars, especially by firewood harvesters. Increase public knowledge about benefits of debris in channels. Increase surveillance of log jams and wood on bars
- Replant degraded riparian zones to restore sources of LWD. Selectively thin, remove and prune invasive species
- Improve routing of wood by addressing channel constrictions caused by bridges and culverts
- Add LWD key pieces and log jams to streams and rivers to address LWD deficits and increase LWD retention
- Map all sites where buffers are cleared

3. Viability Stressor: <u>Loss and Degradation of Side Channels and Floodplain</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Majority of streams have lost more than 66% of wetted area (Haring 2002)

c. Alternative Solutions

- Map all sites of hardened banks
- Accomplish modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect channel migration zones
- Ensure accomplishment of instream flow setting regulations and enforcement
- Ensure enforcement of wetland protection regulations
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD
- Modify USACOE protocols for maintaining bank protection sites in the Watersheds
- Purchasing/sun-setting of water rights no longer being exercised
- Accomplish habitat acquisition, conservation easements and restoration projects to protect or improve existing floodplain and side channel habitat

- Restore and connect wetlands and floodplains to the riverine system through setting back levees and dikes, and relocating infrastructure out of channel migration areas
- Restore lateral channel migration by revetment removal to restore floodplain reconnection and the re-connection of blocked side channel inlets
- Widen stream buffers and enhance riparian forest conditions
- Protect and enhance LWD accumulations
- Accomplish better enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities
- Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosion hazard zones

4. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Loss of pool habitat (Haring 2002)

c. Alternative Solutions

- Map all sites of hardened banks
- Accomplish modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect channel migration zones
- Ensure accomplishment of instream flow setting regulations and enforcement
- Ensure enforcement of wetland protection regulations
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD
- Modify USACOE protocols for maintaining bank protection sites in the Watersheds
- Purchasing/sun-setting of water rights no longer being exercised
- Accomplish habitat acquisition, conservation easements and restoration projects to protect or improve existing floodplain and side channel habitat
- Restore and connect wetlands and floodplains to the riverine system through setting back levees and dikes, and relocating infrastructure out of channel migration areas
- Restore lateral channel migration by revetment removal to restore floodplain reconnection and the re-connection of blocked side channel inlets
- Widen stream buffers and enhance riparian forest conditions
- Protect and enhance LWD accumulations

- Accomplish better enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities
- Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosion hazard zones
- Modify, oversee, and accomplish better enforcement of instream habitat alteration regulations
- Construct log jams, and protect log jams from boaters and wood harvesters
- Reduce artificial channel confinement; remove or setback levees or riprap
- Reduce anthropogenic sources of sediment input by reducing mass-wasting potential
- Increase bank stability with riparian planting and LWD placement

5. Viability Stressor: <u>Degradation of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Degradation of riparian habitat (Haring 2002)

c. Alternative Solutions

- Map all sites where riparian habitat is inadequate
- Replant degraded riparian zones in freshwater and marine areas. Provide incentives and technical assistance to landowners to replant riparian areas
- Enforce Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR
- Modify and enforce Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas. Improve education and enforcement to address the removal of riparian vegetation
- Selectively thin, remove and prune non-native and invasive vegetation; Improve noxious weed enforcement such as knotweed and other invasive species and replanting with appropriate riparian vegetation
- Conduct PR campaigns to educate landowners about non-native plant species with invasive tendencies and the need for controlling invasive species on private property
- Install and maintain fencing or fish friendly stream crossing structures to prevent livestock access to riparian zones and streams.
- Support incentive programs (CREP, WRP). Restore hedgerows along all agricultural drainages
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land owners

- Establish a financial incentive program to encourage multi family or neighborhood use of overwater structures

6. **Viability Stressor: Reduction of Riparian Habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**

   - Less than 60% of watershed with forest stands aged 25 years or more (Haring 2002)

   c. **Alternative Solutions**

   - Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications
   - Preserve at least 65 percent of each stream basin surface area as natural forest cover
   - Support amending the King County Comprehensive Policy to allow habitat restoration projects within Farmland Preservation Program properties
   - Map all areas of inadequate buffer width
   - Promote riparian habitat acquisition projects
   - Purchase conservation easements to protect or improve riparian habitat

7. **Viability Stressor: Loss of summer rearing habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**

   - Low flows exist, especially in upland tributaries and especially during the summer

   c. **Alternative Solutions**

   - Accomplish instream flow setting and enforcement; Accomplish better enforcement of Wetland Protection Regulations
   - Accomplish purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups
   - Increase shading and bank stability with riparian planting in known or presumed fish bearing streams (including wetlands, small/slow channels), agricultural drainage and road side ditches

- Increase shading of small upslope streams that may not bear fish, but contribute stream flow to fish-bearing waters
- Reduce anthropogenic sources of coarse sediment that can widen channels and reduce stream shading
- Enforce storm water standards on new development and redevelopment, and require retrofitting existing development. Encourage better hydrologic infiltration (e.g., through LID) where appropriate
- Protect and restore wetlands and critical aquifer recharge areas
- Accomplish better enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosion hazard zones
- Accomplish habitat acquisition and restoration projects to foster base flow retention (e.g. beaver dams)
- Ensure side channel connection and protection
- Initiate and complete the basin hydrologic model that Tulalip and Battelle have been attempting to get going
- Monitor all aspects of water quality; ensure that good water quality is protected, particularly where development pressures are highest, and ensure cleanup of existing problems

8. Viability Stressors: <u>Loss of winter rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Floodplain habitat, and the connectivity of this habitat, has been severely degraded

c. Alternative Solutions

- Encourage adaptive management to modify existing regulations to take sub basin timber harvest rates and rain-on-snow zone timber harvest rates into consideration when approving timber harvest applications
- Modify and enforce Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and stormwater runoff. Maintain basin imperviousness below 10%
- Map all sites that allow runoff at rates greater than the rate of forested conditions
- Increase flood storage by restoration of floodplain functions
- Accomplish better enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to

modify existing regulations to better protect channel migration zones including erosion hazard zones

- Preserve hydrologic connectivity by protecting and improving side channel connection. Monitor climate change over time and take actions that will mitigate impacts
- Initiate and complete the basin hydrologic model that Tulalip and Battelle have been attempting to get going
- Stabilize fine sediment contributions, particularly in the upper watersheds, which contribute to embeddedness of overwinter habitat by filling interstitial spaces critical for overwintering

Lake Washington/Cedar/Sammamish Watershed

1. **Viability Stressors: <u>Loss of Access to Historical Habitat</u>**

    a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

    b. **Impact Analyses**
    - Loss of historical distribution of winter steelhead (Kerwin 2001)
    - Majority of streams have lost habitat historically accessible to winter steelhead (Kerwin 2001)

    c. **Alternative Solutions**
    - Provide access above Landsberg Dam
    - Improve fish passage through the Locks and ship canal
    - Replace Culverts with bridges or arched culverts that have natural streambed material
    - Decommission roads in upper watershed and replace or remove culverts barriers
    - Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT
    - Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish, Skagit, and King Counties)

2. **Viability Stressor: <u>Loss and Degradation of Side Channels and Floodplain</u>**

    a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

    b. **Impact Analyses**
    - Majority of streams have lost wetted area (Kerwin 2001)
    - Bank Hardening Features, dredging, and fill have increased scour events, reduced side channels and off-channel habitats (Kerwin 2001)

    c. **Alternative Solutions**
    - Restore floodplain connections and channel meanders by reducing confinement
    - Remove armoring along all shorelines
    - Restore backwater pools, LWD and Riparian vegetation
    - Remove/setback levees to restore connections with off channel habitat
    - Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets

- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish, Skagit, and King Counties)
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification of the USACOE’s protocols for maintaining their bank protection sites in the Snohomish and Stillaguamish Watersheds.
- Purchasing/sun-setting of water rights no longer being exercised

3. Viability Stressor: <u>Loss of Large Woody Debris</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Loss of availability of large woody debris (Kerwin 2001)

a. Alternative Solutions

- Restore sources of large woody debris (LWD)
- Increase structure with site specific LWD and meander logjams, including additional gravel placement
- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – USFS, WDNR
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regard to riparian areas – Municipalities and local governments (local cities such as Arlington, Everett, etc.; Snohomish County, Skagit County, and King County)

4. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Loss of pool habitat, very few deep pools, instream complexity is lacking (Kerwin 2001)

c. Alternative Solutions

- Add new LWD to restore pool habitat
- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. Viability Stressor: Degradation of Riparian Habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Degradation of riparian habitat; riparian buffers are inadequate and often fragmented. (Kerwin 2001)
- The Riparian Shoreline of the Lakes and migratory corridors are highly altered. (Kerwin 2001)

c. Alternative Solutions

- Protect and restore riparian habitat
- Restore feeder bluffs, "pocket" estuaries, marine riparian vegetation
- Restore riparian vegetation and freshwater mixing zone downstream of the Locks
- Improve noxious weed enforcement such as Japanese knotweed and other invasive species and replanting with appropriate riparian vegetation
- Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land owners and encourage a financial incentive program to encourage multi family or neighborhood use of overwater structures.
- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish County, Skagit County, and King County)

6. Viability Stressor: Reduction in Degradation of Riparian Habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of forest age class structure; An overall reduction in forest cover and increase in impervious surfaces (Smith 2005)

c. **Alternative Solutions**

- Protect Riparian Zones in case of detrimental human natural events
- Preserve at least 65 percent of each stream basin surface area as natural forest cover
- Support the King County Comprehensive Plan and Annual Growth Report growth targets and Urban Growth Area Designations
- Support amending the King County Comprehensive Policy to allow habitat restoration projects within Farmland Preservation Program properties
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - USFS, WDNR

7. Viability Stressor: <u>Loss of summer rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Low summer flows limit habitat and result in warm water temperatures
- High levels of impervious surfaces have resulted in changes to hydrology (Kerwin 2001)

c. **Alternative Solutions**

- Reduce high temperatures and restore shallow water habitat
- Maintain basin imperviousness below 10 percent or utilize practices to maintain an equivalent stormwater runoff potential
- Minimize groundwater withdraws
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups

8. Viability Stressors: <u>Loss of winter rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- High winter flows reduce over winter survival rates (Kerwin 2001)
- High levels of impervious surfaces have resulted in changes to hydrology. (Kerwin 2001)

c. Alternative Solutions

- Maintain basin imperviousness below 10 percent or utilize practices to maintain an equivalent stormwater runoff potential
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish County, Skagit County, and King County)

Green Habitat Green/Duwamish Watershed

1. **Viability Stressors: <u>Loss of Access to Historical Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**
   - Loss of historical distribution of winter steelhead and summer steelhead (Kerwin and Nelson 2000)
   - Majority of streams have lost habitat historically accessible (Smith 2005)
   - Two Dams in the upper portion of the watershed block upstream passage and severely hamper downstream passage (Kerwin and Nelson 2000)

   c. **Alternative Solutions**
   - Provide access above Howard Hanson Dam
   - Replace culverts with bridges or arched culverts that have natural streambed material
   - Decommission of some of the US Forest Service roads in the upper watershed and replace or remove culverts that are barriers
   - Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT
   - Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish, Skagit, and King Counties)
   - Current projects in the upper watershed are in process to improve upstream and downstream passage at these dams

2. **Viability Stressor: <u>Loss and Degradation of Side Channels and Floodplain</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Majority of streams have lost a majority of their wetted area (Smith 2005)
   - Bank hardening has limited lateral channel migration and limited the creation of new habitat. (Kerwin and Nelson 2000)
   - Urbanization, water diversions and levees have resulted in the lowering of the floodplain and disconnecting off-channel habitats such as sloughs, side channels and adjacent wetlands

   c. **Alternative Solutions**
   - Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets

- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish, Skagit, and King Counties)
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification of the USACOE's protocols for maintaining their bank protection sites in the Snohomish and Stillaguamish Watersheds
- Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups

3. Viability Stressor: <u>Loss of Large Woody Debris</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Loss of large woody debris (Kerwin and Nelson 2000)
- Reducing LWD and associated instream complexity, such as pools and riffles (Kerwin and Nelson 2000)

c. Alternative Solutions

- Increase structure with site specific LWD and meander logjams, including gravel placement
- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow Adaptive Management to modify existing regulations – USFS, WDNR
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments (local cities such as Arlington, Everett, etc.; Snohomish County, Skagit County, and King County)

4. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Loss of pool habitat (Kerwin and Nelson 2000)

c. **Alternative Solutions**
- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
- Cease maintenance dredging in the turning basin
- Modification, oversight, and better enforcement of instream habitat alteration regulations – WDFW, USACOE, NOAA Fisheries

5. **Viability Stressor: <u>Degradation of Riparian Habitat</u>**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**
- Degradation of riparian habitat (Kerwin and Nelson 2000)

c. **Alternative Solutions**
- Improve noxious weed enforcement and replanting with appropriate riparian vegetation
- Rehabilitate degraded riparian areas. Improve riparian habitat through appropriate riparian plantings
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land owners. Encourage a financial incentive program to promote neighborhood use of overwater structures
- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments (local cities such as Arlington, Everett, etc.; Snohomish County, Skagit County, and King County)

6. **Viability Stressor: <u>Reduction of Riparian Habitat</u>**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**
- Less than 60% of watershed with forest stands aged 25 years or more (Smith 2005)

- Reducing forest cover and increasing impervious surfaces. (Kerwin and Nelson 2000)
- Urbanization and industrialization have altered or destroyed significant amounts of nearshore habitat (Kerwin and Nelson 2000)

c. **Alternative Solutions**

- Protect Riparian Zones in case of detrimental human natural events
- Preserve at least 65 % of each stream basin surface area as natural forest cover
- Support the King County Comprehensive Plan and Annual Growth Report growth targets and Urban Growth Area Designations
- Support amending the King County Comprehensive Policy to allow habitat restoration projects within Farmland Preservation Program properties
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - USFS, WDNR

7. Viability Stressor: Loss of summer rearing habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Low summer flows limit habitat and chronic water quality problems (Kerwin and Nelson 2000)
- Some fall low flows have created adult migration problems (Kerwin and Nelson 2000)

c. **Alternative Solutions**

- Maintain basin imperviousness below 10 percent or utilize practices to maintain an equivalent Stormwater runoff potential
- Minimize groundwater withdraws
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. Viability Stressors: Loss of winter rearing habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- High winter flows reduce overwinter survival rates (Kerwin and Nelson 2000)

- Fluctuating flows caused by regulated flows from the Dams have caused spawning issues such as dewatering redds and rearing problems such as stranding of juveniles (Kerwin and Nelson 2000)

c. Alternative Solutions

- Maintain basin imperviousness below 10 percent or utilize practices to maintain an equivalent Stormwater runoff potential
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments (local cities such as Arlington, Everett, Snohomish, etc.; Snohomish County, Skagit County, and King County)

Puyallup Watershed

1. **Viability Stressors: <u>Loss of Access to Historical Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**
   - Loss of 0-24% of historical distribution of winter steelhead and 0-23% of summer steelhead (Scott and Gill 2006)
   - Majority of streams have lost more than 20% of habitat historically accessible (Smith 2005)

   c. **Alternative Solutions**
   - Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT
   - Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments

2. **Viability Stressor: <u>Loss and Degradation of Side Channels and Floodplain</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Majority of streams have lost more than 66% of wetted area (Smith 2005)

   c. **Alternative Solutions**
   - Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones – Municipalities and local governments
   - Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
   - Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
   - Modification of the USACOE’s protocols for maintaining their bank protection sites
   - Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups

3. **Viability Stressor: <u>Loss of Large Woody Debris</u>**

   1. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

2. **Impact Analyses**

- Loss of large woody debris (Smith 2005)

3. **Alternative Solutions**

- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – USFS, WDNR
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments

4. **Viability Stressor: <u>Loss of Pool Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**

- Loss of pool habitat (Smith 2005)

   c. **Alternative Solutions**

- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. **Viability Stressor: <u>Degradation of Riparian Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**

- Degradation of riparian habitat (Smith 2005)

   c. **Alternative Solutions**

- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments

6. **Viability Stressor: <u>Reduction of Riparian Habitat</u>**

   a. **Primary VSP Parameter(s) Affected** Abundance and Productivity

   b. **Impact Analyses**

   - Less than 60% of watershed with forest stands aged 25 years or more (Smith 2005)

   c. **Alternative Solutions**

   - Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - USFS, WDNR

7. **Viability Stressor: Loss of summer rearing habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**

   - Low summer flows limit habitat and result in warm water temperatures

   c. **Alternative Solutions**

   - Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
   - Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. **Viability Stressors: <u>Loss of winter rearing habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**

   - High winter flows reduce overwinter survival rates

   c. **Alternative Solutions**

   - Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – USFS, WDNR
   - Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments

Nisqually Watershed

1. **Viability Stressors: <u>Loss of Access to Historical Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**
   - Loss of 0-24% of historical distribution of winter steelhead and 0-23% of summer steelhead (Scott and Gill 2006)
   - Majority of streams have lost more than 20% of habitat historically accessible (Smith 2005)

   c. **Alternative Solutions**
   - Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT
   - Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments

2. **Viability Stressor: <u>Loss and Degradation of Side Channels and Floodplain</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Majority of streams have lost more than 66% of wetted area (Smith 2005)

   c. **Alternative Solutions**
   - Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments
   - Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
   - Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
   - Modification of the USACOE's protocols for maintaining their bank protection sites
   - Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups

3. **Viability Stressor: <u>Loss of Large Woody Debris</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of large woody debris (Smith 2005)

c. **Alternative Solutions**

- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – USFS, WDNR
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments

4. **Viability Stressor: <u>Loss of Pool Habitat</u>**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of pool habitat (Smith 2005**)**

c. **Alternative Solutions**

- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. **Viability Stressor: <u>Degradation of Riparian Habitat</u>**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Degradation of riparian habitat (Smith 2005)

c. **Alternative Solutions**

- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands); and Northwest Forest Plan (federal lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR

- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments

6. **Viability Stressor: Reduction of Riparian Habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Less than 60% of watershed with forest stands aged 25 years or more (Smith 2005)

   c. **Alternative Solutions**
   - Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - USFS, WDNR

7. **Viability Stressor: Loss of summer rearing habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Low summer flows limit habitat and result in warm water temperatures

   c. **Alternative Solutions** Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
   - Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. **Viability Stressors: Loss of winter rearing habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - High winter flows reduce overwinter survival rates

   c. **Alternative Solutions**
   - Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – USFS, WDNR

- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments

South Sound Watershed

1. **Viability Stressor: Loss of Access to Historical Habitat**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**
   - Loss of historical distribution of winter steelhead (SPSSEG 2003) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (Tobiason 2003) (CCWC 2007)
   - Majority of streams have lost habitat that was historically accessible (CTC 2002) (Mobrand 2004) (SPSSEG 2003) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (Tobiason 2003) (CCWC 2007)

   c. **Alternative Solutions**
   - Replace culverts with bridges or stream simulation culverts that have natural streambed material
   - Decommission or maintain forest roads in the upper watersheds and replace or remove culverts that are barriers
   - Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT, local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc., and Pierce, Thurston, Mason, and Kitsap Counties
   - Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc., and Pierce, Thurston, Mason, and Kitsap Counties)
   - Current lead entity and SRFB projects are in process to improve upstream passage

2. **Viability Stressor: Loss and Degradation of Side Channels and Floodplain**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Majority of streams have lost a significant portion of their wetted area (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (Tobiason 2003) (CCWC 2007)
   - Bank hardening has limited lateral channel migration, degraded existing habitat, and limited the creation of new habitat. (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA)

- Urbanization, water diversions, and channelization have resulted in the lowering of the floodplain and disconnecting off-channel habitats such as sloughs, side channels and adjacent wetlands. (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (Tobiason 2003) (CCWC 2007)

c. **Alternative Solutions**

- Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE.
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries, WDOE, local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc., and Pierce, Thurston, Mason, and Kitsap Counties.
- Purchasing/sunsetting of water rights no longer being exercised
- Require alternatives to bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program (WDFW, USACOE, WDOE, local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

3. Viability Stressor: <u>Loss of Large Woody Debris</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of large woody debris (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (TCD 2007) (CCWC 2007)
- Reduced LWD and associated instream complexity, such as pools and riffles (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (CCWC 2007)

c. **Alternative Solutions**

- Increase structure with site-specific LWD and meander logjams, including additional gravel placement
- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing

regulations to better protect channel migration zones including erosional hazard zones. – WDFW, WDNR.

- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

4. **Viability Stressor: <u>Loss of Pool Habitat</u>**

    a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

    b. **Impact Analyses**

    - Loss of pool habitat (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA)

    c. **Alternative Solutions**

    - Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
    - Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. **Viability Stressor: <u>Degradation of Riparian Habitat</u>**

    a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

    b. **Impact Analyses**

    - Degradation of riparian habitat (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (TCD 2007) (CCWC 2007)

    c. **Alternative Solutions**

    - Improve noxious weed enforcement such as Japanese knotweed and other invasive species and replanting with appropriate riparian vegetation
    - Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings
    - Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land-owners and encourage a financial incentive program to encourage multi family or neighborhood use of overwater structures

- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

6. Viability Stressor: Reduction of Riparian Habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Less than 60% of watershed with forest stands aged 25 years or more (CCWC 2007) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA)
- Reduced forest cover and increased impervious surfaces. (CTC 2002) (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (CCWC 2007)
- Urbanization and industrialization have altered or destroyed significant amounts of nearshore habitat (CTC 2002) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (Tobiason 2003) (CCWC 2007)

c. Alternative Solutions

- Protect Riparian Zones from development and in cases of detrimental human caused or natural events
- Preserve at least 65 percent of each stream basin surface area as natural forest cover
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)
- Prevent development in coastal erosion hazard areas and landslide zones (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

- Require alternatives to marine bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program or programmatic beach nourishment (WDFW, USCOE, WDOE, local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

7. Viability Stressor: Loss of summer rearing habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Low summer flows, high temperatures, and chronic water quality problems limit habitat (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (Tobiason 2003) (CCWC 2007)

c. Alternative Solutions

- Maintain basin imperviousness below 10 percent or utilize LID and stormwater manual BMPs to maintain an equivalent stormwater runoff potential (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)
- Minimize groundwater withdrawals (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. Viability Stressor: Loss of winter rearing habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- High winter flows reduce overwinter survival rates (Mobrand 2004) (WRIA 13 LFA) (WRIA 14 LFA) (WRIA 15 LFA) (CCWC 2007)

c. Alternative Solutions

- Maintain basin imperviousness below 10 percent or utilize LID and stormwater manual BMPs to maintain an equivalent stormwater runoff potential (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments (local cities such as Tacoma, Steilacoom, University Place, Lakewood, Lacey, Olympia, Tumwater, Shelton, etc.; Pierce, Thurston, Mason, and Kitsap Counties)

Dungeness Watershed

1. **Viability Stressor: <u>Loss of Access to Historical Habitat</u>**

   a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

   b. **Impact Analyses**

- The Dungeness hatchery maintained an adult salmon collection rack across the Dungeness at RM 10.8. The Dungeness rack was in place from 1938 to 1981 (Smith, C.J. and P. Wampler 1995). Although some Chinook and other species are known to have gotten past the rack, when in place, its presence clearly influenced the use of the upper Dungeness and Gray Wolf drainages by anadromous salmon
- Orsborn and Ralph (1994) indicate that the extent of rearing habitat in the Dungeness is not well understood
- Primary stressors to steelhead in the lower river are the floodplain is disconnected from the river. Dungeness Meadows dike had a huge impact to river processes, straightening out the channel, increasing energy, flushing gravel downstream, and causing bed down-cutting. The riverbed appears to have down-cut up to several feet since the 1950's between Hwy 101 and Kinkade Island (Delineation of the Dungeness CMZ report)
- Loss of refugia (Instream habitat structures) that steelhead can hide and loss of spawning habitat

   c. **Alternative Solutions**

- It is critical to address problems associated with forest roads in the headwaters, and to restore functional floodplain processes (in the lower 2.6 miles of the Dungeness and upstream)
- Restore fish passage to Canyon Creek
- Reestablish functional channel and floodplain in the lower 2.6 miles through dike management and constriction abatement (Dungeness River Restoration Workgroup 1997)
- Salmon are vulnerable to low flows. Suggest finalizing the Comprehensive Irrigation District Management Plan. This plan has been at an impasse for several years due to disagreement between the irrigators and NOAA Fisheries. At issue was how much water to leave in the river at very low flow periods. Water users wanted a 60 cfs floor with 105 cfs 5 out of 10 years; NOAA wanted 105 cfs 8 out of 10 years
- Replace culverts with bridges or stream simulation culverts that have natural streambed material
- Decommission or maintain forest roads in the upper watersheds and replace or remove culverts that are barriers
- Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT

- Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments
- Current Lead Entity and SRFB projects are in process to improve upstream passage at several crossings

2. Viability Stressor: Loss and Degradation of Side Channels and Floodplain

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Alterations are from diking, floodplain constrictions at bridge sites, and from natural rates of channel down-cutting or sediment accretion
- Road crossings at Highway101, Anderson Road, Woodcock Road, and Old Olympic Highway each constrict the channel/floodplain and affect the alignment of the channel within the floodplain upstream of the constriction
- Dikes preclude the ability of high flows to access the historic floodplain, utilizing the floodplain to reduce stream energy and to store and transport sediment availability of side channel habitats is adversely affected by diking and floodplain constrictions that eliminate the connectivity of the main channel with the full extent of the meander belt. Channelizing, diking, and bedload aggradation reduce the potential access and use of side channels and remove essential habitat diversity
- Majority of streams have lost a significant portion of their wetted area
- Bank hardening has limited lateral channel migration, degraded existing habitat, and limited the creation of new habitat
- Urbanization, water diversions, and channelization have resulted in the lowering of the floodplain and disconnecting off-channel habitats such as sloughs, side channels and adjacent wetlands

c. Alternative Solutions

- Reestablish functional channel and floodplain in the lower 2.6 miles through dike management and constriction abatement (Dungeness River Restoration Workgroup 1997)
- Abate man-made constrictions upstream of the Corps dike (everything upstream of RM 2.6) (Dungeness River Restoration Workgroup 1997)
- Restore functional riparian zones throughout watershed, and identify and correct areas affected by unrestricted animal access. Restore suitable riparian vegetation and riparian-adjacent upland vegetation (Dungeness River Restoration Workgroup 1997)
- County should adopt and implement a stormwater strategy for this rapidly developing watershed, including tributaries, that will remediate current stormwater effects and minimize additional future effects

- Construct and/or protect side channels (Dungeness River Restoration Workgroup 1997)
- Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries, WDOE, local cities
- Purchasing/sunsetting of water rights no longer being exercised – WSDOE, local restoration groups
- Require alternatives to bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program (WDFW, USACOE, WDOE, local cities)
- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander

3. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of pool habitat presence of pools/holes in the lower Dungeness River has dramatically decreased over the last 5-10 years
- Summer steelheads need deep pools, which are currently lacking

c. **Alternative Solutions**

- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

4. Viability Stressor: <u>Reduction of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- The PSCRBT (1991) and TAG identify the upper Dungeness (upstream of RM 10.8) as having excellent streambank cover, and the lower portion (downstream of RM 10.8) as having poor riparian condition (sporadic streambank cover, primarily deciduous vegetation, lack of conifer, pasture land, armored riprap banks)

c. **Alternative Solutions**

- Protect Riparian/ Channel Migration Zones from development and in cases of detrimental human caused or natural events
- Require alternatives to marine bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program or programmatic beach nourishment (WDFW, USCOE, WDOE, local cities)
- Preserve at least 65 percent of each stream basin surface area as natural forest cover
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments
- Prevent development in Channel Migration Zones, coastal erosion hazard areas and landslide zones

5. Viability Stressor: <u>Degradation of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Degradation of riparian habitat

c. **Alternative Solutions**

- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments
- Improve noxious weed enforcement/removal for plants such as Japanese knotweed, butterfly bush (*Buddleia davidii*), and herb Robert (*Geranium robertianum*) and other invasive species and replanting with appropriate riparian vegetation
- Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land-owners and

encourage a financial incentive program to encourage multi family or neighborhood use of overwater structures
- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – WDFW, WDNR

6. Viability Stressor: Loss of summer rearing habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**
- Low summer flows, high temperatures, and chronic water quality problems limit habitat
- Some late fall low flows have created adult migration problems
- Although the Dungeness may meet the water quality temperature standard of <18^{o}C, extensive portions of the lower river exceed the preferred maxima for Chinook and pink (<14^{o}C preferred for chinook spawning, <12.8^{o}C preferred for pink spawning, and <13.3C preferred for rearing) (Orsborn and Ralph 1994). Temperature data support a trend of increasing mean temperature since the 1950s, of perhaps as much as 2^{o}F (Clark and Clark 1996)
- Dungeness valley housing population is rapidly increasing – with new 5 ac landowners using Dungeness water for “lawn-scapes” often using Dungeness water for lawns

c. **Alternative Solutions**
- Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups
- Change Washington State water laws to give River Instream Flows the most senior Water Right status. The water right for a river should not be compromised
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Maintain basin imperviousness below 10 percent or utilize LID and stormwater manual BMPs to maintain an equivalent stormwater runoff potential
- Minimize groundwater withdrawals

7. Viability Stressor: Loss of Large Woody Debris

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Reduced LWD and associated instream complexity, such as pools and riffles

c. Alternative Solutions

- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments
- Develop and implement a short-term LWD strategy to provide LWD presence and habitat diversity until full riparian function is restored
- Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets. This action (in loss of side channels) is also important for LWD and pool formation
- Clallam County update their Critical Areas Ordinance "Channel Meander Hazard Area" maps. Delineation of the Dungeness River channel migration zone
- Increase structure with site-specific LWD and meander logjams
- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – WDFW, WDNR
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Historically, removal of LWD and log jams was a prominent element of flood control activities on the Dungeness River (cleaned of LWD every year for several years until early 1980's. Sporadic LWD cleaning also occurred upriver)
- Stable log jams are now scarce throughout the lower section (lower 10.8 miles) of the Dungeness River

Elwha River Watershed

1. Viability Stressor: <u>Loss of Access to Historical Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

b. **Impact Analyses**

- Access to over 70 miles of salmonid spawning and rearing habitat has been precluded since 1910, by construction of the Elwha Dam (RM 4.9)
- Restoration potential was further impaired by construction of the Glines Canyon Dam (RM 13.2) in 1927. These hydroelectric dams are complete barriers to upstream adult passage of salmonids; no fish passage facilities have been constructed
- The number of Elwha River native anadromous salmonids has dropped from an estimated 380,000 (or more) to fewer than 3,000 (1995)

c. **Alternative Solutions**

- Removal of both Elwha Dams
- Replace culverts with bridges or stream simulation culverts that have natural streambed material
- Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT
- Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments
- Current Lead Entity and SRFB projects are in process to improve upstream passage at several crossings

2. Viability Stressor: Loss and Degradation of Side Channels and Floodplain

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Like most large rivers in western Washington, the Elwha River's floodplain has been altered and encroached upon. The lower river has been diked in several places, most significant being the Army Corps dike on the Lower Elwha Klallam Tribe's reservation
- Dikes have also been constructed to protect the City of Port Angeles industrial water line at RM 3.5, and on the west side of the estuary. The latter has severely impacted estuary processes and is responsible for eliminating all flow through one of the historic distributaries
- Over time, the channel below Elwha and Glines Canyon Dam has decreased horizontally, incised vertically, and the bed has coarsened. Present estimates, based on interpretation of visual evidence of terraces downstream of the dams,

are that the riverbed downstream of the dams may be 1-5 ft lower and more channelized (ONP 1995)

- Historic side-channel and other off-channel refuge areas critical for over-wintering species such as coho are now largely isolated from the mainstem

c. **Alternative Solutions**

- Acquisition/conservation easement access and set back of structures constructed within the channel migration zone
- Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries, WDOE, local cities
- Purchasing/sunseting of water rights no longer being exercised – WSDOE, local restoration groups
- Require alternatives to bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program (WDFW, USACOE, WDOE, local cities)

3. Viability Stressor: Loss of Large Woody Debris

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of large woody debris
- Reduced LWD and associated instream complexity, such as pools and riffles
- Large wood is currently chronically low in the Elwha River below Elwha Dam

c. **Alternative Solutions**

- Develop and implement a short-term LWD strategy to provide LWD presence and habitat diversity until full riparian function is restored
- Manage sediment to stabilize the channel and reduce risk of flooding
- Increase structure with site-specific LWD and meander logjams, including additional gravel placement. Systematic restructuring of the lower and middle river with large wood
- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing

regulations to better protect channel migration zones including erosional hazard zones

- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments

4. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Loss of pool habitat

c. **Alternative Solutions**

- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
- Modification, oversight, and better enforcement of instream habitat alteration regulations – WDFW, USACOE, NOAA Fisheries

5. Viability Stressor: <u>Degradation of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Riparian reestablishment would be required adjacent to restored channels through areas currently occupied by the Lake Aldwell and Lake Mills reservoirs

c. **Alternative Solutions**

- Improve noxious weed enforcement such as Japanese knotweed and other invasive species and replanting with appropriate riparian vegetation
- Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land-owners and encourage a financial incentive program to encourage multi family or neighborhood use of overwater structures

- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments

6. Viability Stressor: Reduction of Riparian Habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Riparian vegetation downstream of RM 4.9 is dominated by deciduous species including black cottonwood, red alder, and big leaf maple. It is unknown how this compares to historic state. Many cottonwoods are large (4-6' diameter) and can provide at least temporary habitat function
- In Olympic National Park stands of late-successional conifer forest are common, particularly on terraces adjacent to the river

c. Alternative Solutions

- Protect Riparian Zones from development and in cases of detrimental human caused or natural events
- Acquisition/conservation easement access and set back of structures constructed within the channel migration zone
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments
- Prevent development in coastal erosion hazard areas and landslide zones
- Require alternatives to marine bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program or programmatic beach nourishment (WDFW, USCOE, WDOE, local cities)

7. Viability Stressor: Loss of summer rearing habitat

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- The Elwha River is on the CWA 303(d) List of impaired water bodies, for temperature (resulting from impacts of the dams) and for presence of PCBs (Barecca 1998). Otherwise, water quality in the Elwha is generally excellent

c. **Alternative Solutions**

- Change Washington State water laws to give River Instream Flows the most senior Water Right status. The water right for a river should not be compromised. Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Maintain basin imperviousness below 10 percent or utilize LID and stormwater manual BMPs to maintain an equivalent stormwater runoff potential
- Minimize groundwater withdrawals
- Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. Viability Stressor: <u>Loss of winter rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- High winter flows reduce overwinter survival rates

c. **Alternative Solutions**

- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – WDFW, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments (local cities)

Morse Creek Watershed

1. **Viability Stressor: Loss of Access to Historical Habitat**

   a. **Primary VSP Parameter(s) Affected** Abundance & Spatial Structure

   b. **Impact Analyses**
   - No artificial fish migration barriers are known to exist in this watershed

   c. **Alternative Solutions**
   - Better oversight and enforcement of instream work; especially culvert replacements/road building – WDFW, DNR, WSDOT
   - Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating to stream crossings – Municipalities and local governments
   - Current Lead Entity and SRFB projects are in process to improve upstream passage at several crossings

2. **Viability Stressor: Loss and Degradation of Side Channels and Floodplain**

   a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

   b. **Impact Analyses**
   - Stormwater runoff from Highway 101 and other impermeable surfaces as a concern. There does not appear to be a concerted strategy or effort to manage adverse effects of stormwater runoff throughout WRIA 18
   - Morse Creek is diked and armored, effectively confining the creek between the dike and a bedrock outcrop for a significant portion of its anadromous zone. Lower Morse Creek was channelized in the late 1950s to facilitate housing development. As a result of the hydro modifications, pool habitat and suitable spawning gravel have been almost completely lost. The percentage of pool area in the lower mile of Morse Creek has been estimated at 12%
   - The extreme channel simplification and associated lack of channel diversity downstream of RM 1.75 has eliminated refugia for juvenile salmonids (steelhead) over-wintering in the lower river, likely resulting in them being flushed to saltwater during high flow events
   - Historic mainstem, side-channel and other off-channel refuge areas critical for steelhead are severely limited
   - An abandoned fly ash dump is located just above Morse Creek at RM 1.5 (on the west side of the stream). Because the dump received a variety of materials, including chlorine compounds associated with pulp bleaching, there are concerns that toxic compounds including dioxin may leach to Morse Creek

c. Alternative Solutions

- Restore floodplain function downstream of RM 1.7, including the removal/pull back of dikes, elimination of floodplain constrictions, and restoration of natural banks
- Acquisition/conservation easement access and set back of structures constructed within the channel migration zone
- Restore lateral channel migration, restore floodplain reconnection and the re-connection of blocked side channel inlets
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Municipalities and local governments
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries, WDOE, local cities
- Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups
- Require alternatives to bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program (WDFW, USACOE, WDOE, local cities)

3. Viability Stressor: <u>Loss of Large Woody Debris</u>

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Large wood is currently chronically low
- Loss of large woody debris
- Reduced LWD and associated instream complexity, such as pools and riffles
- When mature trees do fall in the riparian zone or in the creek, they are typically removed or destabilized by local residents

c. Alternative Solutions

- Restore LWD presence throughout the channel downstream of the natural falls at RM 4.9; develop and implement a short-term LWD strategy to provide LWD presence
- Manage sediment to stabilize the channel and reduce the risk of flooding
- Develop/implement a short-term LWD strategy to provide habitat diversity until riparian function is restored
- Increase structure with site-specific LWD and meander logjams, including additional gravel placement. Systematic restructuring of the lower and middle river with large wood

- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regards to riparian areas – Municipalities and local governments

4. Viability Stressor: Loss of Pool Habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Loss of pool habitat

c. Alternative Solutions

- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. Viability Stressor: Degradation of Riparian Habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Dominant canopy is deciduous trees, which do not provide high quality LWD recruitment potential

c. Alternative Solutions

- Improve noxious weed enforcement/removal for plants such as Japanese knotweed, butterfly bush (*Buddleia davidii*), and herb Robert (*Geranium robertianum*) and other invasive species and replanting with appropriate riparian vegetation
- Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings

- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land-owners and encourage a financial incentive program to encourage multi family or neighborhood use of overwater structures
- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands). Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments

6. Viability Stressor: <u>Reduction of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Reduced forest cover and increased impervious surfaces
- Urbanization and industrialization have altered or destroyed significant amounts of nearshore habitat

c. Alternative Solutions

- Protect Riparian Zones from development and in cases of detrimental human caused or natural events
- Acquisition/conservation easement access and set back of structures constructed within the channel migration zone
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments
- Prevent development in coastal erosion hazard areas and landslide zones. Reestablish estuarine characteristics and function
- Require alternatives to marine bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program or programmatic beach nourishment

7. Viability Stressor: <u>Loss of Summer Rearing Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Low summer flows, high temperatures, and chronic water quality problems limit habitat
- Some late fall low flows have created adult migration problems

c. **Alternative Solutions**

- Change Washington State water laws to give River Instream Flows the most senior Water Right status. The water right for a river should not be compromised. Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Maintain basin imperviousness below 10 percent or utilize LID and stormwater manual BMPs to maintain an equivalent stormwater runoff potential
- Minimize groundwater withdrawals
- Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

Hood Canal (West and Mid) Watersheds

1. Viability Stressors: Loss of Access to Historical Habitat

a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

b. **Impact Analyses**

- Major river systems in the area support both winter and summer steelhead, while smaller systems are thought to support winter steelhead. Steelhead distribution is presumed by SSHIAP to occur upstream to a sustained 12% gradient and is a potential for many West Hood Canal streams of moderate size in the lower reaches
- Projects to restore fish passage in the upper watersheds have not been prioritized, due to the emphasis for funding on recovery of summer chum and Chinook salmon in the larger rivers. Small streams along the shoreline are often completely or partially blocked due to inadequate or poorly installed culverts at road crossings (Correa 2003, 2002)
- Much of the upper watershed is in federal ownership as a working forest (USFS) or national park

c. **Alternative Solutions**

- Restore fish passage to North Fork Skokomish and upper Skokomish River through actions described in the Skokomish Chinook recovery plan
- Minimize new stream crossings for rural development, forestry and agriculture
- Remove/replace existing culverts with bridges or stream simulation culverts
- Improve tidal connectivity to streams in lower reaches and estuaries constricted by roadways at stream mouths. Reconnect distributaries in major river estuaries
- Decommission or improve maintenance of roads in the upper watersheds on forested and rural lands, with removal or replacement of culverts that are barriers
- Improve oversight/enforcement of instream work; especially culvert replacements/road building and bank protection.
- Enforce local ordinances relating to stream crossings
- Continue Lead Entity and local work to improve fish passage and to restore more natural channel conditions. Implement habitat projects described in Skokomish and Mid-Hood Canal Chinook recovery plan and Hood Canal summer chum recovery plan
- Instream flow setting and enforcement; wetland protection regulations

2. Viability Stressor: Loss and Degradation of Side Channels and Floodplain

a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

b. **Impact Analyses**

- West Hood Canal rivers and streams have lost habitat connectivity with floodplain and side channels from channel re-alignment, dike construction, dredging, constrictions at road crossings, water withdrawal, and bank armoring
- Loss of natural floodplain processes increases frequency and severity of redd scour/sediment deposition, reduces pool habitat quality (May and Peterson 2003, WDFW & PNPTT 2000)
- Majority of streams have lost a substantial portion of their wetted area. Bank hardening has limited lateral channel migration
- Residential development, agricultural practices, power development, water diversions and levees have resulted in the loss of floodplain and disconnecting off-channel habitats such as side channels and adjacent wetlands

c. **Alternative Solutions**

- Minimize floodplain development and alteration through regulatory and non-regulatory actions
- Support efforts to address floodplain planning through the Skokomish River General Investigation (ACOE, Mason Co, Skokomish Tribe) and Dosewallips / Duckabush (Jefferson County)
- Restore lateral channel migration; restore floodplain connections and re-connect side channel inlets
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Local governments
- Modify existing regulations to limit “emergency actions” such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries
- Require alternatives to bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program
- Continue Lead Entity and local work to improve channel conditions in Dosewallips, Duckabush, Skokomish and Quilcene Rivers, as well as other streams in watershed. Implement actions described in Mid-Hood Canal and Skokomish Chinook salmon recovery plans.
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Purchasing/sun-setting of water rights no longer being exercised – WSDOE, local restoration groups

3. **Viability Stressor: <u>Loss of Large Woody Debris</u>**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Lack of adequate Large Woody Debris (LWD) in streams, particularly large stable coniferous "key" pieces that are critical to forming pools, providing cover, retaining organic matter and maintaining instream habitat complexity (May & Peterson 2003)
- Lower river valleys were converted from forested floodplains in the late 1800s to channelized rivers with little wood (WDFW and PNPTT 2000, Amato 1996). Historic logging practices and removal of LWD along rivers for flood protection and firewood also contributed to lack of LWD in streams (Correa 2003)
- LWD was rated as "poor" or "poor/fair" in Dosewallips, Duckabush, Hamma Hamma and lower Skokomish Rivers (Correa 2003) and in most of the streams of WRIA 17 (Correa 2002)
- Timber production remains an important part of this watershed

Alternative Solutions

- Protect existing LWD structure (reduce modification of logjams, enforce regulations regarding wood cutting) through regulatory and non-regulatory actions
- Develop and implement short-term strategy to address LWD shortage to improve habitat complexity until full riparian function is restored
- Improve riparian habitat to allow longterm recruitment of LWD
- Increase channel complexity with site specific LWD and meander logjams, including additional gravel placement
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private landowners
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries, local jurisdictions
- Enforcement of Northwest Forest Plan (federal lands). Habitat Conservation Plans (state lands), Forest and Fish Rules (private lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regard to riparian areas – Mason and Jefferson County

4. Viability Stressor: <u>Loss of Pool Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Simplification of stream systems (see Amato 1996, Correa 2002 & 2003 for descriptions of individual watersheds) results in alteration of sediment dynamics and loss of pool habitat. High quality pools are important for juvenile rearing and adult migration

c. **Alternative Solutions**

- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. Viability Stressor: <u>Degradation of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Existing riparian habitat is fragmented and degraded by development and past logging and agricultural practices (May and Peterson 2003), particularly in lower reaches
- “Riparian condition” was rated as “poor” or “poor/fair” in lower reaches of Dosewallips, Duckabush, Hamma Hamma, Skokomish Rivers (Correa 2003) and in most of the streams of WRIA 17 (Correa 2002). Remaining riparian stands in river valleys of the larger systems are often sparsely vegetated and/or narrow in width (Brewer et al 2005). Riparian stands within the forest service lands are rated in better condition than lower reaches (Correa 2003)

c. **Alternative Solutions**

- Protect remaining intact high quality riparian habitat through acquisition, regulatory and non-regulatory actions
- Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings
- Improve noxious weed education and enforcement, targeting invasive plants such as Japanese knotweed, and replanting with appropriate riparian vegetation
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land owners
- Enforcement of Northwest Forest Plan (federal lands). Habitat Conservation Plans (state lands), Forest and Fish Rules (private lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR

- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments

6. Viability Stressor: <u>Reduction of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- River valleys in West Hood Canal were desirable locations for development. Sites were logged and farmed in late 1800s using levees and channel changes to limit floodway (Amato 1996, Brewer et al 2005), resulting in reduction/fragmentation of habitat
- Upper watersheds of the rivers and streams of West Hood Canal are working forests or national park (Correa 2002, 2003) with less loss of riparian habitat than the river valleys and lower reaches
- Concentration of residential development along Hood Canal shorelines has altered or destroyed significant amounts of nearshore habitat (Correa 2002, 2003)

c. Alternative Solutions

- Protect Riparian / Channel Migration Zones from development. Protect remaining high quality riparian habitat (May and Peterson 2003)
- Retain at least 65% of stream basin surface area as natural forest cover in undeveloped watersheds
- Rehabilitate riparian areas wherever possible within the watershed. Improve riparian habitat through appropriate plantings
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Local governments
- Require alternatives to marine bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program or programmatic beach nourishment (WDFW, USCOE, WDOE, local governments)

7. Viability Stressor: <u>Loss of summer rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- Low summer flows, high temperatures, and chronic water quality problems limit habitat during summer low flows

c. Alternative Solutions

- Restore flows to North Fork Skokomish and mainstem Skokomish River through actions described in the Skokomish Chinook recovery plan
- Maintain basin imperviousness below 10 percent or utilize LID and stormwater BMPs to maintain an equivalent stormwater runoff potential
- Minimize groundwater withdrawals
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. Viability Stressors: <u>Loss of winter rearing habitat</u>

a. Primary VSP Parameter(s) Affected Abundance and Productivity

b. Impact Analyses

- High winter flows reduce overwinter habitat
- Land use practices historically filled or drained wetlands and re-channelized streams in upper watersheds, degrading and reducing overwinter habitat

c. Alternative Solutions

- Restore flows to North Fork Skokomish and mainstem Skokomish River through actions described in the Skokomish Chinook recovery plan to facilitate access to rearing habitat
- Support efforts to address floodplain planning through the Skokomish River General Investigation (ACOE, Mason Co, Skokomish Tribe) and Dosewallips / Duckabush (Jefferson County)
- Maintain basin imperviousness below 10 percent or utilize LID and stormwater BMPs to maintain an equivalent stormwater runoff potential
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Local governments
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to protect wetlands and small tributaries – DOE, local governments

East Hood Canal Watersheds

1. Viability Stressors: Loss of Access to Historical Habitat

a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

b. **Impact Analyses**

- Streams are typically low gradient in relatively small watersheds
- Few natural barriers identified; most are man-made
- Steelhead presence is presumed or observed in over 70 mi of stream in 20 watersheds, although likely underestimated. Steelhead distribution is presumed to occur upstream to a sustained 12% gradient, which includes most East Hood Canal streams
- Restoring fish access to lower watersheds has been a major emphasis for salmon recovery in this area such that many of the worst fish passage problems have been corrected. However, projects to restore fish passage in the upper watersheds have not been prioritized, due to the emphasis for funding on recovery of Chinook. Small streams along the shoreline are often completely or partially blocked (Kuttel 2003)

c. **Alternative Solutions**

- Minimize number of new stream crossings for rural development, forestry, etc
- Remove or replace existing culverts with bridges or stream simulation culverts that have natural streambed material
- Improve tidal connectivity to streams in lower reaches and estuaries, often constricted by roadways at stream mouths
- Decommission or improve maintenance of roads in the upper watersheds on forested and rural lands, with removal or replacement of culverts that are barriers
- Improve oversight and enforcement of instream work; especially culvert replacements/road building and bank protection.
- Enforce local ordinances relating to stream crossings
- Continue Lead Entity/local work to improve fish passage and restore natural channel conditions. Implement habitat projects described in summer chum recovery plan
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Management of lake levels should not affect stream flow at critical times

2. Viability Stressor: Loss and Degradation of Side Channels and Floodplain

a. **Primary VSP Parameter(s) Affected:** Abundance & Spatial Structure

b. **Impact Analyses**

- Streams have lost habitat connectivity with floodplain and side channels from channel re-alignment, dike construction, dredging, etc.
- Loss of natural floodplain processes increasing frequency and severity of redd scour and sediment deposition, reducing pool habitat quality (May and Peterson 2003, WDFW & PNPTT 2000)
- Majority of streams have lost substantial wetted area. Bank hardening has limited channel migration and creation of new habitat. Urbanization, water diversions and levees have resulted in loss of floodplain and disconnected off-channel habitats

c. **Alternative Solutions**

- Minimize floodplain development and alteration
- Restore lateral channel migration; restore floodplain connection and the re-connection of blocked side channel inlets
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes relating channel migration zones– Local governments
- Adopt and implement a stormwater strategy for developing watersheds (Counties)
- Modify existing regulations to limit “emergency” bank armoring and LWD removal
- Require alternatives to bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program
- Continue Lead Entity and local work to improve channel conditions in Tahuya, Little Anderson and Dewatto Creeks, as well as upper watersheds of major streams
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Purchasing/sun-setting of water rights no longer being exercised

3. Viability Stressor: <u>Loss of Large Woody Debris</u>

a. **Primary VSP Parameter(s) Affected** Abundance and Productivity

b. **Impact Analyses**

- Lack of adequate Large Woody Debris (LWD) in streams, particularly large stable coniferous “key” pieces that are critical to forming pools, providing cover, retaining organic matter and maintaining instream habitat complexity (May & Peterson 2003)

- West Kitsap / North Mason streams are dependent on LWD for habitat structure due to low gradient and gravel composition (boulders and bedrock are atypical). Few old growth stands remain on the Kitsap Peninsula. It was nearly completely logged in the 1800's due to the accessibility of the lowlands and the proximity to mills (Amato 1996, Kuttel 2003). Adding to this disturbance, rivers were cleared of logjams in lower reaches to improve fish accessibility in the 1960s, particularly in the Union, Tahuya and Big Beef river systems, and subject to illegal cedar salvage. (Brewer et al. 2005)
- Many large trees remaining are removed as "danger trees" due to proximity to development
- Timber production remains an important part of this watershed

c. Alternative Solutions

- Protect existing LWD structure (reduce modification of logjams, enforce regulations regarding wood cutting) through regulatory and non-regulatory actions
- Develop and implement short-term strategy to address LWD shortage to improve habitat complexity until full riparian function is restored
- Improve riparian habitat to allow longterm recruitment of LWD
- Increase channel complexity with site specific LWD and meander logjams, including additional gravel placement
- Promote habitat restoration on private property. Provide soft armoring technical assistance and a cost-share program for private land owners
- Modify existing regulations to limit "emergency actions" such as bank armoring and the removal of LWD - WDFW, USACOE, NOAA Fisheries, local jurisdictions
- Enforcement of Habitat Conservation Plans (state lands); Forest and Fish Rules (private lands).. Allow for Adaptive Management to modify existing regulations to better protect channel migration zones including erosional hazard zones. – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes with regard to riparian areas – Mason and Kitsap County

4. Viability Stressor: Loss of Pool Habitat

a. Primary VSP Parameter(s) Affected: Abundance and Productivity

b. Impact Analyses

- Simplification of stream systems (see Amato 1996, Kuttel 2003 for descriptions of individual watersheds) results in alteration of sediment dynamics and loss of pool habitat. High quality pools are important for juvenile rearing and adult migration

c. **Alternative Solutions**

- Improve system complexity by restoring lateral channel migration, floodplain reconnection with the placement of site specific LWD and logjams that re-establish meander
- Modification, oversight, and better enforcement of instream habitat alteration regulations– WDFW, USACOE, NOAA Fisheries

5. Viability Stressor: <u>Degradation of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Existing riparian habitat is fragmented and degraded by development and past logging and agricultural practices (May and Peterson 2003). Few old growth stands remain on the Kitsap Peninsula
- Remaining riparian stands are often sparsely vegetated and/or narrow in width (Brewer et al 2005). However, pockets of intact habitat exist, e.g., Dewatto and Stavis Creek, and were given the highest rating of "priority refugia with natural ecological integrity" (May and Peterson 2003) and should be protected

c. **Alternative Solutions**

- Protect remaining intact high quality riparian habitat through acquisition, regulatory and non-regulatory actions
- Rehabilitate degraded riparian areas within the watershed. Improve riparian habitat through appropriate riparian plantings
- Improve noxious weed education and enforcement, targeting invasive plants such as Japanese knotweed, and replanting with appropriate riparian vegetation
- Promote habitat restoration on private property. Provide soft armoring technical assiatance and a cost-share program for private land owners
- Enforcement of Habitat Conservation Plans (state lands) and Forest and Fish Rules (private lands) during Riparian Harvest activities. Allow for Adaptive Management to modify existing regulations to better protect natural functions – USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas

6. Viability Stressor: <u>Reduction of Riparian Habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- East Hood Canal watersheds are desirable locations for residential development and are subject to development pressure. Some of the watershed was subdivided into parcels decades ago, resulting in reduction and fragmentation of riparian habitat. Building setbacks were minimal during development of many streamside parcels and land clearing was permitted for lawns or building maintenance, often up to the stream edge. Sparse riparian vegetation that remained was subject to windthrow or removal as danger trees, resulting in loss of the riparian area
- Urbanization and industrialization have altered or destroyed significant amounts of nearshore habitat in the lower Hood Canal

c. **Alternative Solutions**

- Protect Riparian / Channel Migration Zones from development. Protect remaining high quality riparian habitat (e.g. Dewatto watershed) (May and Peterson 2003)
- Reduce or maintain (i.e. no net loss) impervious surface area in developed watersheds. Retain at least 65% of stream basin surface area as natural forest cover in undeveloped watersheds
- Rehabilitate riparian areas wherever possible within the watershed. Improve riparian habitat through appropriate plantings.
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates into consideration when approving timber harvest applications - USFS, WDNR
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to better protect riparian areas – Municipalities and local governments
- Require alternatives to marine bank hardening, such as bioengineered shoreline protection projects as described in the WDFW Aquatic Habitat Guidelines (AHG) Program or programmatic beach nourishment (WDFW, USCOE, WDOE, local governments)

7. **Viability Stressor: <u>Loss of summer rearing habitat</u>**

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. **Impact Analyses**

- Low summer flows, high temperatures, and chronic water quality problems limit habitat during summer low flows

c. **Alternative Solutions**

- Maintain basin imperviousness below 10 percent or utilize LID and stormwater BMPs to maintain an equivalent stormwater runoff potential
- County should adopt and implement a stormwater strategy for developing watersheds that will remediate current stormwater impacts and minimize future effects
- Minimize groundwater withdrawals
- Instream Flow Setting and Enforcement; Wetland Protection Regulations – WSDOE
- Purchasing/sun setting of water rights no longer being exercised – WSDOE, local restoration groups

8. Viability Stressors: <u>Loss of winter rearing habitat</u>

a. **Primary VSP Parameter(s) Affected:** Abundance and Productivity

b. Impact Analyses

- High winter flows reduce overwinter habitat
- Land use practices historically filled or drained wetlands and re-channelized streams in upper watersheds, degrading and reducing overwinter habitat

c. Alternative Solutions

- Maintain basin imperviousness below 10 percent or utilize LID and stormwater BMPs to maintain an equivalent stormwater runoff potential
- Allow for Adaptive Management to modify existing regulations to take sub basin harvest rates/rain-on-snow zone harvest rates into consideration when approving timber harvest applications. – USFS, WDNR.
- Modification and enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to minimize increases in impervious surfaces and storm-water runoff – Municipalities and local governments
- Modification and Enforcement of Critical Area Regulations, Shoreline Master Plans, and Land Use Codes to protect wetlands and small tributaries, particularly in upper watershed of Tahuya, Big Beef and Dewatto watersheds (Morgans Marsh) – DOE, local governments

Summary

Steelhead are among the most widely distributed salmonid species in the Puget Sound Basin. Steelhead are known to transcend waterfalls of 12 feet or more while migrating to native spawning grounds, accessing habitats unused by other salmonids. Yet, despite their diverse life history, wide-ranging distribution, and superior swimming and leaping abilities, steelhead are imperiled. Throughout their range in Puget Sound, wild steelhead abundances are depressed in nearly all watersheds.

The reasons for the decline of Puget Sound steelhead are not precisely known. However, habitat stressors, including elevated temperature regimes, fish blocking dams and culverts, degraded floodplain habitats, poor water quality, excessive fine sediment, and loss of instream cover all contribute to the loss of steelhead abundance in Puget Sound. Despite aggressive restoration efforts, steelhead habitat continues to decline. Adult wild steelhead mortality from commercial, recreational, and tribal fisheries is likely minor. However, incidental harvest of steelhead through rainbow trout fisheries, and hatchery steelhead interbreeding and competing with wild fish require further action in recovery planning efforts. Survival rates of ocean-bound steelhead are surprisingly low in the marine waters of Puget Sound. Recent studies show that 70-90% of steelhead leaving their watersheds perish before reaching the open ocean. Causal mechanisms for the loss of these fish require greater attention. Finally, whereas monitoring efforts for Chinook salmon increased after they were listed under ESA in 1999, less focus has been applied to steelhead monitoring efforts. In fact, the extent of steelhead distribution in most watersheds is only partially known, leading to some efforts to improve our understanding through modeling efforts (see NWIFC Appendix). Strategic monitoring and distribution efforts should be developed for Puget Sound steelhead in future recovery planning efforts.

Steelhead have provided a source of food as well as cultural and spiritual benefits to the native peoples of Puget Sound for millennia. Even in more modern times, steelhead provided widespread angling and fish viewing opportunities that have generated economic and cultural benefits to the residents of Washington State. Indeed, steelhead are an important symbol of Pacific Northwest heritage. Their recovery to healthy levels is a cultural imperative.

References

Amato, C. 1996. Historical Changes Affecting Freshwater Habitat of Coho Salmon in the Hood Canal Basin from pre-1850 to the Present. Point No Point Treaty Council.

Ames, J., Graves, G., and C. Weller. 2000. Summer chum salmon conservation initiative. Washington Department of Fish and Wildlife and Point-No-Point Treaty Tribes.

Andrews, E. and M. Swint. 1994. A Twentieth Century History of Sequalitchew Creek.

Ashbrook, C., Mizell, M., and K. Warheit. In prep. Adult winter steelhead trout hooking mortality estimation and movement patterns using surgically implanted radio telemetry tags. Washington Department of Fish and Wildlife. Olympia, Washington.

Barreca, J., 1998, Needs assessment for the eastern Olympic water quality management area: Washington State Department of Ecology Report WQ-98-20.

Beacham, T.D. and C.B. Murray. 1990. Temperature, egg size, and development of embryos and alevins of five species of Pacific salmon: A comparative analysis. Transactions of the American Fisheries Society 119(6): 927–945.

Beamer, E., Beechie, T., Perkowski, B., and Klochak, J. 2000. River basin analysis of the Skagit and Samish Basins: tools for salmon habitat restoration and protection, Skagit Watershed Council.

Beamer, E., R. Henderson, and K. Larsen. 2002a. Evidence of an estuarine habitat constraint on the production of wild Skagit chinook. Presentation at Western Division AFS Meeting in Spokane April 29-May1, 2002. Skagit System Cooperative. LaConner, Washington.

Behnke, R.J. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6. 275 pp.

Behnke, R.J. 2002. Trout and Salmon of North America. Free Press, New York.

Berejikian, B. A., E. P. Tezak, S. C. Riley, and A. L. LaRae. 2001. Competitive ability and social behaviour of juvenile steelhead reared in enriched and conventional hatchery tanks and a stream environment. Journal of Fish Biology 59:1600-1613.

Bisson, P.A., K. Sullivan, and J.L. Neilsen. 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.

Bjornn, T.C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication No. 19:83-138.

Bonneville Power Administration (BPA). 1992. Stock summary reports for Columbia River anadromous salmonids, 5 volumes. Columbia River Coordinated Information System (CIS).

Bortelson, G.C., M.J. Chrzastowski, and A.K. Helgerson. 1980. Historical changes of shoreline and wetland at Snohomish River and Possession Sound, Washington. Sheet 6. Hydrologic Investigations Atlas HA-617, USGS.

Brenkman, S.J. and C. Stephen. 2005. Extent of Anadromy in Bull Trout and Implications for Conservation of a Threatened Species. North American Journal of Fisheries Management 25:1073–1081.

Brewer, S., Watson, J., Christensen, D., and R. Brocksmith. 2005. Hood Canal & Eastern Strait of Juan de Fuca Summer Chum Salmon Recovery Plan. Hood Canal Coordinating Council

Brenkman, S.J. and S.C. Corbertt. 2005. Extent of anadromy in bull trout and implications for conservation of a threatened species. North American Journal of Fisheries Management 25:1073–1081.

Brulle, R.V. 2002. Washington Trout files notice to sue Puget Sound Energy and the FERC. Washington Trout, Duvall, Washington. http://www.washingtontrout.org/pse.shtml

Bulkley, R.V. 1967. Fecundity of steelhead trout, Salmo gairdneri Richardson, from Alsea River, Oregon. Journal of Fisheries Research Board of Canada 24:917-926.

Burge. R.T, Mantua, N.J; Berryman, J.W., and L.B. Doyle. 2006. The Status of Wild Steelhead and Their Management in Western Washington: Strategies for Conservation and Recreation Wild Steelhead Coalition May 10, 2006.

Burgner, R.L. J.T. Light, L. Margolis, T. Okazaki, A. Tautz, and S. Ito. 1992. Distribution and origins of steelhead trout Oncorhynchus-mykiss in offshore waters of the North Pacific Ocean. International North Pacific Fisheries Commission Bulletin 51:1-92.

Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-27, 261 pp.

Bustard, D.R., and D.W. Narver. 1975. Aspects of winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of Fisheries Research Board of Canada 32:667-680.

Cederholm, C.J., L.M. Reid, and E.O. Salo. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Washington. Pages 38-74 *in* Proceedings, conference on spawning gravel: a renewable resource in the Pacific Northwest? Report 39. Washington State University, Water Research Center, Pullman, Washington.

Chapman, D.W. 1958. Studies on the life history of Alsea River steelhead. The Journal of Wildlife Management 22(2):123-134.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmon in streams, with special reference to food and feeding. Pages 153-176 *in* T. G. Northcote, editor, Symposium on salmon and trout in streams. University of British Columbia, Vancouver.

Chittenden, H.M. 1907. Report of an Investigation by a Board of Engineers, of the Means of Controlling Floods in the Duwamish-Puyallup Valleys and Their Tributaries in the State of Washington. Lowman & Hanford S. and P. Company, Seattle, Washington.

Christensen, V. 2007. Riverine and early ocean migration and mortality patterns of juvenile steelhead trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia. Hydrobiologica 582:55–65.

Christie, M.R., M.L. Marine, and M.S. Blouin. 2011. Who are the missing parents? Grandparentage analysis identifies multiple sources of gene flow into a wild population. Molecular Ecology 20(6):1263–1276.

City of Seattle. 2001. Seattle's watersheds outside the municipal boundaries. In: Seattle's Urban Blueprint for Habitat Protection and Restoration. City of Seattle, Seattle Public Utilities, Seattle, Washington.

Clothier, B.G., and others. 2003. Chambers-Clover Management Plan Technical Assessment. Prepared for the Tacoma-Pierce County Health Department.

Coe, T. 2001. Nooksack River Watershed Riparian Function Assessment. Report #2001-001. October 2001. Nooksack Indian Tribe, Natural Resources Department, Deming, WA.

Collier, T.K., L.L. Johnson, M.S. Myers, C.M. Stehr, M.M. Krahn and J.E. Stein. 1998. Fish injury in the hylebos waterway of commencement bay, washington. U.S. Department of Commerce, NOAA Technical Memo. NMFS-NWFSC-36, 576 p.

Collins, B.D. and A.J. Sheikh. 2004. Historical riverine dynamics and habitats of the Nooksack River. Final Project Report to the Nooksack Indian Tribe, Natural Resources Department. August 2004. Department of Earth & Space Sciences, University of Washington. Seattle, WA.

Consoer, Townsend, and Assoc. 1977. Clover Creek Basin Drainage Plan: An Engineering Study for an Optimim Flood Control Plan. Pierce County.

Correa, G. 2002. Salmon and Steelhead Habitat Limiting Factors. Water Resource Inventory Area 17. Quilcene-Snow Basin. Washington State Conservation Commission. Final Report. November 2002. 316 pp.

Correa, G. 2003. Salmon and Steelhead Habitat Limiting Factors. Water Resource Inventory Area 16. Dosewallips-Skokomish Basin. Washington State Conservation Commission. Final Report. November 2003. 257 pp.

Crawford, B.A. 1979. The Origin and History of the Trout Brood Stocks of the Washington Department of Game. Olympia: Washington State Game Department.

CTC. 2002. WRIA 14 Salmon Refugia Study, Concurrent Technologies Corporation.

Currence, N. 2000. Middle Fork Nooksack anadromous salmonid potential upstream of the diversion dam. Nooksack Indian Tribe, Natural Resources Department, Deming, WA. 9 pp.

Dauble, D.D. 2009. Fishes of the Columbia Basin A Guide to their Natural History and Identification. Publisher: Keokee Books, first edition. July 1, 2009.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Can. J. Fish. Aquat. Sci. 54:1685–1698.

Dorn, P. and D. Small. 2011. North Kitsap Nearshore Fish Use 2007 -2009 Results. RCO Salmon Recovery Conference. April 26 and 27, 2011. Great Wolf Lodge Conference Center.

Duke Engineering. 1999. Final technical report lower Skagit River instream flow studies. Prepared for Public Utility District No. 1 of Skagit County and the City of Anacortes. Duke Engineering and Services, Inc., Bellingham, Washington. 140 pp.

Fessler, J.L., and H.H. Wagner. 1969. Some morphological and biochemical changes in steelhead trout during the parr–smolt transformation. Journal of the Fisheries Research Board of Canada 26(11):2823-2841.

Ford, M.J. (ed.), T. Cooney, P. McElhany, N. Sands, L. Weitkamp, J. Hard, M. McClure, R. Kope, J. Myers, A. Albaugh, K. Barnas, D. Teel, P. Moran, and J. Cowen. 2010. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Northwest. *Draft* U.S. Department of Commerce, NOAA Technical Memorandum NOAA-TM-NWFSC-XXX.

Fresh, K.L. 1997. The Role of Competition and Predation in the Decline of Pacific Salmon and Steelhead (pages 245-275) Chapter in PACIFIC SALMON & THEIR ECOSYSTEMS: STATUS AND FUTURE OPTIONS. Deanna J. Stouder, Peter A. Bisson and Robert J. Naiman, editors.

Gargett, A.E. 1997. The optimal stability ‘‘window’’: a mechanism underlying decadal fluctuations in North Pacific salmon stocks? Fisheries Oceanography 6: 109–117.

GeoEngineers. 2001. North Fork Nooksack River Corridor Analysis. Prepared for Washington State Department of Transportation. June 22, 1001. Bellingham, WA.

GeoEngineers, Inc., Cascade Environmental Services, Inc., Urban Regional Research, Jefferson County Dept Public Works, and Local Interagency Team Agencies 1998. Lower Big Quilcene River Comprehensive Flood Hazard Management Plan. Jefferson County Dept of Public Works; Washington State Dept of Ecology.

Gersib, R., L. Wildrick, C. Freeland, S. Grigsby, K. Bauersfeld, S. Butkus, R. Coots, and J. Franklin. 1999. Process-based river basin characterization: a case study Snohomish Basin, Washington. Washington State Department of Ecology. Olympia, WA.

Goetz, F., S. Hodgson, B. Leland, E. Connor, R. Ladley, and A. Berger. 2008. Migratory behavior of hatchery and wild steelhead smolts in Puget Sound as measured by acoustic telemetry. Pacific Coast Steelhead Meeting presentation. Boise ID. March 4 – 6, 2008.

Graybill, J.P., Burgner, R.L., Gislason, J.C., Huffman, P.E., Wyman, K.H., Gibbons, R.G., Kurko, K.W., Stober, Q.J., Fagnan, T.W., Stayman, A.P., and D.M. Eggers. 1979. Assessment of the reservoir-related effects of the Skagit River project on downstream fishery resources of the Skagit River, Washington. University of Washington, Fisheries Research Institute, Final Report (FRI-UW- 7905) to Seattle City Light, Seattle.

Groot C., and L. Margolis. 1991. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver. 564 pp.

Hard, J.J., J.M. Myers, M.J. Ford, R.G. Kope, G.R. Pess, R.S. Waples, G.A. Winans, B.A. Berejikian, F.W. Waknitz, P.B. Adams. P.A. Bisson, D.E. Campton, and R.R. Reisenbichler. 2007. Status review of Puget Sound steelhead (*Oncorhynchus mykiss*). U.S. Dept. Commerce, NOAA Technical Memorandum NMFS-NWFSC-81, 117 p.

Haring, D. 1999. Salmon habitat limiting factors analysis final report. Water Resource Inventory Area 7, Snohomish Watershed. 331 pages.

Haring, D. 2000. Salmonid habitat limiting factors: Water Resource Inventory Area 15 (East) – Final Report. Washington State Conservation Commission. 364 pages.

Haring, D. 2002. Salmonid Habitat Limiting Factors Analysis: Snohomish River Watershed (WRIA 7).

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 22:(4) 1035-1081.

Hartman, G.F., and J.C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 223. Department of Fisheries and Oceans, Ottawa, Ontario, Canada.

Hatch, D.R., Branstetter, R., Blodgett J., Bosch B., Fast D., and T. Newsome. 2003. Kelt Reconditioning: A research project to enhance iteroparity in Columbia Basin steelhead (*Oncorhynchus mykiss*). Annual Report 2003 Bonneville Power Administration. DOE/BP-00004185-4.

Hiss, J.M., Harrington-Tweit, B., and S.R. Boomer. 1982. Downstream migration of juvenile rainbow/steelhead trout in the Nisqually River and Muck Creek. NMFS 80-ABG-00007. U.S. Fish and Wildlife Service.

Holtby, L.B., Andersen, B.C., and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 47:2181–2194.

Hyatt, T.L. and A.D. Rabang. 2003. Nooksack Chinook Spawning and Incubation Assessment. December 31, 2003. Nooksack Indian Tribe, Natural Resources Department, Deming, WA.

Hyatt, T. 2005. Lower North Fork Reach Assessment, Ecological Findings and Restoration Recommendations Nooksack Natural Resources, Deming, WA.

Indrebo, M. 1998. Stream channel classification and historical channel changes along the North Fork, Nooksack River, Washington. Prepared for the Lummi Natural Resources Department, Bellingham, WA. 47 pp.

Jensen, J.O.T., and D.F. Alderdice. 1989. Comparison of mechanical shock sensitivity of eggs of five Pacific salmon (*Oncorhynchus*) species and steelhead trout (*Salmo gairdneri*). Aquaculture 78:163-181.

Johnson, J.H., and P.A. Kucera. 1985. Summer-autumn habitat utilization of subyearling steelhead trout in tributaries of the Clearwater River, Idaho. Canadian Journal of Zoology 63:2283-2290.

Johnson, H.J. and H.N. Ringler. 1979. Diet of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*) relative to prey availability. School of Biology , Chemistry and Ecology, State University of New York, College of Environmental Science and Forestry, Syracuse, NY, U.S.A. 13210

Jones, D.E 1973. Steelhead and sea-run cutthroat life histories in Southeast Alaska. Alaska Dept. Fish Game Ann Rep. Study AFS-42-1, 14:1-18

Kahler, T.H. 1999. Summer movement and growth of individually marked juvenile salmonids in western Washington streams. Master's Thesis. University of Washington, School of Aquatic Fisheries and Sciences.

Keefer, M.L., Peery, A.C., Firehammer, J., and L.M. Moser. 2005. Straying rates of known-origin adult Chinook salmon and steelhead within the Columbia River Basin, 2000-2003. Technical Report 2005-5 U.S. Army Corps of Engineers and Bonneville Power Administration.

Keeley, E.R., and J.D. McPhail. 1998. Food abundance, intruder pressure, and body size as determinants of territory size in juvenile steelhead trout (*Oncorhynchus mykiss*). Behaviour, 135:65–82.

Kerwin, J. 1999a. Salmon habitat limiting factors report for the Puyallup River Basin (Water Resource Inventory Area 10). 104 pages.

Kerwin, J. 1999b. Salmon and steelhead habitat limiting factors, Water Resource Inventory Area 11. Final Report. Washington State Conservation Commission. 158 pages.

Kerwin, J. 2001. Salmon habitat limiting factors analysis final report. Water Resource Inventory Area 8, Cedar-Sammamish Basin. 587 pages.

Kerwin, J. and T.S. Nelson (Eds.). 2000. Habitat Limiting Factors and Reconnaissance Assessment Report, Green/Duwamish and Central Puget Sound Watersheds (WRIA 9 and Vashon Island). Washington Conservation Commission and the King County Department of Natural Resources. 587 pp.

Kondolf G.M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129:262-281.

Kostow, K. 2003. Factors that influence evolutionarily significant unit boundaries and status assessment in a highly polymorphic species, *Oncorhynchus mykiss*, in the Columbia Basin. Oregon Department of Fish and Wildlife Information Report #2003-04.

Kovalenko, S.A., A.O. Shubin, and I.A. Nemchinova. 2005. Distribution and biological characteristics of Kamchatka steelhead *Parasalmon mykiss* (Salmonidae) in Pacific waters off the Kurils and in the Sea of Okhotsk. Journal of Ichthyology 45(1):70-80.

Kuttel Jr, M. 2002. Salmonid Habitat Limiting Factors in Water Resource Inventory Areas 15 (West), Kitsap Basin, and 14 (North), Kennedy – Goldsborough Basin. Washington State Conservation Commission. Olympia, WA.

Leider, S.A., M.W. Chilcote, and J.J. Loch. 1986. Comparative life history characteristics of hatchery and wild steelhead trout (*Salmo gairdneri*) of summer and winter races in the Kalama River, Washington. Canadian Journal of Fisheries and Aquatic Sciences 43(7):1398-1409.

Light, J. T., S. Fowler, and M. L. Dahlberg 1988. High seas distribution of North American steelhead as evidenced by recoveries of marked or tagged fish. (Document submitted to the International North Pacific Fisheries Commission.) FRI-UW88 16. Fisheries Research Institute, Univ. Washington, Seattle. 21 pp.

Love, M. 1996. Probably more Than You Want To Know About The Fishes Of The Pacific Coast. Really Big Press, Santa Barbara California.

Ma, Z., Gan, X., Cai, Y., Chen, J., and Li, B. 2011. Effects of exotic *Spartina alterniflora* on the habitat patch associations of breeding saltmarsh birds at Chongming Dongtan in the Yangtze River estuary, China. Biological Invasions 13(7): 1673-1686.

Maher, F. P., and P. A. Larkin. 1955. Life history of the steelhead trout of the Chilliwack River, British Columbia. Transactions of the American Fisheries Society 84:27-38.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society, 78: 1069-1079.

Marshall, A.R., M. Small, and S. Foley. 2006. Genetic relationships among anadromous and non-anadromous *Oncorhynchus mykiss* in Cedar River and Lake Washington - implications for steelhead recovery planning. Washington Department of Fish and

Wildlife Final Report to Cedar River Anadromous Fish Committee and Seattle Public Utilities.

Maudlin, M., Coe, T., Currence, N., and J. Hansen. 2002. South Fork Nooksack River Acme-Saxon Reach Restoration Planning: Analysis of Existing Information and Preliminary Recommendations. November 26, 2002. Lummi Natural Resources, Bellingham, WA, and Nooksack Natural Resources, Deming, WA.

Maudlin, M. 2007 Nooksack River Watershed Large Woody Debris Assessment Lummi Natural Resources, Bellingham, WA.

May, C. and G. Peterson. 2003. Landscape Assessment and Conservation Prioritization of Freshwater and Nearshore Salmonid Habitat in Kitsap County: 2003 Kitsap Salmonid Refugia Report. Kitsap County. Port Orchard, WA

McKinnell, S., A.J. Thomson, E.A. Black, C.M. Guthrie III, B.L. Wing, J.F. Koerner, and J.H. Helle. 1997. Atlantic salmon in the North Pacific. Aquaculture, 28:145-157.

McMillan, J., Katz, S., and G. Pess. 2007. Observational evidence of spatial and temporal structure in a sympatric anadromous (winter steelhead) and resident rainbows trout mating system on the Olympic Peninsula, Washington. Transactions of the American Fisheries Society, 136:736-748.

McMillan, J. 2009. Early maturing males in a partially migratory population of anadromous and resident rainbow trout *Oncorhynchus mykiss*: influences of individual condition and stream temperature. Master's Thesis, Oregon State University.

McNeil, W.J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. fish and Wildlife Service, Special Scientific Report – Fisheries. 469 Washington D.C. 15 pp.

McNeil, W.J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. Fisheries Bulletin U.S. 64:495-523.

Melnychuk, M.C., Welch, D.W., Walters, C.J., and V. Christensen. 2007. Riverine and early ocean migration and mortality patterns of juvenile steelhead trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia. Hydrobiologica 582:55–65.

Melnychuk, M.C., Hausch, S., McCubbing, D., and Welch, D. 2009. Acoustic tracking of hatchery-reared and wild Cheakamus River steelhead smolts to address residualisation and early ocean survival. Report submitted to Canadian National Railway Company, Monitor 2, Project F. [*Available on-line at* www.certc.ca].

Meyer, K.A., and J.S. Griffith. 1997. First-winter survival of rainbow trout and brook trout in the Henrys Fork of the Snake River, Idaho. Canadian Journal of Zoology 75(1): 59-63.

Miller, C. and D. Somers. 1989. TFW Stillaguamish river early action project. Tulalip Tribes Natural Resources Department, Marysville, WA.

Mobrand. 2004. EDT Analysis of Coho Habitat Potential and Restoration Options for South Puget Sound Streams, Mobrand Biometrics, Inc., 2004.

Molenaar, D. and J. Noble. 1970. Geology and Related Ground-Water Occurrence, Southeastern Mason County, Washington. Water-Supply Bulletin No. 29. State of Washington Department of Water Resources in cooperation with United States Geological Survey Water Resources Division.

Montgomery, D.R., Beamer, E.M., Pess, G.R., and T.P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Can. J. Fish. Aquat. Sci. 56: 377-387

Moore, M.E., Goetz, F.A., Van Doornik, D.M., Tezak, E.P., Quinn, T.P., Reyes-Tomassini, J.J., and B.S. Berejikian. 2010. Early marine migration patterns of wild coastal cutthroat trout (*Oncorhynchus clarki clarki*), steelhead trout (*Oncorhynchus mykiss*), and their hybrids. PLoS ONE 5(9): e12881.

Morrow, J.E. 1980. The Freshwater Fishes of Alaska. Alaska Northwest Publ. Co. Anchorage, AK. 248pp.

MBSNF (Mt. Baker-Snoqualmie National Forest), Darrington District. 1995. Watershed analysis: South Fork upper Stillaguamish river. Darrington, WA.

Munn, M.D., R.W. Black, A.L. Haggland, M.A. Hummling, and R.L. Huffman. 1998. An Assessment of Stream Habitat and Nutrients in the Elwha River Basin: Implications for Restoration. U.S. Geological Survey Water Resources Investigations Report 98-4223.

Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler, and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956–1995. North Pacific Anadromous Fish Commission Doc. 192, FRI-UW-9614, Seattle: University of Washington.

Narum, S.R., Banks, M., Beacham, T.D., Bellinger, M.R., Campbell, M.R., Dekoning, J., Elz, A., III, C.M.G., Kozfkay, C., Miller, K.M., Moran, P., Phillips, R., Seeb, L.W., Smith, C.T., Warheit, K., Young, S.F., and J.C. Garza. 2008. Differentiating salmon populations at broad and fine geographical scales with microsatellites and single nucleotide polymorphisms. Molecular Ecology 17: 3464-3477.

National Marine Fisheries Service. 2006. Final ESA listing determinations for 10 distinct population segments of West Coast steelhead. Federal Register [Docket No. 051216341–5341–01, 5 January 2006] Vol. 71(3): 834-861. See: http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Steelhead/Steelhead-FRN.cfm

National Marine Fisheries Service. 2007. Puget Sound Salmon Recovery Plan. http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Recovery-Plan.cfm

Needham, P.R. and A.C. Taft. 1934. Observations on the spawning of steelhead trout. Transactions of the American Fisheries Society 64(1):332-338.

Newton, J., C. Bassin, A. Devol, M. Kawase, W. Ruef, M. Warner, D. Hannafious, and R. Rose. 2007. Hypoxia in Hood Canal: An overview of status and contributing factors. *In:* Proceedings of the 2007 Georgia Basin Puget Sound Research Conference, http://www.engr.washington.edu/epp/psgb/2007psgb/2007proceedings/index.html

Nichols, K.M., Edo, A.F., Wheeler, P.A., and G.H. Thorgaard. 2008. The genetic basis of smoltification-related traits in *Oncorhynchus mykiss*. Genetics 179(3): 1559-1575.

Nightingale, B. 2000. Summary Report on the Status of Marine Resources in Jefferson County. Jefferson County Marine Resources Committee.

Olympic National Park 1995. Final Environmental Impact Statement (EIS) on Elwha River Ecosystem Restoration. National Park Service.

Orcutt, D.R., B.R. Pulliam, and A. Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. Transactions of the American Fisheries Society 97:42-45.

Osborn, J.F. and S.C. Ralph. An Aquatic Resource Assessment of the Dungeness River System. 1994.

Pauley, G.B., Oshima, K., Bowers, K.L., 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 and Wildlife Service Biological Report 82 (11.86). U.S. Army Corps Eng. TR EL-82-4.

Pautzke, C.F. and R.C. Meigs. 1940. Studies of the life history of the Puget Sound steelhead (*Salmo gairdnerii*). Washington Department of Game, Biological Bulletin 3. Olympia WA.

Pierce County Public Works and Utilities. 1996. Chambers-Clover Creek Management Committee: Watershed Action Plan.

Pierce County Public Works and Utilities. 1997. Chambers-Clover Creek Management Committee: Watershed Characterization.

Pentec Environmental and NW GIS. 1999. Snohomish River Basin Conditions and Issues Report – Revised Final Report. Prepared for the Snohomish River Basin Work Group.

Penttila, D. 2007. Marine forage fishes in Puget Sound Puget Sound Nearshore Partnership report No. 2007-03, Seattle District, U.S. Army Corps of Engineers, Seattle, WA. 30pp.

Pollard, W.R., G.F. Hartman, C. Groot, and P. Edgell. 1997. Field identification of coastal juvenile salmonids. Harbour Publ., Madiera Park, British Columbia, Canada. 31pp.

Puget Sound Cooperative River Basin Team. June, 1991. Dungeness River Area Watershed – Clallam County Washington.

Puget Sound Salmon Recovery Plan. 2007. Adopted by the National Marine Fisheries Service (NMFS) January 19, 2007 Submitted by the Shared Strategy Development Committee.

Quinn, T.P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. American Fisheries Society, Bethesda, Maryland. 381pp.

Reeves, G.H., J.B. Grunbaum, and D.W. Lang. 2010. Seasonal variation in diel behaviour and habitat use by age 1+ Steelhead (Oncorhynchus mykiss) in Coast and Cascade Range streams in Oregon, U.S.A. Environmental Biology of Fishes 87:101–111.

Reisenbichler, R.R. and S.R. Phelps. 1989. Genetic Variation in Steelhead (Salmo gairdneri) from the North Coast of Washington. Canadian Journal of Fisheries and Aquatic Sciences, 46:66-73.

Reiser, D.W., and T.C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in western North America habitat requirements of anadromous salmonids. United States Forest Service, Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-96, Corvallis, Oregon, USA.

Richardson, J. 1836. The Fish. in Fauna Boreali-Americana; or the zoology of the northern parts of British America containing descriptions of the objects of natural history collected on the late northern land expeditions, under the command of Sir John Franklin, R.N. Part 3, pp i-xv + 1-327, Pls. 74-97.

Roni, P., and T.P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282-292.

Roni, P., and A. Fayram. 2000. Estimating winter salmonid abundance in small western Washington streams: a comparison of three techniques. North American Journal of Fisheries Management 20:683–692.

Ruggerone, G.T., T.P. Quinn, I.A. McGregor, and T.D. Wilkinson. 1990. Horizontal and vertical movements of adult steelhead trout, *Oncorhynchus mykiss*, in the Dean and Fisher Channels, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 47(10):1963-1969.

Ruzycki, J.R., Flesher, M.W., Carmichael, R.W., and D.L. Eddy. 2003. Lower Snake River Compensation Plan: Oregon Evaluation Studies-Steelhead Life History, Genetics, and Kelt Reconditioning. Oregon Department of Fish and Wildlife. La Grande, OR. 57pp.

Ryding, K.E. and J.R. Skalski. 1999. Multivariate regression relationships between ocean conditions and early marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 56: 2374–2384.

Satterthwaite, W.H., Beakes, M.P., Collins, E., Swank, D.R., Merz, J.E., Titus, R.G., Sogard, S.M., and Mangel, M. 2009. Steelhead life history on California’s central coast: insights from a state dependent model. Transactions of the American Fisheries Society, 138, 532–48.

Savvaitova, K.A., Kuzishchin, K.V., Maksimov, S.V., and S.D. Pavlov. 1996. Population structure of Mikizha, *Salmo mykiss* in the Utkholok River (Western Kamchatka). Journal of Ichthyology : 37(3): 216-225.

Shaffer, J. A. 2002. Nearshore mapping of the Strait of Juan de Fuca: II. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. A report to the Wash. Dept. of Fish and Wildlife and the Clallam County Marine Resources Committee. Port Angeles, WA.

Schmidt, S.P. and E.W. House. 1979. Precocious sexual development in hatchery-reared and laboratory maintained male steelhead trout (*Salmo gairdneri*). J Fisheries Res Board Can 36: 90–93.

Schuett-Hames, J. and D. Schuett-Hames. 1984. Spawning gravel fine sediment levels and stream channel stability ratings for salmonid streams in the Nooksack Basin, Washington, 1982 and 1983. Lummi Tribal Fisheries Department, Bellingham, Washington. 26 pp.

Schuett-Hames, D., H. Flores, and I. Child. 1996. An Assessment of Salmonid Habitat and Water Quality for Streams in the Eld, Totten-Little Skookum and Hammersley Inlet-Oakland Bay Watersheds in Southern Puget Sound, Washington 1993-1994. Squaxin Island Tribe.

Scott, J. B. Jr. and W. T. Gill. 2008. *Oncorhynchus mykiss:* Assessment of Washington State's Steelhead Populations and Programs, Washington Department of Fish and Wildlife, Olympia, WA.

Scrivener, J. C., and M. J. Brownlee. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum *(Oncorhynchus keta)* and coho salmon *(O. kisutch)* in Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:681-696.

Seamons, T.R. and T.P. Quinn. 2010. Sex-specific patterns of lifetime reproductive success in single and repeat breeding steelhead trout (*Oncorhynchus mykiss*). Behavioral Ecology and Sociobiology 64(4):505-513.

Shapovalov, L. and A.C. Taft. 1954. The life histories of the rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*), with special reference to Waddell Creek, California, and recommendations regarding their management. U.S. Fish and Wildlife Service Fishery Bulletin 98: 1–373.

Shumway, D.L., C.E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Transactions of the American Fisheries Society 93:342-356.

Skagit River System Cooperative (SRSC) and Washington Department of Fish and Wildlife (WDFW). 2005. *Skagit Chinook Recovery Plan*. Skagit River System Cooperative, LaConner, WA.

Small, M.P., McLellan, J.G., Loxterman, J., Von Bargen, J., Frye, A., and C. Bowman. 2007. Fine-scale population structure of rainbow trout in the Spokane River drainage in relation to hatchery stocking and barriers. Transactions of the American Fisheries Society 136: 301-317.

Smith, A.K. 1973. Development and application of the spawning velocity and depth criteria for Oregon salmonids. Transactions of the American Fisheries Society 102(2):312-316.

Smith, C. 2002. Salmon and Steelhead Habitat Limiting Factors in WRIA 1, the Nooksack Basin. July, 2002. Washington State Conservation Commission. Lacey, WA.

Smith, C.J. 2003. Salmon and Steelhead Habitat Limiting Factors Water Resource Inventory Areas 3 And 4. The Skagit and Samish Basins, Washington State Conservation Commission Lacey, Washington.

Smith, C.J. and P. Wampler, eds. 1995. Dungeness River Chinook Salmon Rebuilding Project Progress Report 1992-1993. In Cooperation with Washington Department of Fish and Wildlife, Jamestown S'Klallam Tribe and U.S. Fish and Wildlife Service. Olympia, WA.

Smith, J.J., and H.W. Li. 1983. Energetic factors influencing foraging tactics of juvenile steelhead trout, *Salmo gairdneri*. Pages 173-180 *in* D. L. G. Noakes, editor, Predators and prey in fishes: proceedings of the 3rd biennial conference on the ethology and behavioral ecology of fishes. Norrmal, Illinois.

Smith, B.D., and B.R. Ward. 2000. Trends in wild adult steelhead (*Oncorhynchus mykiss*) abundance for coastal regions of British Columbia support the variable marine survival hypothesis. Canadian Journal of Fisheries and Aquatic Sciences 57(2): 271-284.

Smith, G.R. and R.F. Stearley. 1989. The classification and scientific names of cutthroat and rainbow trouts. Fisheries 14(1):1-62.

Strickland, R. 1983. *The fertile fjord.* Seagrant Publications, University of Washington Press. Seattle, Washington.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64: 1506-1514.

Taylor, K., T. Moreland, and M. Stevie. 2000. Oakland Bay/Hammersley Inlet Watershed Assessment. Squaxin Island Tribe. Natural Resources Department. Shelton, WA.

Tetra Tech/KCM, Inc. 2002. Pierce County Clover Creek Basin Plan; Draft. Seattle: Pierce County.

Thorpe, J.E. 2007. Maturation responses of salmonids to changing developmental opportunities. Marine Ecology Progress Series 335:285-288.

Thurston County. 1989. Henderson Inlet Watershed Action Plan. Olympia, Washington.

Thurston County Advance Planning and Historic Preservation. 1995. Budd Inlet-Deschutes River Watershed Action Plan. Olympia, Washington.

Tipping, J.M., Gannam, A.L., Hillson, T.D., and J.B. Poole. 2003. Use of size for early detection of juvenile hatchery steelhead destined to become precocious males. North American Journal of Aquaculture 65: 318–323.

Turner, M. 1993. Budd Inlet/Deschutes River Watershed Characterization: part I, watershed description. Thurston County, Washington.

U.S. Army Corps of Engineers. 1992. Commencement Bay, Washington Cumulative Impact Study. USACE Seattle District, Seattle. Washington.

U.S. Army Corps of Engineers. 1997. Reconnaissance report: Stillaguamish river ecosystem restoration general investigation, Stillaguamish River, Snohomish County. Seattle, Washington.

U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and National Oceanic and Atmospheric Administration. 1993. Commencement Bay Cumulative Impact Study. Volumes 1 and 2.

U.S. Fish and Wildlife Service. 2004. Draft Recovery Plan for the Coastal-Puget Sound Distinct Population Segment of Bull Trout (*Salvelinus confluentus*). Volume I (of II): Puget Sound Management Unit. Portland, Oregon. 389 + xvii pp.

U.S. Fish and Wildlife Service and U.S. National Oceanic and Atmospheric Administration. 1997. Commencement Bay Natural Resource Damage Assessment: Restoration Plan and Final Programmatic Environmental Impact Statement.

U.S. Forest Service. 1995. North Fork Nooksack River Watershed Analysis. Mount Baker Ranger District, Sedro Woolley, Washington.

U.S. Forest Service. 1997. Hamma Hamma River and Hood Canal tribs watershed analysis. US Department of Agriculture, Olympic National Forest, Olympia, WA.

U.S. Forest Service. 1999. Dosewallips River watershed analysis. US Department of Agriculture, Olympic National Forest, Olympia, WA.

U.S. Forest Service. 2002. Baker River watershed analysis. U.S. Forest Service, Mt. Baker Ranger District. Sedro Woolley, Washington.

U.S. Office of the Federal Register. 2007. Endangered and Threatened Species: Final Listing Determination for Puget Sound Steelhead. Code of Federal Regulations, Title 50, Part 223. U.S. Government Printing Office, Washington, D.C.

Van Hulle, F. 1985. Alaska steelhead workshop. Juneau, AK: Alaska Department of Fish and Game, Sport Fish Division. in Lohr, S.C. and Bryant, M.D. 1999. Biological Characteristics and Population Status of Steelhead (Oncorhynchus mykiss) in Southeast Alaska. USDA. Forest Service General Technical Report PNW-GTR-407.

Wagner, H.H. 1974. Photoperiod and temperature regulation of smolting in steelhead trout (Salmo gairdneri) Canadian Journal of Zoology 52:(2) 219-234.

Walker, R.V., K.W., Myers, N.D. Davis, K.Y. Aydin, K.D. Friedland, H.R. Carlson, G.W. Boehlert, S. Urawa, Y. Ueno, G. Anma. 2000. Diurnal variation in thermal environment experienced by salmonids in the North Pacific as indicated by data storage tags. Fisheries Oceanography 9:171–186.

Ward, B.R. and P.A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Canadian Journal of Fisheries and Aquatic Sciences 45(7):1110-1122.

Ward, B.R., Slaney, P.A., Faccin, A.R., and R.W. Land. 1989. Size-biased survival in steelhead trout (*Oncorhynchus mykiss*): back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia. Can J Fish Aquat Sci 46: 1853–1859.

Watts, W.M. 1996. Upslope erosion assessment for: South Fork Nooksack River watershed-Skookum Creek to Howard Creek, Howard Creek watershed, Hutchinson Creek watershed. Lummi Natural Resources Department. Bellingham, Washington.

Watts, W.M. 1997. North Fork Nooksack River watershed: preliminary upslope erosion assessment. Lummi Natural Resources Department. Bellingham, Washington.

Watts, W.M. 1998. Middle Fork Nooksack River watershed: preliminary upslope erosion and channel assessment. Prepared for Lummi Natural Resources Department. Bellingham, Washington. 31 pp.

Washington Department of Ecology. 2000. Oblique Aerial Photos, Shorelands & Environmental Assistance Program.

Washington Department of Fisheries. 1975. A Catalog of Washington Streams and Salmon Utilization, Volume 1, Puget Sound. Washington Department of Fisheries. Olympia, WA.

Washington Department of Fish and Wildlife. 1996. Washington GAP Analysis Project GIS data.

WDFW and WWTIT (Washington Department of Fish and Wildlife, and Western Washington Treaty Indian Tribes). 1994. 1992 Washington State Salmon and Steelhead Stock Inventory (SASSI). Washington. Department of Fish and Wildlife, Olympia, 212 p. and 5 regional volumes.

WDFW and WWTIT (Washington Department of Fish and Wildlife, and Western Washington Treaty Indian Tribes). 2002. Salmonid Stock Inventory (SaSI), Washington Department of Fish and Wildlife and the Western Washington Treaty Indian Tribes, Olympia, WA.

WDFW and PNPTT (Washington Department of Fish and Wildlife and Point No Point Treaty Council). 2000. Summer Chum Salmon Conservation Initiative – An Implementation Plan to Recover Summer Chum in Hood Canal and Strait of Juan de Fuca Region. Washington Department of Fish and Wildlife. Olympia, WA. 800 pp.

Washington Department of Fish and Wildlife and Point No Point Treaty Tribes. 2005. Mid Hood Canal Chinook Recovery Planning Chapter.

Washington State Conservation Commission. 1999. Salmon habitat limiting factors final report. Water Resource Inventory Area 5, Stillaguamish Watershed. 83 pages.

Welch, D.W., Y. Ishida, K. Nagasawa, and J.P. Eveson. 1998. Thermal limits on the ocean distribution of steelhead trout (*Oncorhynchus mykiss*). North Pacific Anadromous Fish Commission. Bulletin 1:396-404.

Welch, D.W., Ward, B.R., Smith, B.D., and J.P. Evenson. 2000. Temporal and spatial responses of British Columbia steelhead (*Oncorhynchus mykiss*) populations to ocean climate shifts. Fisheries Oceanography 9: 17–32.

Welch, D.W., Rechisky, E.L., Melnychuk, M.C., Porter, A.D., Walters, C.J., Clements, S., Clemens, B.J., McKinley, R.S., and C. Schreck. 2008. Survival of migrating salmon smolts in large rivers with and without dams. PLoS Biology 6(10): e265.

Welch, D.W., Ward, B.R., and S.R. Batten. 2004. Early ocean survival and marine movement of hatchery and wild steelhead trout (*Oncorhynchus mykiss*) determined by an acoustic array: Queen Charlotte Strait, British Columbia, Deep-Sea Research II, 51: 897-909.

Whatcom Department of Public Works (DPW). 2006 Whatcom County Fish Passage Barrier Inventory Report

Whatcom Department of Public Works (DPW). 1999. Lower Nooksack River Comprehensive Flood Management Plan. September 1999 Draft Report to Whatcom County Flood Control Zone District. Bellingham, WA.

Williams, R.W., R.M. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization. Washington State Department of Fisheries.

Withler, I.L. 1966. Variability in life history characteristics of steelhead trout (*Salmo gairdneri*) along the Pacific Coast of North America. Journal of the Fisheries Research Board of Canada 23(3): 365-393.

Whitt, C. R. 1954. The age, growth, and migration of steelhead trout in the Clearwater River, Idaho. M.S. Thesis, University of Idaho, Moscow. 67 pp.

Wolcott, E. E. 1973. Lakes of Washington. Olympia: State of Washington Department of Ecology.

WRIA 1 Salmon Recovery Board. 2005a. WRIA 1 Salmonid Recovery Plan Preliminary Draft, Section 3 Technical background.

WRIA 1 Salmon Recovery Board. 2005b. Water Resource Inventory Area (WRIA) 1 Salmonid Habitat Restoration Strategy (Version 2.5a).

Wydoski, R.S. and R.R Whitney. 1979. Inland fishes of Washington. University of Washington Press, Seattle.

Zander, A.D. 1996. Road inventory for the South Fork Nooksack River watershed. Prepared for the Lummi Natural Resources Department, Bellingham, Washington. 54.

Zander, A.D. 1997. Road inventory for the North Fork Nooksack River watershed. Prepared for the Lummi Natural Resources Department, Bellingham, Washington. 60.

Zander, A.D. 1998. Road inventory and preliminary upslope erosion and channel assessment for the Middle Fork Nooksack River watershed. Prepared for the Lummi Natural Resources Department, Bellingham, Washington. 57.

Zaugg, W.S. and H.H. Wagner 1973. Gill atpase activity related to parr-smolt transformation and migration in steelhead trout (*Salmo gairdneri*): Influence of photoperiod and temperature, Comparative Biochemistry and Physiology Part B: Comparative Biochemistry 45(4):955-965.

Zimmerman, C.E., and G.H. Reeves. 2000. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otolith microchemistry. Canadian Journal of Fisheries and Aquatic Sciences 57:2152–2162.

Appendix

Puget Sound Steelhead Foundations Project

Puget Sound Steelhead, *Oncorhynchus mykiss*

NOAA-Fisheries Threshold Intrinsic Potential Model Assessment

By

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Northwest Indian Fisheries Commission
Salmon and Steelhead Habitat
Inventory and Assessment Program

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Contents

Introduction

The Puget Sound Steelhead Foundations Project is a cooperative agreement among the Puget Sound Partnership (PSP), Washington Department of Fish and Wildlife (WDFW, Northwest Indian Fisheries Commission (NWIFC), National Oceanic Atmospheric Administration (NOAA), Recreation and Conservation Office (RCO), and the Governor's Salmon Recovery Office (GSRO). The main purpose of the Foundations Project is to compile and provide baseline information for ecosystem based steelhead recovery planning, implementation, and decision-making. In partial fulfillment of the Foundations Project, the Puget Sound Partnership contracted the services of NWIFC to assess and map the results of the NOAA-Fisheries100,000-scale Threshold Intrinsic Potential (IP) model for Puget Sound steelhead and to integrate WDFW's 'natural' fish passage barrier datasets with model outputs.

There are two primary output objectives for this project. First, produce for a series of maps, one for each Water Resource Inventory Area (WRIA) within the Puget Sound steelhead distinct population segment (DPS). Each map depicting the results of the Threshold IP model overlaid with 'total blockages' from the WDFW natural barriers dataset. The second objective is assess what steps will be necessary to extend the Intrinsic Potential model from the 100,000-scale medium resolution National Hydrography Dataset (NHD) to the high resolution, 24,000-scale or larger, NHD. It is believed that a higher resolution model of the intrinsic potential of steelhead habitat will be more useful to local watershed level salmon recovery planning efforts.

Study Area

The Puget Sound steelhead distinct population segment (DPS) is comprised of streams in the river basins of the Strait of Juan de Fuca, Puget Sound, and Hood Canal, Washington, bounded to the west by the Elwha River (inclusive) and to the north by the Nooksack River and Dakota Creek (inclusive) (Figure 1). The DPS includes all naturally spawned anadromous winter-run and summer-run *O. mykiss* (steelhead) populations, the Green River natural and Hamma Hamma winter-run steelhead hatchery stocks (NOAA-Fisheries 2007).

Fig. 1. Puget Sound Steelhead DPS
(NOAA-Fisheries 2006)

Data Sources

Puget Sound Steelhead Threshold Intrinsic Potential Model (NOAA 2010)

The Puget Sound Steelhead Threshold Intrinsic Potential (IP) Model was created by Damon Holzer and George Pess of NOAA-Fisheries with guidance from the Puget Sound Technical Review Team (TRT) (NOAA-Fisheries 2009). The model approach and habitat curves were initially based on the Coast Oregon IP model (Burnett Et al. 2007). The Coast Oregon IP model was created to evaluate steelhead and *o. kisutch* (Coho) intrinsic potential habitat for the Oregon coast. Habitat curves from the Coast Oregon IP model are meant to represent habitat intrinsic potential for steelhead rearing habitat. Each stream reach score is the geometric mean of index values for flow, gradient, and confinement.

Upon review of the Puget Sound IP model, George Pess and other TRT members exchanged the Coast Oregon IP approach for a 'threshold' or 'matrix' IP approach. The two approaches differ in both design and variables used. The threshold IP approach is based on the combination of stream width, stream gradient and habitat type. In the threshold approach, low gradient (0-4%) and moderate width (3-50 m) stream habitats have the highest intrinsic habitat potential. While high gradient (>4%) sites of all widths have a low intrinsic habitat potential, and lake and tidal areas have extremely low to no intrinsic habitat potential (Table 1).

Table 1.

Stream Habitat Rating Thresholds (intrinsic habitat potential below natural barriers)				
		Stream width (bankfull)		
		0 - 3 m	**3 - 50 m**	**> 50 m**
Stream gradient	**0 - 4%**	**low**	**high**	**moderate**
	>4%	**low**	**low**	**low**
Lakes and Tidal Zones		**Extremely Low**		

Puget Sound habitats selected for threshold IP analysis include those that meet the following criteria:

1. gradient <= 0.20
2. bankfull width >= 2 m,
3. confinement and flow > 0,
4. downstream of in-stream gradient blocks
5. downstream of documented waterfalls

Crucial Natural Barriers_version-4 (NOAA 2010)

Damon Holzer of NOAA-Fisheries created a natural barrier layer that included in-stream gradient blocks and documented natural barriers from the Puget Sound stream catalog (Williams Et al. 1975), WDFW biologists, Washington State Conservation Commission Salmon Habitat Limiting Factors Reports (WSCC 2005), StreamNet (2011) and Waterfalls Northwest (NWS 2011). This barrier file was used to make upstream gradient and waterfall blockages of steelhead migration for the Threshold IP model.

Washington State Department of Fish and Wildlife Natural Barriers (WDFW 2011)

Information for natural barriers is provided on the type and degree of blockage, location, and data source. Fish passage natural barriers data are compiled from a variety of sources including WDFW Fish Passage and Diversion Screening Inventory database (FPDSI), Limiting Factors Analysis reports, WDFW biologists, counties, conservation districts, Washington Department of Ecology, U.S. Forest Service, U.S. Geological Survey, Tribes, and others (WDFW 2011).

Natural Barrier Blockage Types:

1. Total Barrier: Effectively blocks all life stages of all species to upstream migration.
2. Partial Barrier: Blocks some species or life stages to upstream migration.
3. Non-Barrier: No blockage to upstream migration.
4. Unknown: Insufficient information to determine blockage status.
5. Fishway: Base structure has been modified to provide fish passage.
6. Non-Fish Bearing: Structure located on a non-fish bearing natural drainage.

WDFW Fish Distribution (WDFW 2004)

The FISH DISTRIBUTION layer contains fish presence and use type information for salmon, steelhead, and Bull Trout/Dolly Varden in Washington streams. Where use type information (known spawning or known juvenile rearing) exists, it is displayed instead, with spawning shown in preference to rearing where they overlap. Fish distribution sources include WDFW StreamNet Project; Washington Conservation Commission's Limiting Factors Analysis (LFA) Project; WDFW Bull Trout 2000 Update.

Fish Presence and Use Attributes:

1. Presence-Documented: Verified presence.
2. Presence-Presumed: Best professional judgment of presence, without verification.
3. Presence-Potential: Potential presence based on GIS modeled characteristics
4. Spawning: Verified use of habitat for spawning.
5. Rearing: Verified use of habitat for rearing.

NWIFC-WSCC LFA Fish Distribution (Cutler Et al. 2003)

This salmonid distribution data is a collection of several datasets combined into one standardized GIS dataset. These projects include: the Washington Conservation Commission’s (WCC) work on the Salmon Habitat Limiting Factors Analysis (LFA) and the Conservation Reserve Enhancement Program (CREP) and the Northwest Indian Fisheries Commission’s (NWIFC) Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP).

Fish Presence Attributes:

1. Known Distribution: Verified presence.
2. Presumed Distribution: Best professional judgment of presence without verification.
3. Potential Distribution: Potential anadromous salmon distribution based on SSHIAP mapped stream gradients.

NHDPlus, 100,000-scale (Horizon Systems 2011)

The NHDPlus Version 1.0 is an integrated suite of application-ready geospatial data sets that incorporate many of the best features of the National Hydrography Dataset (NHD) and the National Elevation Dataset (NED). The NHDPlus includes a stream network (based on the 1:100,000-scale NHD), improved networking, naming, and "value-added attributes" (VAA's). NHDPlus also includes elevation-derived catchments (drainage areas) produced using a drainage enforcement technique first broadly applied in New England, and thus dubbed "The New-England Method". This technique involves "burning-in" the 1:100,000-scale NHD and when available building "walls" using the national Watershed Boundary Dataset (WBD). The resulting modified digital elevation model (HydroDEM) is used to produce hydrologic derivatives that agree with the NHD and WBD.

NHD High Resolution, 24,000-scale or larger (USGS 2010)

The National Hydrography Dataset (NHD) is a vector geospatial theme for surface water hydrography obtained from topographic maps and additional sources. It is available Nationwide as medium resolution at 1:100,000-scale, and as high resolution at 1:24,000-scale or better. In Alaska, the NHD is available at 1:63,360-scale. A few “local resolution” areas also are available at varying scales. The hydrography of the United States is organized by drainage areas. The subbasin [(8-digit Hydrologic Unit Code (HUC)] drainage area is the most practical area for high resolution NHD. Subregions (4-digit HUCs) are composed of varying numbers of subbasins. The NHD is available in Environmental Systems Research Institute (ESRI) personal geodatabase format known as NHDinGEO, a file-based geodatabase format, and in ESRI shapefile format known as NHDGEOinShape. The NHD is organized by hydrologic units, but can be downloaded in various extents.

Methods

Objective 1: Creating WRIA based steelhead threshold IP maps with natural barrier locations.

Our first objective is to produce a series of maps depicting the modeled intrinsic potential of steelhead habitat, one for each Water Resource Inventory Area (WRIA) within the Puget Sound steelhead distinct population segment (DPS). To symbolize the data and calculate intrinsic potential habitat summaries, we add two new fields to the attribute table of the Puget Sound threshold IP dataset: [CartCode] and [Miles]. The [CartCode] field is based on the stream habitat rating thresholds that were derived by NOAA-Fisheries and the TRT (see Table 1). The [Miles] field stores segment length in miles, and is based on the original GIS generated [ShapeLength] field.

[CartCode] is calculated from the [NEWRATESB] field in the threshold IP data attribute table, with the exception of a new code that is added to symbolize stream reaches that are naturally blocked from steelhead utilization (Table 2). Naturally blocked segments are queried from the threshold steelhead IP dataset using the [Block_Natu] and the [Block_Grad] fields. The [Block_Natu] and [Block_Grad] fields are used to select a subset of the [NEWRATESB] = 0 stream reaches that are naturally blocked by waterfalls and steep gradients, this subset is re-coded [CartCode] = 5. This is done to represent naturally blocked habitat separate from naturally poor habitat.

Table 2.

NEWRATESB	CartCode	Steelhead Habitat Ratings Thresholds
0	0	Extremely Low
1	1	Low
2	2	Moderate
3	3	High
0 ([Block_Grad] =1 Or [Block_Natu] =1)	5	Not utilized by Anadromous Salmon

In the final WRIA maps threshold steelhead IP data are overlaid by complete natural barriers. The natural barriers shown on the map are a combination ‘total’ gradient, cascade and waterfall barriers. Natural barrier data was compiled from the WDFW natural barrier dataset (WDFW 2011) and the natural barriers compiled by NOAA-Fisheries for use in the threshold IP model

(NOAA-Fisheries 2010). The natural barriers on the map are those that snapped to the medium resolution (100,000-scale) NHD streamline.

In many cases natural barriers are mapped above the steelhead habitat in the upper reaches of the watershed. These barriers were included on the WRIA maps. In a few cases, potential steelhead habitat stops with no associated natural barrier point. These are gradient stoppages that were not included in the natural barrier databases, but that were derived from the NHDPlus hydrography.

In addition to the IP model and natural barrier cartography, the final WRIA maps include summary bar graphs showing the [Miles] of steelhead threshold IP habitat by [CartCode] for each WRIA. The summary tables were created in ArcMap using the [Miles] field to represent stream length, and [CartCode] as the dissolve or summarizing field representing intrinsic potential. The summary tables were exported to Microsoft Excel to create bar graphs. The bar graphs are also used as legends for the final WRIA threshold IP maps.

Objective 2: Assess what steps will be necessary to extend the Intrinsic Potential model from the Medium Resolution 100,000-scale National Hydrography Dataset (NHD) to High Resolution 24,000-scale or larger NHD.

NOAA-Fisheries completed the Puget Sound steelhead threshold IP model including natural barrier integration using medium resolution NHD data. This provides a 100,000- scale depiction of the intrinsic potential for steelhead habitat in the Puget Sound. It can be used to assist planners visualizing and comparing relative intrinsic steelhead habitat potential between watersheds in the Puget Sound. It will be useful as an overview dataset for regional planning, for navigating the federal regulatory framework and in the development of communication tools for citizen outreach across the Puget Sound. However, it is too coarse of a dataset to be useful for local governments targeting regulation and enforcement, or for local watershed lead entity groups targeting conservation, protection and restoration.

The Washington State Department of Ecology (WAECY) has already moved hydrographic GIS data for the entire state to high resolution NHD (24,000-scale or larger). Currently, if anyone goes to the WAECY GIS data download website to acquire hydrography they are re-directed to the NHD website. WDFW and NWIFC both recognize with WAECY that the future for freshwater related GIS data collaboration is through high resolution hydrography NHD, and as a result, both organizations are in a long-term process to move their geographic based information to NHD. With WAECY, WDFW and NWIFC all committed to using high resolution NHD, the best option for creating a higher resolution threshold IP is to re-model threshold IP on high resolution NHD.

As part of Objective 2, we will compile existing natural barrier data (NOAA-Fisheries 2010 and WDFW 2011) into a single Puget Sound steelhead natural barrier dataset and steelhead fish distribution data (Cutler Et al. 2003 and WDFW 2010) into a single Puget Sound steelhead fish distribution dataset. Upon compilation, we will snap both of the datasets to high resolution NHD streamlines.

All points within the compiled natural barrier and fish distribution datasets that fall within 80-feet of the NHD High Resolution (24,000-scale or better) hydrography are coded [Snap] = 1, and automatically snapped to NHD using ArcGIS snapping tools. All points outside of 80-feet are individually evaluated and if they can be logically moved they are coded [Snap] = 2 and snapped to NHD. If the barrier or fish distribution points cannot be logically moved, they are coded [Snap] = 3 and left unsnapped.

Results

Objective 1:

Maps have been created for WRIA 1 through WRIA 18. Each map includes Puget Sound steelhead threshold IP streamlines symbolized to show modeled intrinsic potential of steelhead habitat within a particular WRIA. In addition to the maps, amounts of modeled steelhead habitat have been summarized in bar graphs by miles of stream length based on intrinsic potential. The most total intrinsic potential for Puget Sound steelhead was modeled in the WRIA 3 (Lower Skagit/Samish) and WRIA 4 (Upper Skagit), followed by WRIA 7 (Snohomish), and WRIA 1 (Nooksack). The least intrinsic potential is in WRIA 13 (Deschutes). See Table 3 for full results.

To view the map results, see the accompanying *Appendix: Maps of modeled Puget Sound steelhead threshold intrinsic potential for WRIA(s) 01 through WRIA 18.*

Objective 2:

All of the natural barrier data (NOAA-Fisheries 2010 and WDFW 2011) has been compiled into one Puget Sound Natural Steelhead Barrier dataset, and snapped to high resolution NHD streamlines where appropriate. All of the known and presumed steelhead distribution data points (WDFW 2011 and Cutler Et al. 2003) have been compiled into one Puget Sound steelhead distribution dataset and snapped to high resolution NHD where appropriate. SSHIAP has compiled all of the final data into a Puget Sound Steelhead ArcGIS geodatabase and it is currently stored at the NWIFC offices.

Table 3. WRIA 01 – 18: Total stream miles of modeled intrinsic potential of Puget Sound steelhead habitat

WRIA	Name	Extremely Low	Low	Moderate	High	Total IP Habitat
1	Nooksack	55	160	40	370	624
2	San Juan	6	69	0	1	76
3 and 4	Lower Skagit/ Samish and Upper Skagit	117	227	153	287	784
5	Stillaguamish	39	102	40	156	337
6	Island	7	39	0	0	46
7	Snohomish	99	130	69	347	645
8	Cedar-Sammamish	54	85	0	180	319
9	Duwamish-Green	10	95	55	121	281
10	Puyallup-White	9	115	58	190	372
11	Nisqually	9	38	37	116	200
12	Chambers-Clover	4	5	0	29	38
13	Deschutes	5	5	0	27	37
14	Kennedy-Goldsborough	16	31	0	133	180
15	Kitsap	18	117	0	234	369
16	Skokomish-Dosewallips	11	43	5	83	142
17	Quilcene-Snow	26	99	0	31	156
18	Elwha-Dungeness	11	81	17	57	166

Discussion

NOAA-Fisheries produced a valuable ‘foundation’ layer in the Puget Sound steelhead threshold intrinsic potential habitat dataset. It uses medium resolution (100,000-scale) NHD data to comprehensively map potential steelhead habitat for all of the steelhead bearing watersheds in the Puget Sound steelhead distinct population segment (DPS). It also provides a data model for incorporating natural barriers to map steelhead utilization in potential habitats that are not restricted by waterfalls and steep gradients.

At a medium resolution, the threshold IP model results can be used for discussing the conditions of the Puget Sound steelhead DPS to national and international audiences. The threshold IP model data is useful for national, regional and state-level recovery planners, as they establish perspective on potential steelhead habitat utilization in the Puget Sound. However, a medium resolution (100,000-scale) model is too coarse for optimum use in local level salmon recovery planning.

Moving the threshold IP model from medium resolution to higher resolution NHD hydrography will provide a dataset that is more useful for local level salmon recovery planners, because the smaller streams that are at the heart of their knowledge will be visible for them to reflect upon. In turn, if local level salmon recovery professionals are using the high resolution steelhead threshold IP data, their knowledge will lead them to find errors in the modeled data, and their error finding provides the best opportunity to improve the high resolution steelhead threshold IP dataset for the region.

Modeling steelhead threshold IP to high resolution NHD has not been done, but the data needed to do so is now available, in a consistent format, for the entire Puget Sound steelhead DPS. To use the threshold IP approach with high resolution NHD will require modeling stream gradient, stream width, and identifying lake and tidal zone habitat types. The high resolution NHD is built upon a topologically connected GIS data model and 10-meter raster digital elevation data is available for the extent of the Puget Sound DPS, so modeling both stream gradient and stream width can be done relatively systematically for the high resolution NHD streamlines. Water bodies including lakes, ponds, wetlands and tidal zones are all part of the high resolution NHD dataset, and can be used to identify lakes and tidal zones.

Once the high resolution NHD streamlines are attributed for natural barriers, stream width, stream gradient, lakes and tidal zones the Puget Sound steelhead threshold IP model can be applied, and the [NEWRATESB] and [CartCode] fields can be calculated. This would complete the process of moving the steelhead threshold IP model from medium resolution NHD to high resolution NHD. The high resolution steelhead threshold IP outputs combined with WDFW and NWIFS-WSCC Fish Distribution data (WDFW 2010 and Cutler Et al. 2003) would provide the most comprehensive steelhead distribution dataset available in the Puget Sound region.

To comprehensively and efficiently integrate local level information into the Puget Sound steelhead threshold IP data will require a web-GIS platform. The web-GIS should include natural barriers, known fish distribution, presumed fish distribution and high resolution steelhead threshold IP data. It needs to be a place to view the data, and a place to edit the data. Edits need to be incorporated into the viewable data in near real-time.

It has always been known that the best habitat information resides in the knowledge of those working at the local level. Readily available web-GIS tools allow for the incorporation of that knowledge in a comprehensive, efficient and affordable fashion. Still, local level participants have to find meaning in the information being served if they are going to be asked to contribute, thus moving the IP model from medium to high resolution NHD remains a necessary first step towards engaging locals in the process of improving the IP model.

Acknowledgements

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Literature Cited

Cutler, J. B. Johnson. R. McFarlane. 2003. Combined LFA/SSHIAP Fish Distribution Coverages and Data Tables.

Horizon Systems. 2011. NHDPlus 100,000-scale. http://www.horizon-systems.com/nhdplus/

NOAA-Fisheries. 2006. Puget Sound Steelhead Distinct Population Segment GIS polygon. http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm

NOAA-Fisheries. 2007. Description of Puget Sound Steelhead Distinct Population Segment. http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Steelhead/STPUG.cfm

NOAA-Fisheries. 2009. Puget Sound Steelhead Threshold Intrinsic Potential Model. NOAA-Fisheries. Seattle, WA Contact: Damon.holzer@noaa.gov or George.pess@noaa.gov

NOAA-Fisheries. 2010. Crucial Natural Barriers_Version 4. NOAA-Fisheries. Seattle, WA Contact: Damon.holzer@noaa.gov

NWS. 2011. Waterfalls Northwest. www.waterfallsnorthwest.com

StreamNet. 2011. StreamNet: Fish Data for the Northwest. http://www.streamnet.org/

USEPA, USGS. 2005. National Hydrography Dataset Plus Version 1.0 Metadata. ftp://ftp.horizon-systems.com/NHDPlus/documentation/metadata.pdf

USGS. 2010. National Hydrography Dataset 24K Model Version 2.0. http://nhd.usgs.gov/data.html

WDFW. 2011. Fish Passage Natural Barriers. Washington Department of Fish and Wildlife. Olympia, WA. http://wdfw.wa.gov/mapping/salmonscape/index.html

Williams, R. Walter. R.M. Laramie. J.J. Ames. 1975. A Catalog of Washington Streams and Salmon Utilization, Volume 1, Puget Sound Region. Washington Department of Fisheries. Olympia, WA.

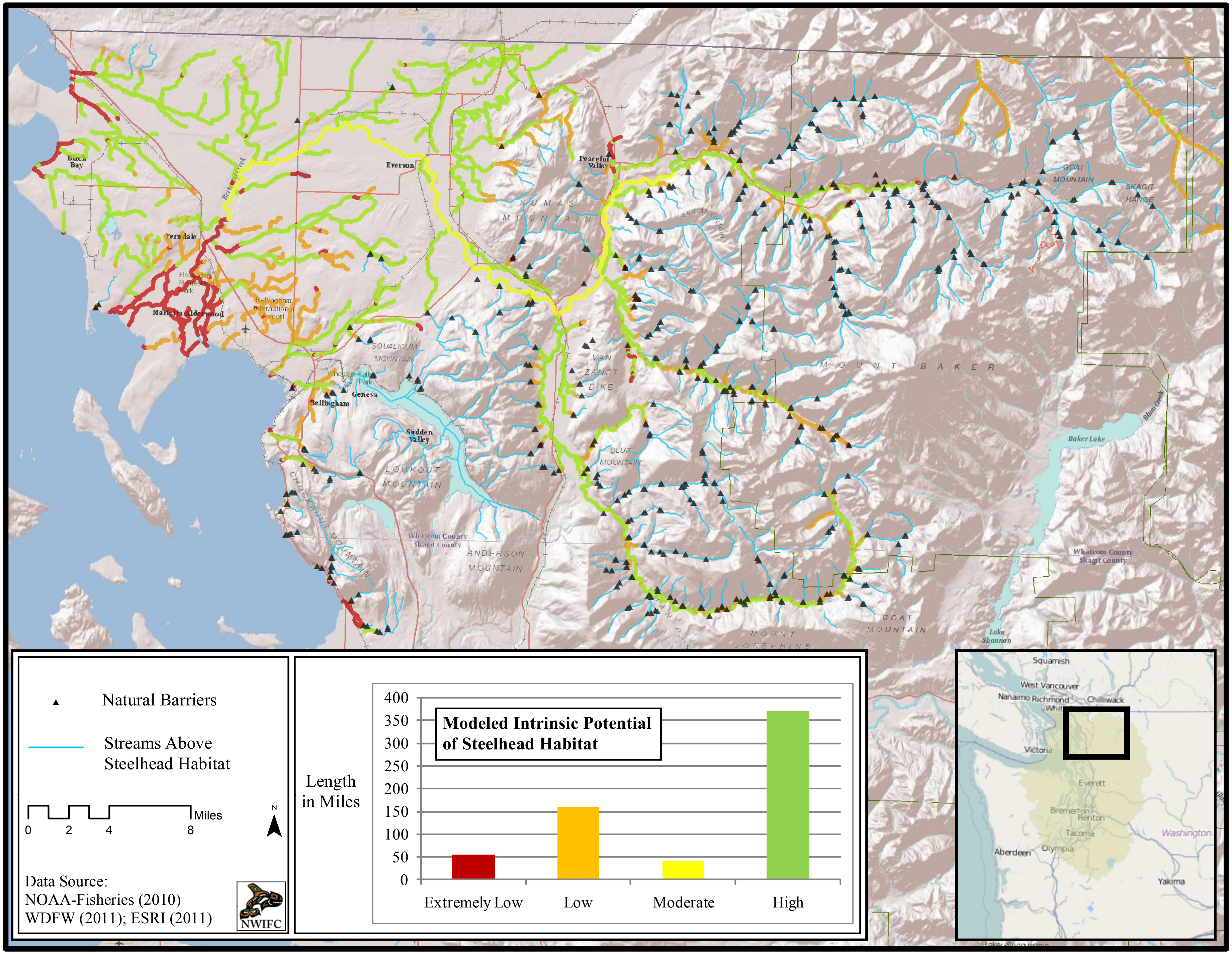
WSCC. 2005. Salmon Habitat Limiting Factors Reports. Washington State Conservation Commission. Olympia, WA. http://www.scc.wa.gov/index.php/174-Salmon-Habitat-Limiting-Factors-Reports/View-category/Page-6.html

APPENDIX

Maps of Modeled Puget Sound Steelhead Threshold Intrinsic Potential for WRIA 01-18.

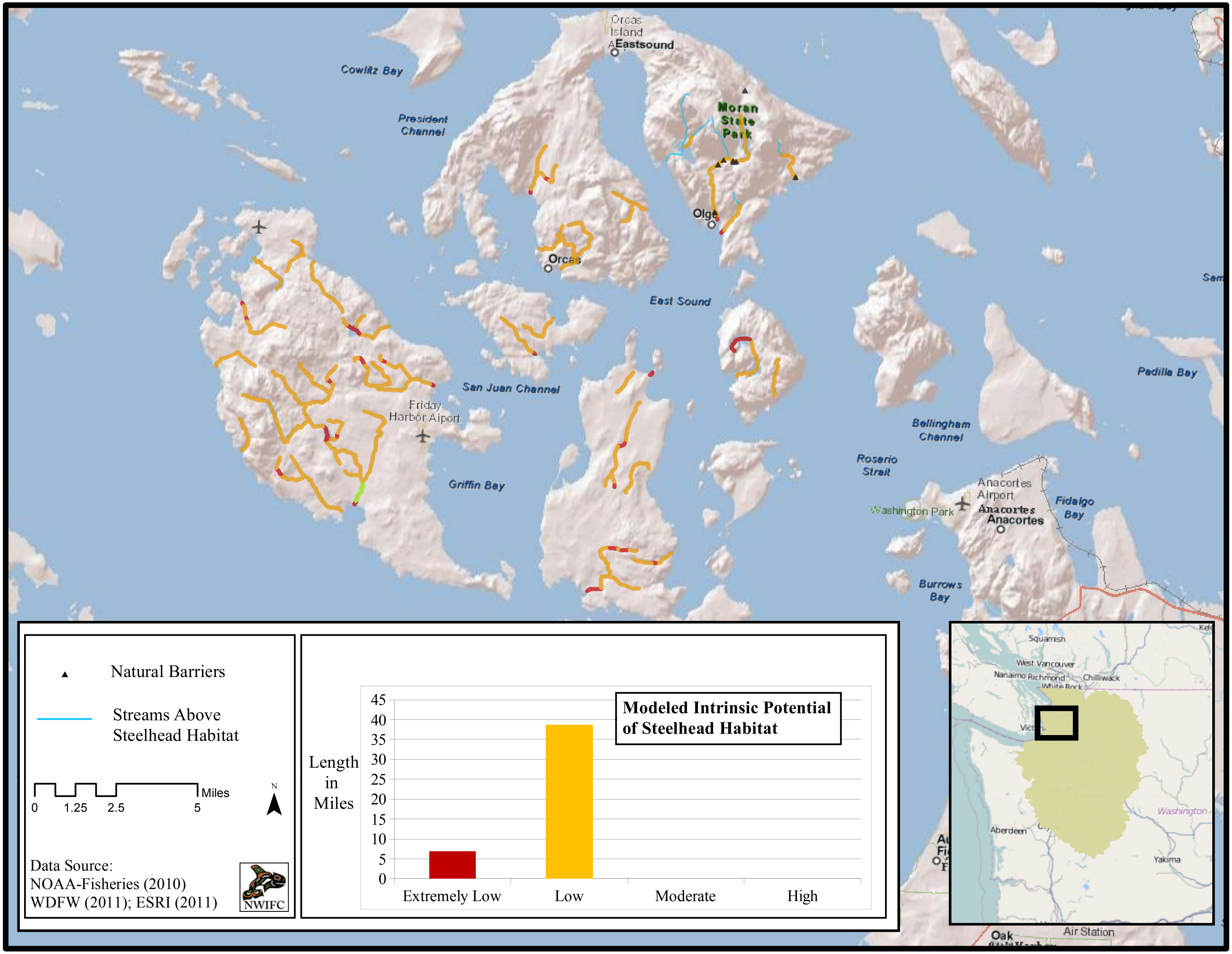
WRIA #	WRIA Name
01	Nooksack
02	San Juan
03 & 04	Lower Skagit-Samish & Upper Skagit
05	Stillaguamish
06	Island
07	Snohomish
08	Cedar-Sammamish
09	Duwamish-Green
10	Puyallup-White
11	Nisqually
12	Chambers-Clover
13	Deschutes
14	Kennedy-Goldsborough
15	Kitsap
16	Skokomish-Dosewallips
17	Quilcene-Snow
18	Elwha-Dungeness

Map 1. Modeled instrinsic potential of steelhead habitat in WRIA 01 (Nooksack)



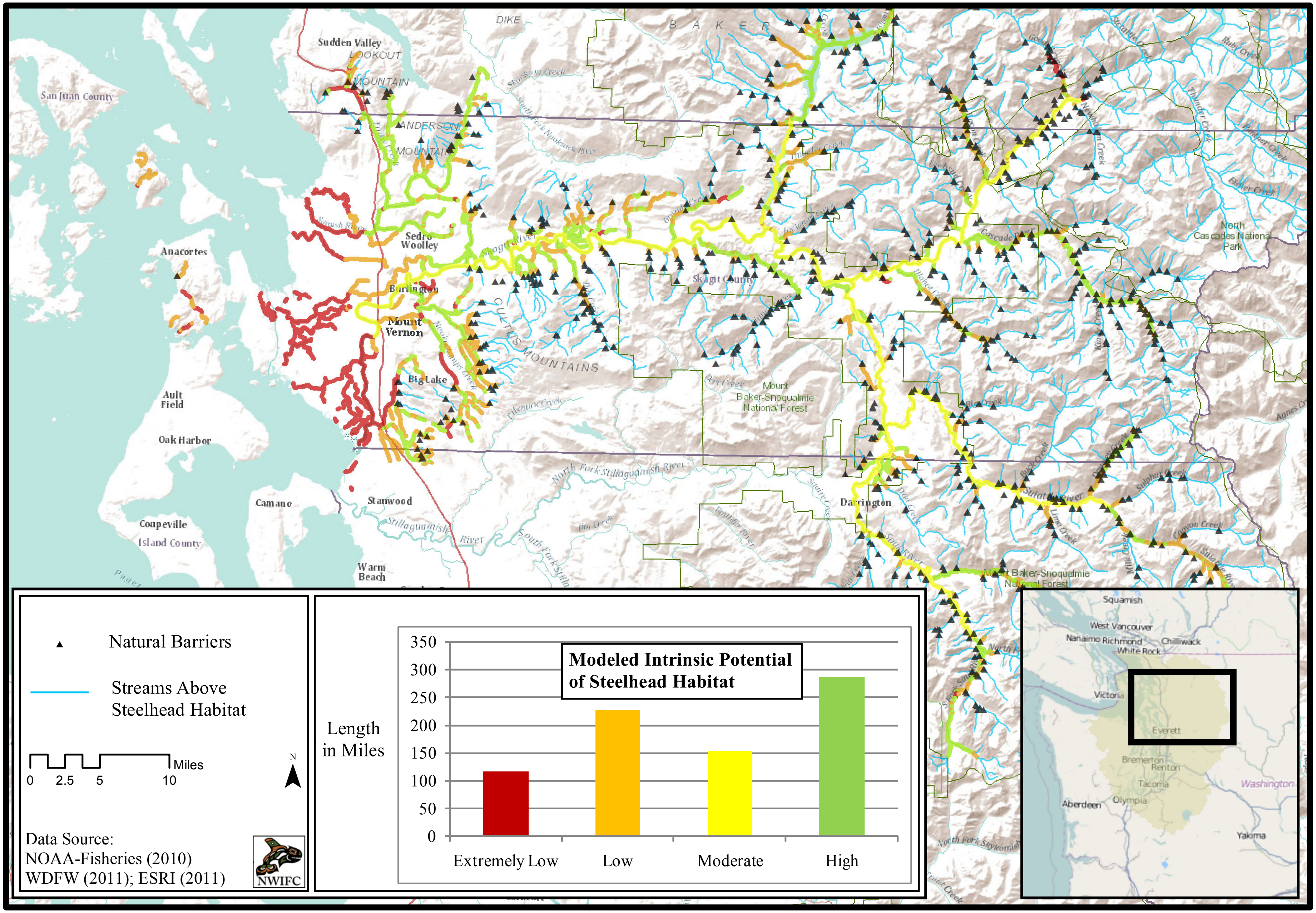
Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 2. Modeled instrinsic potential of steelhead habitat in WRIA 02 (San Juan)

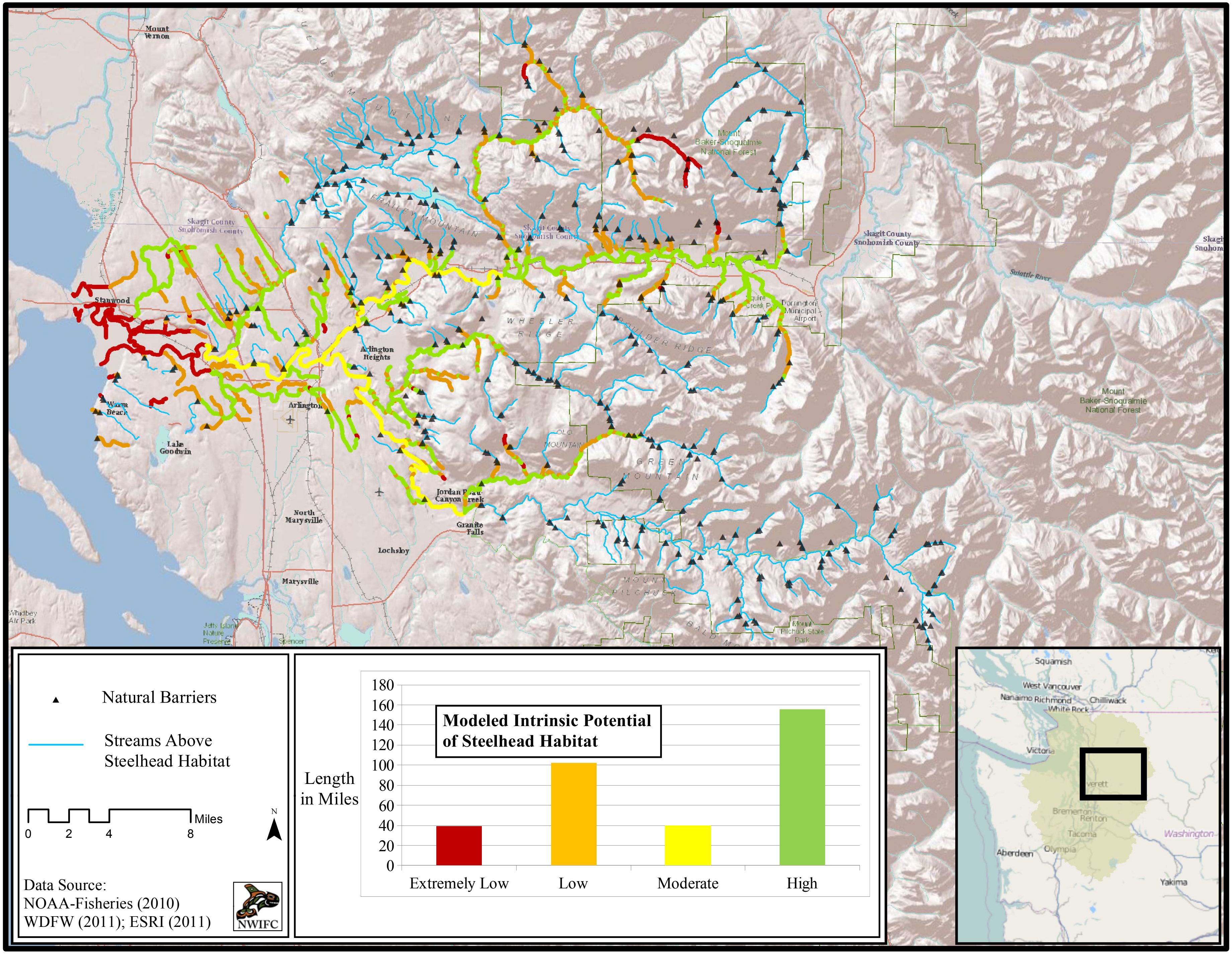


Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 3. Modeled instrinsic potential of steelhead habitat in WRIA 03 (Lower Skagit/ Samish) and WRIA 04 (Upper Skagit)

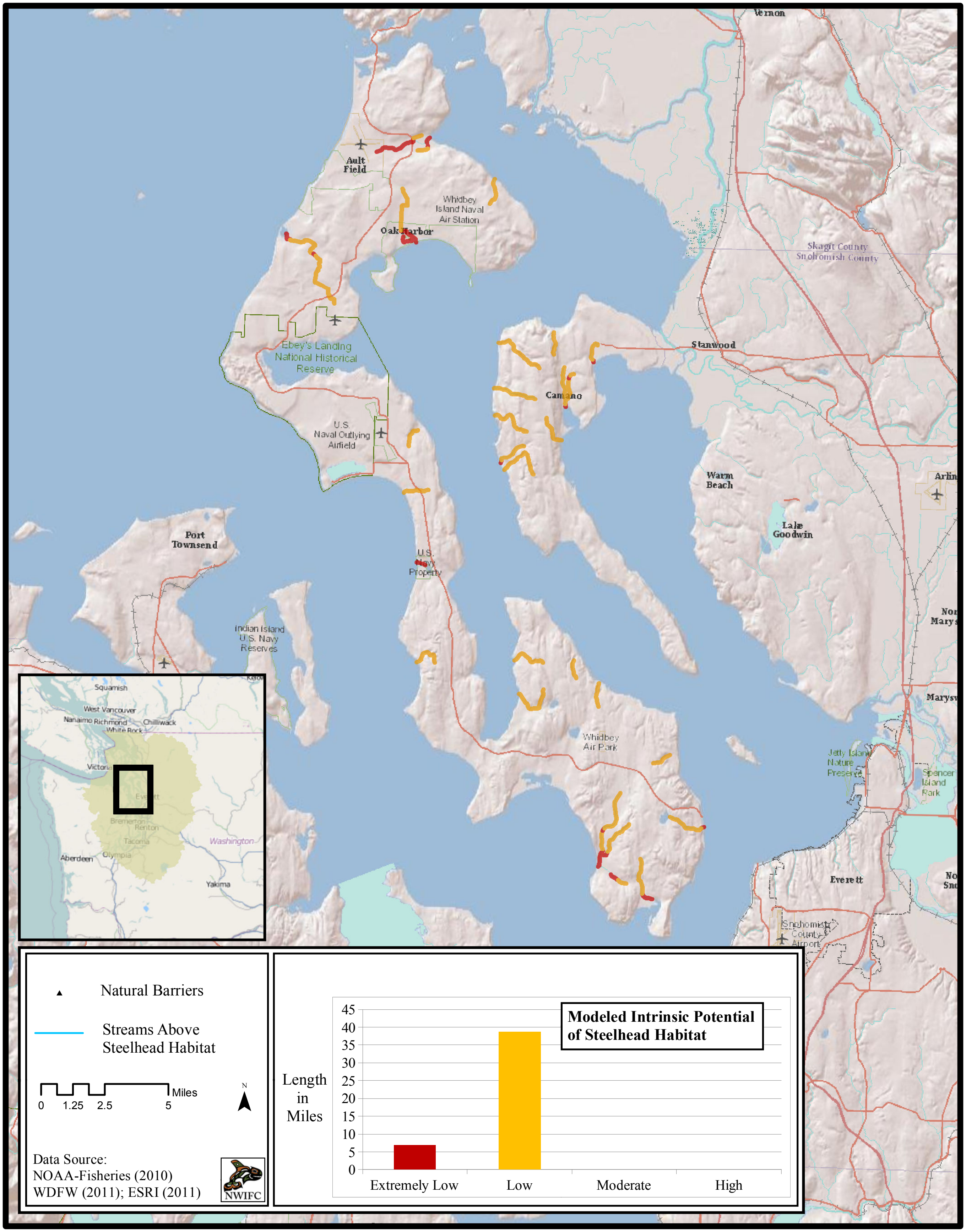


Map 4. Modeled instrinsic potential of steelhead habitat in WRIA 05 (Stillaguamish)

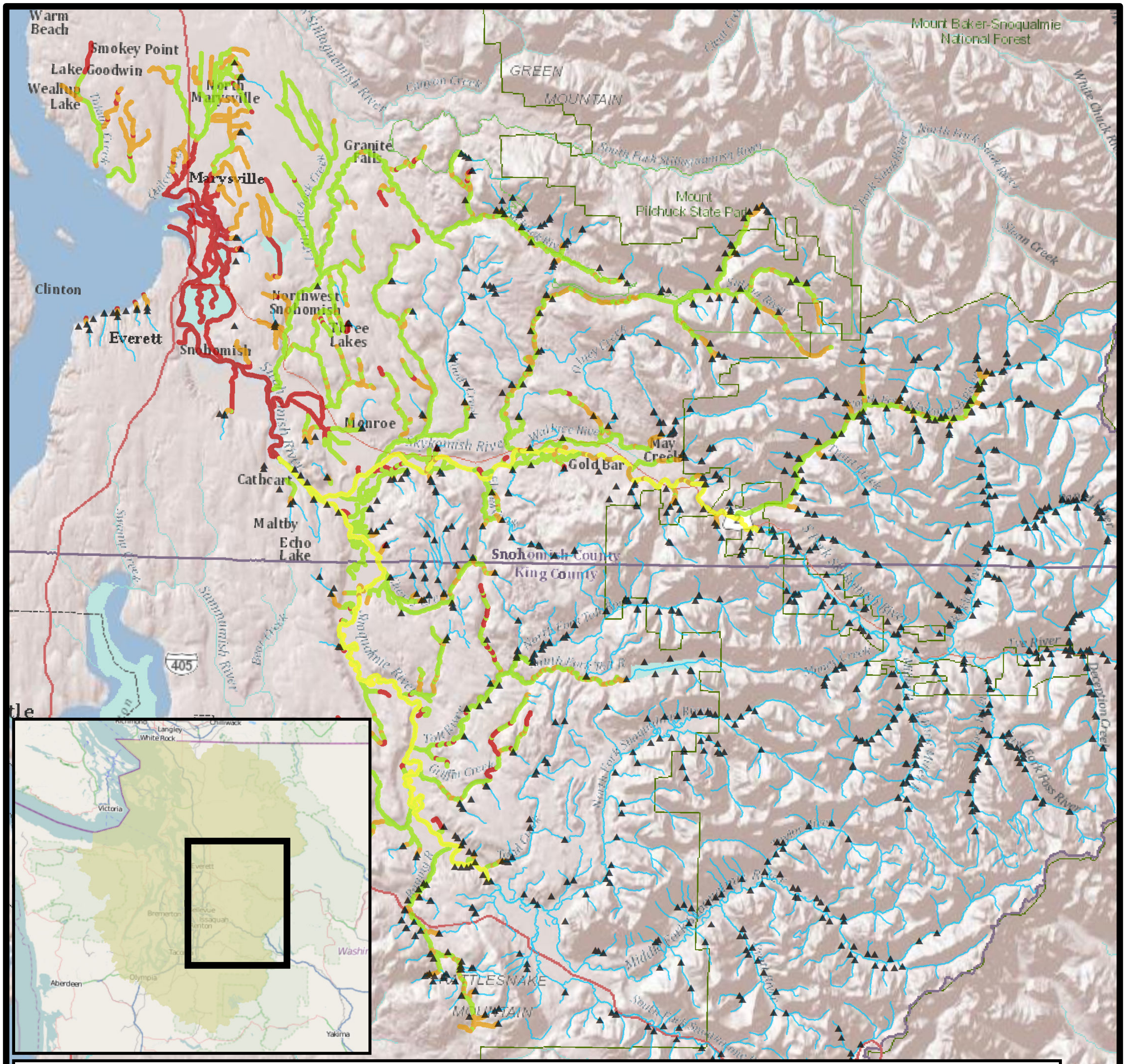


Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 5. Modeled instrinsic potential of steelhead habitat in WRIA 06 (Island)



Map 6. Modeled instrinsic potential of steelhead habitat in WRIA 07 (Snohomish)



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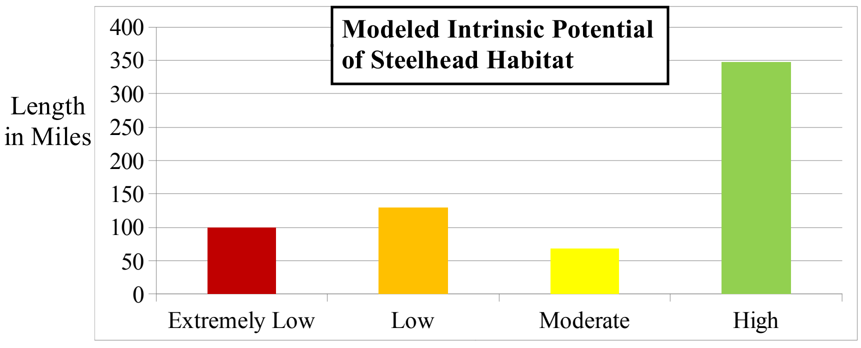
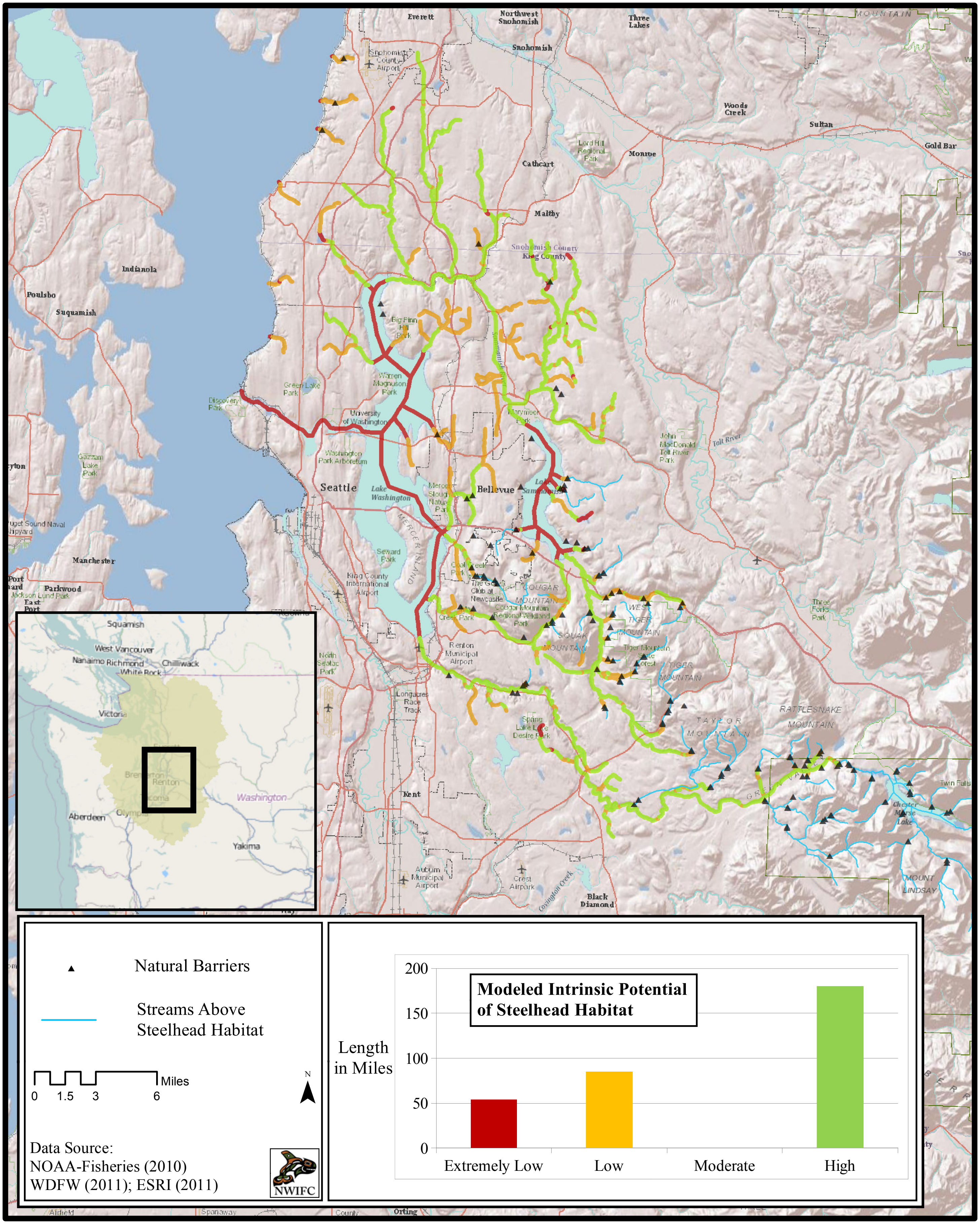
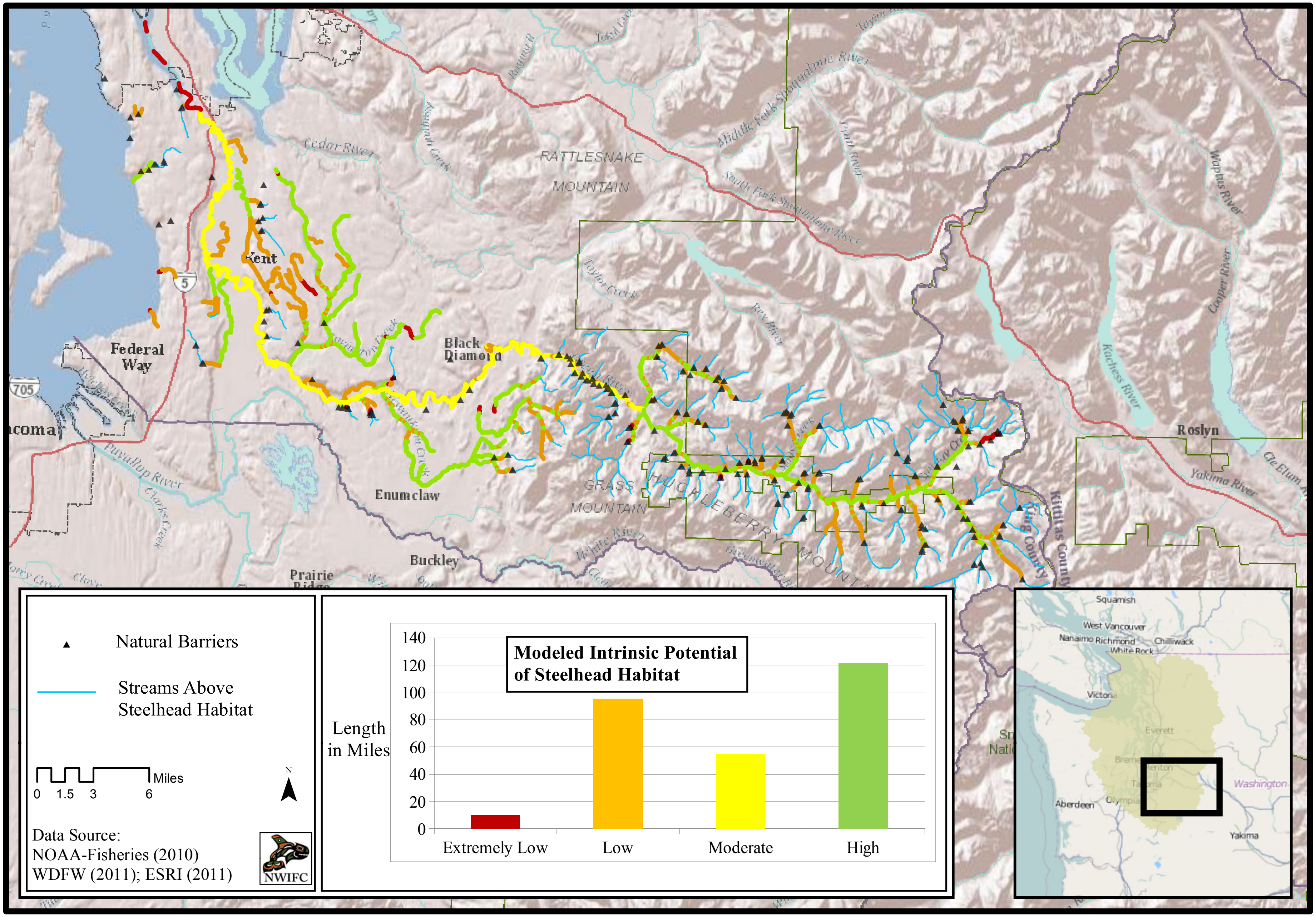
WDFW (2011); ESRI (2011)



Map 7. Modeled instrinsic potential of steelhead habitat in WRIA 08 (Cedar-Sammamish)

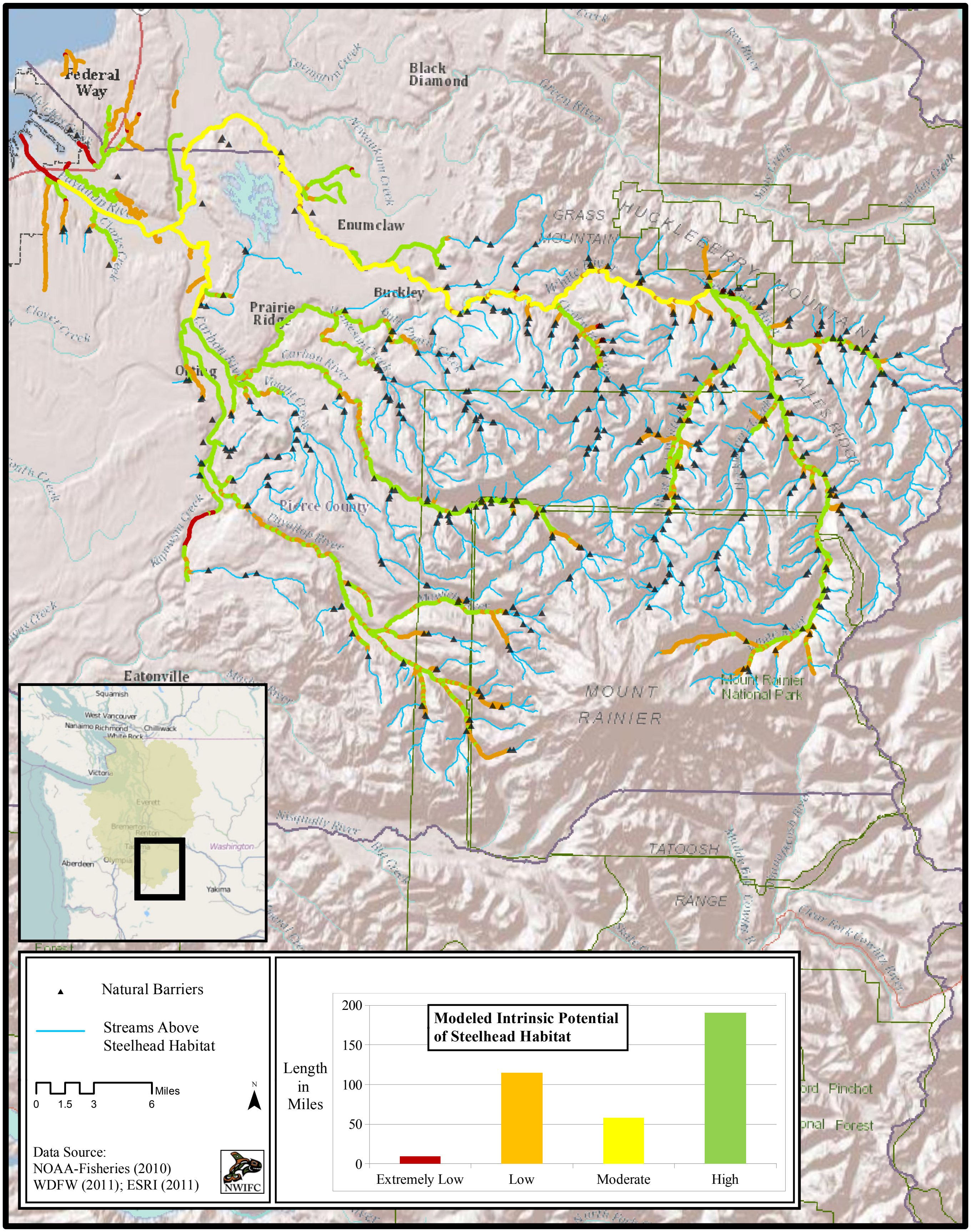


Map 8. Modeled instrinsic potential of steelhead habitat in WRIA 09 (Duwamish-Green)

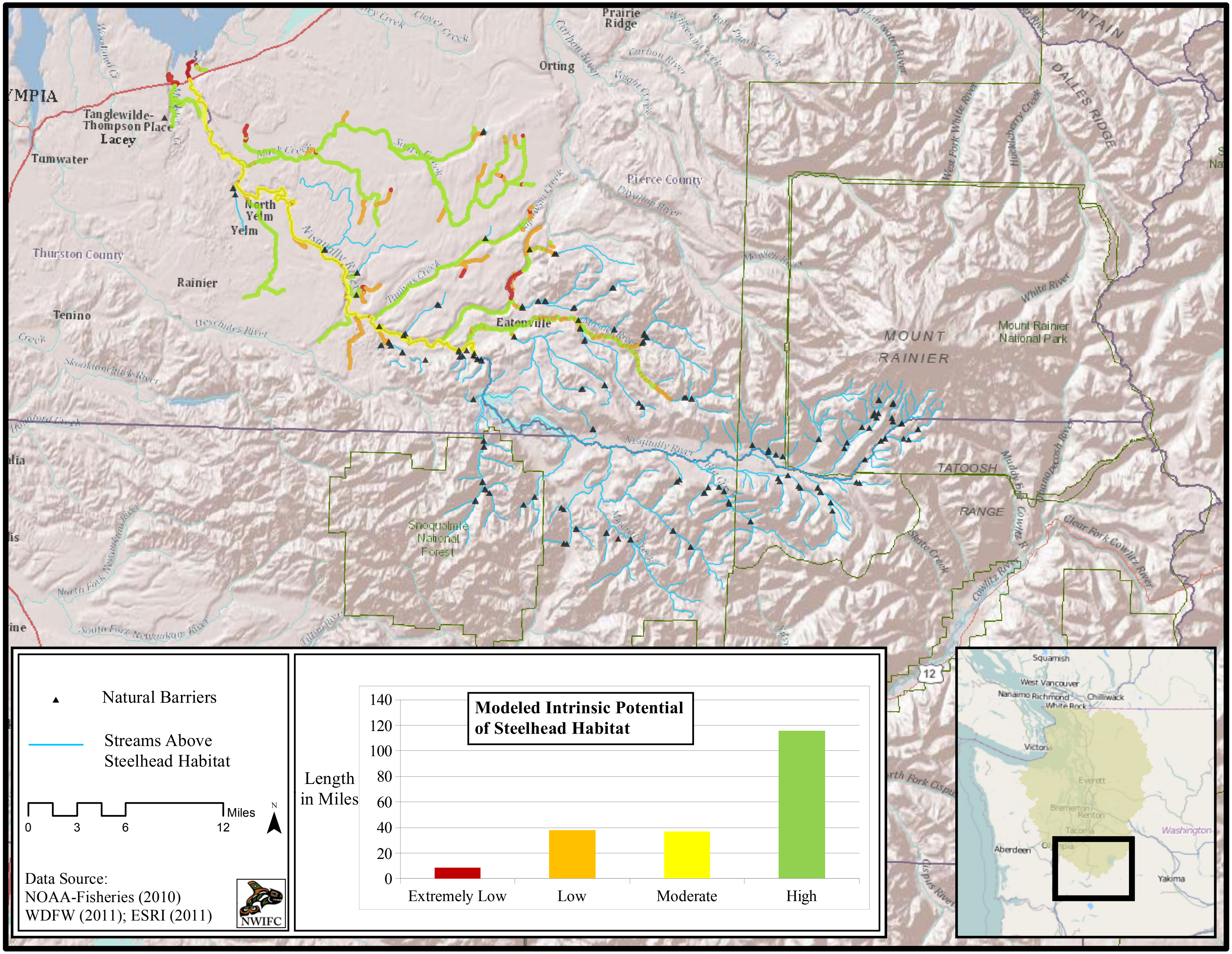


Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

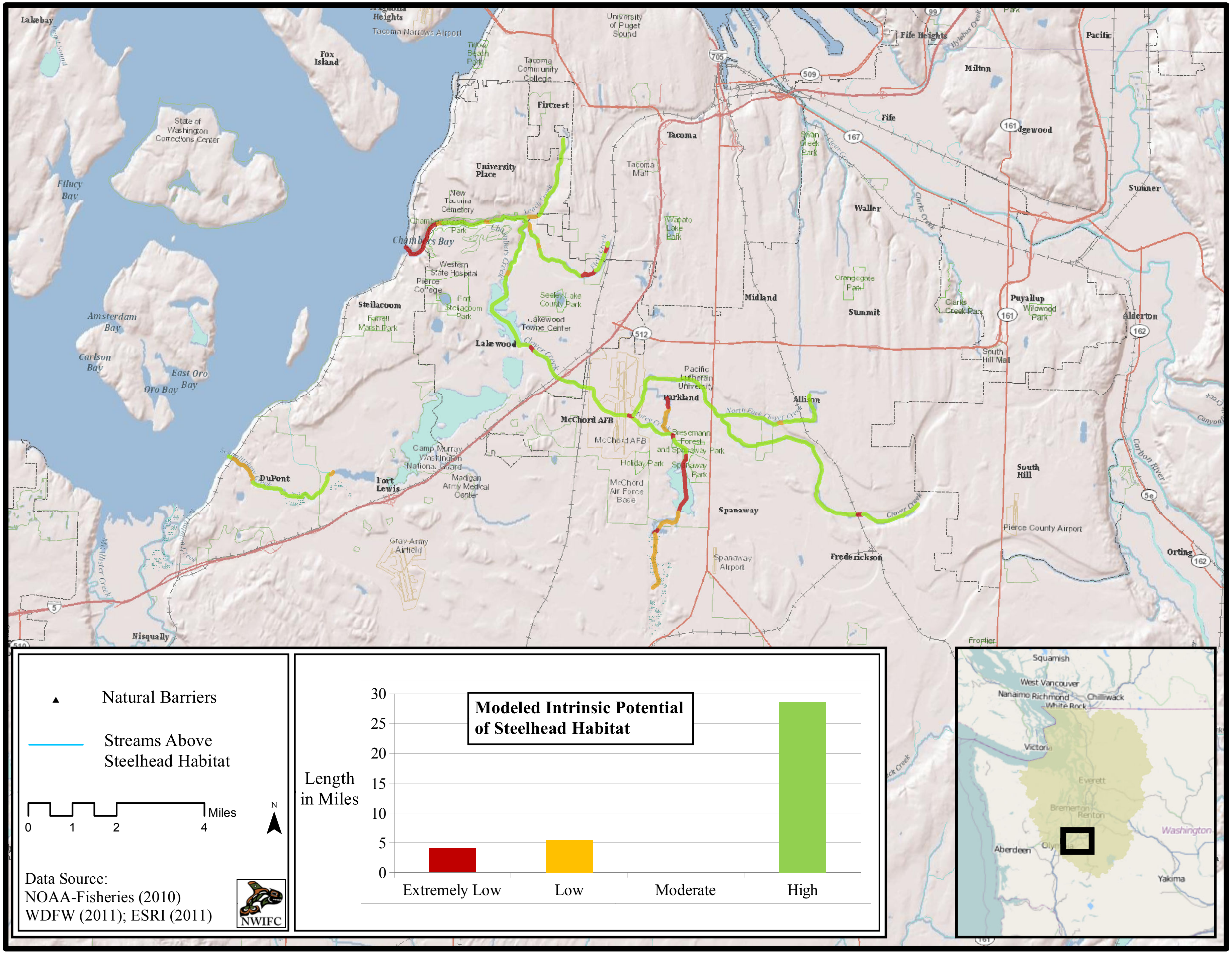
Map 9. Modeled instrinsic potential of steelhead habitat in WRIA 10 (Puyallup-White)



Map 10. Modeled instrinsic potential of steelhead habitat in WRIA 11 (Nisqually)

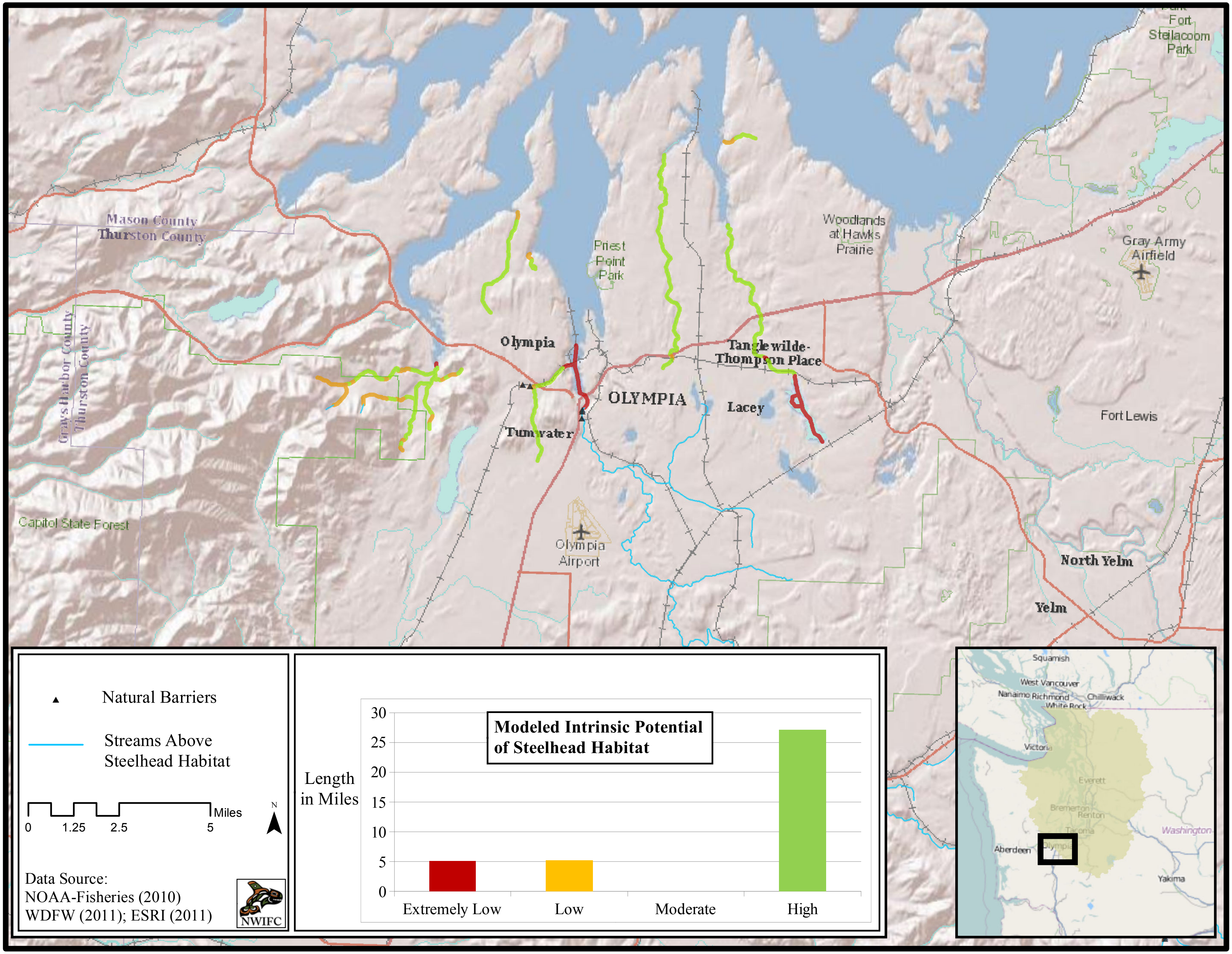


Map 11. Modeled instrinsic potential of steelhead habitat in WRIA 12 (Chambers-Clover)



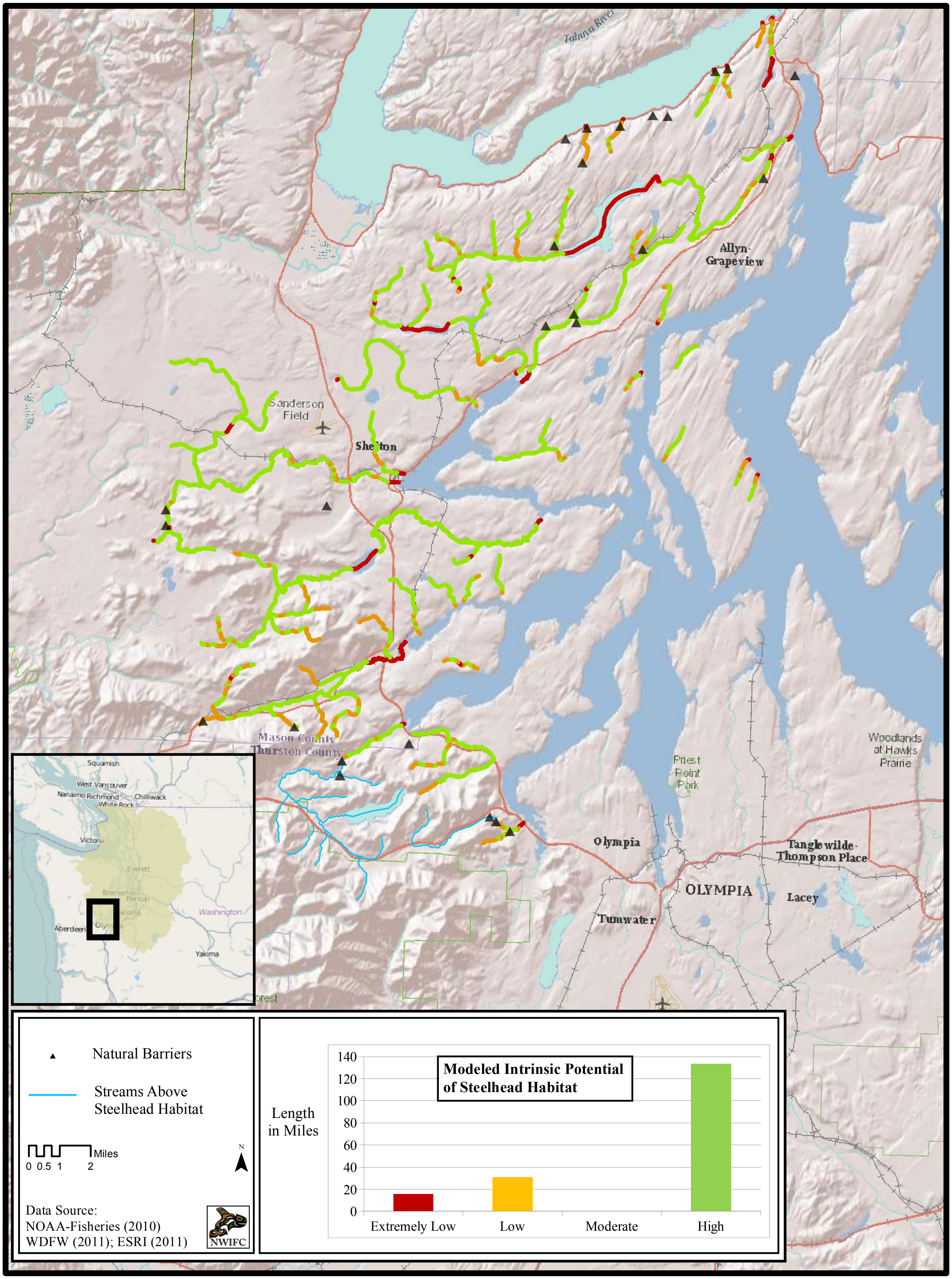
Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 12. Modeled instrinsic potential of steelhead habitat in WRIA 13 (Deschutes)

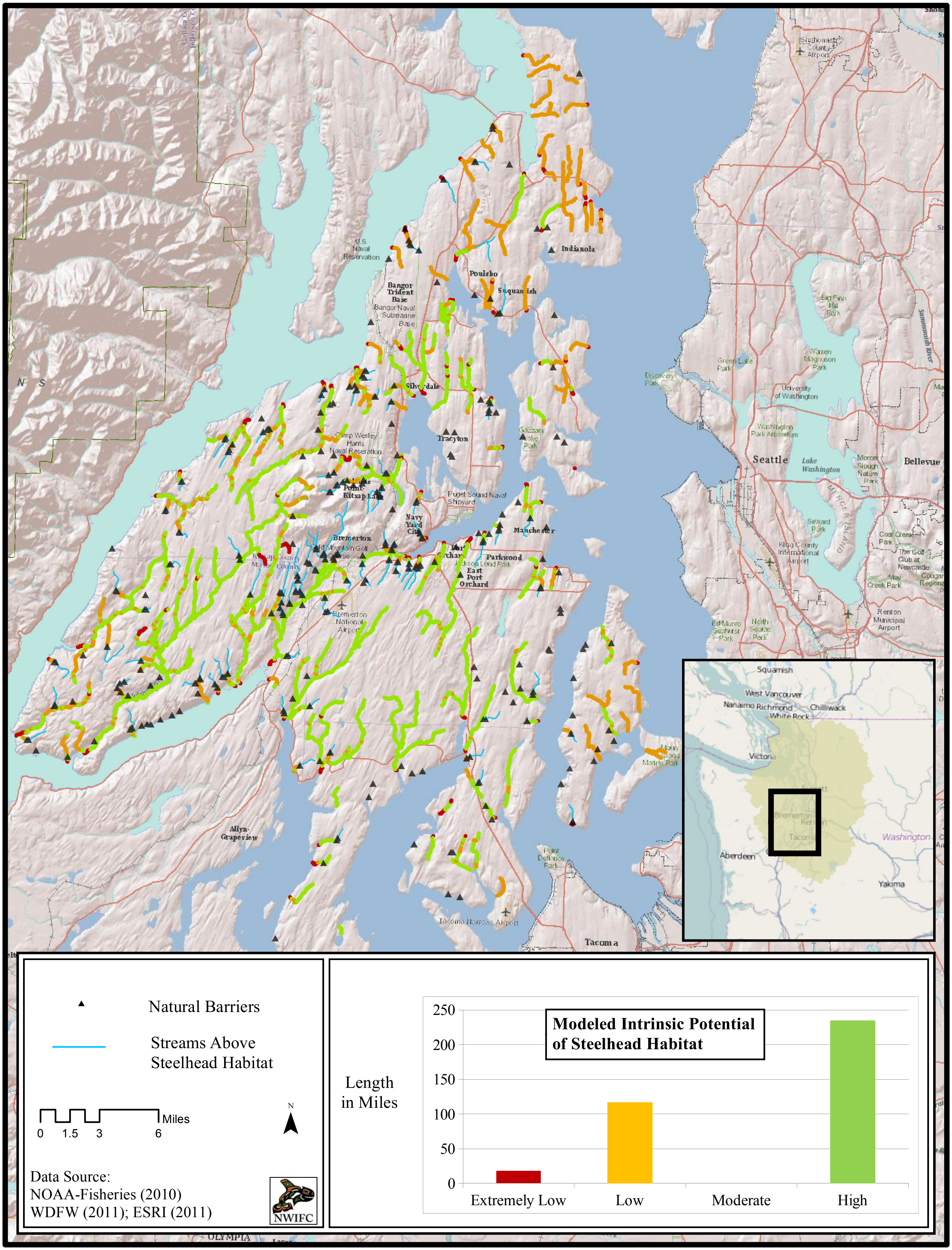


Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 13. Modeled instrinsic potential of steelhead habitat in WRIA 14 (Kennedy-Goldsborough)

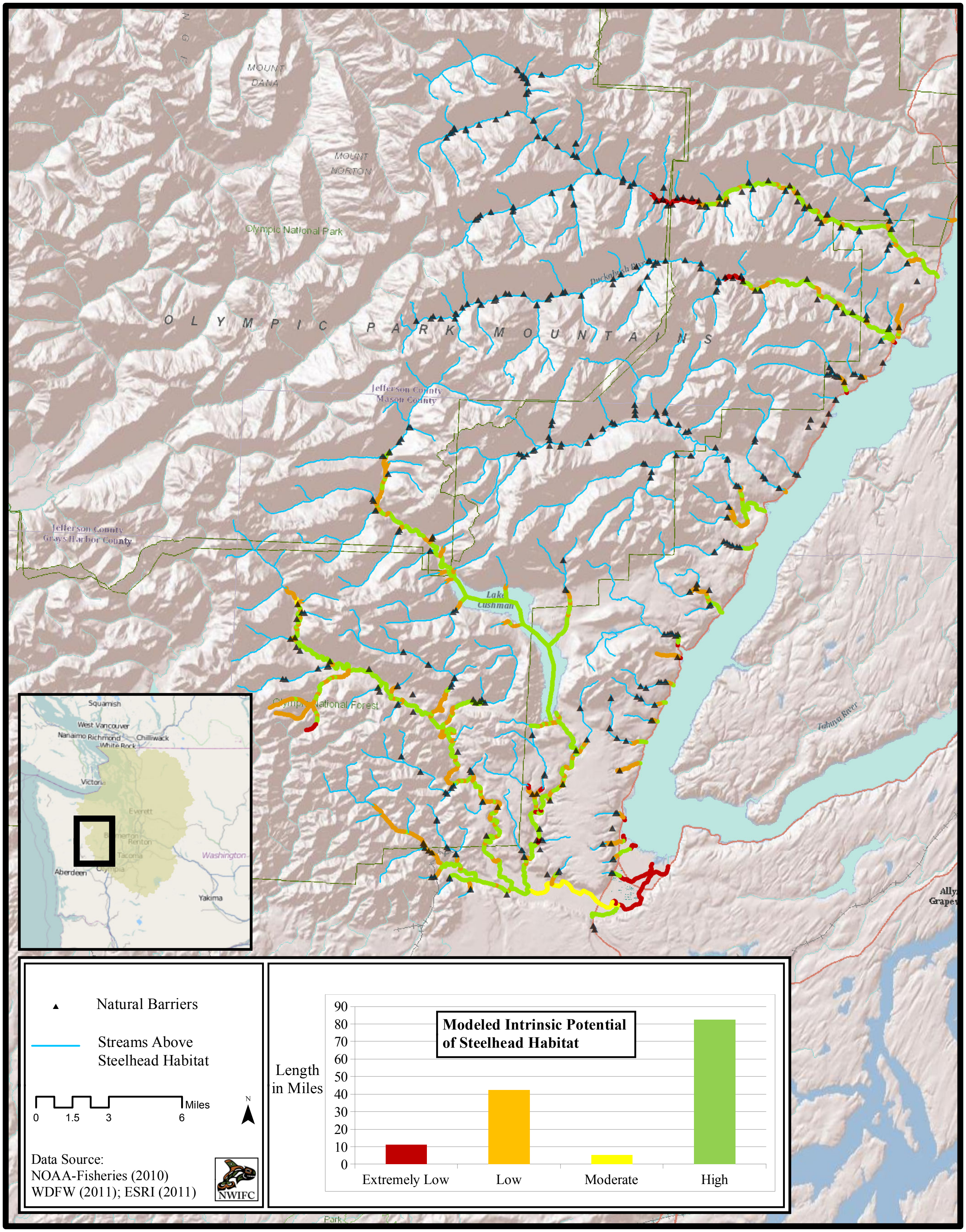


Map 14. Modeled instrinsic potential of steelhead habitat in WRIA 15 (Kitsap)



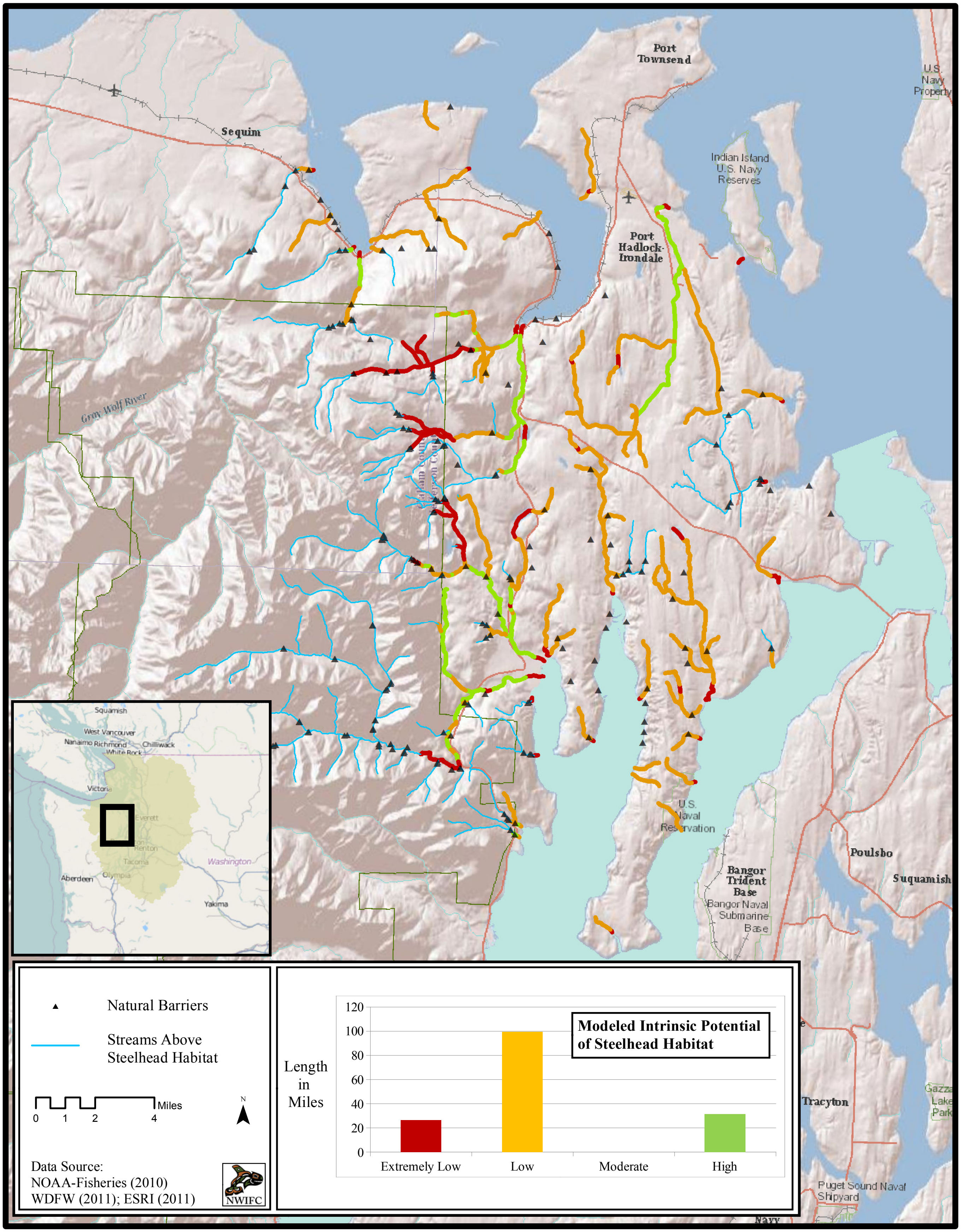
Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 15. Modeled instrinsic potential of steelhead habitat in WRIA 16 (Skokomish-Dosewallips)



Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 16. Modeled instrinsic potential of steelhead habitat in WRIA 17 (Quilcene-Snow)



Data Source:
NOAA-Fisheries (2010)
WDFW (2011); ESRI (2011)

Map 17. Modeled instrinsic potential of steelhead habitat in WRIA 18 (Elwha-Dungeness)