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LITERATURE REVIEW

& MONITORING RECOMMENDATIONS
for

SALMONID WINTER HABITAT

TIMBER FISH
& WILDLIFE

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WINTER HABITAT UTILIZATION BY JUVENILE SALMONIDS

A LITERATURE REVIEW

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Table of Contents

Introduction

Problem Statement

Many salmonids use freshwater habitat during the winter for incubation of eggs and alevin in the gravel and for rearing of juveniles overwintering in the stream system before migrating to saltwater the following spring. This report will focus on winter habitat utilization by juvenile salmonids. Information on the factors affecting salmonid incubation is presented in separate literature reviews of spawning habitat availability (Schuett-Hames and Pleus 1996) and gravel scour (Schuett-Hames et al. 1996).

Salmonids rearing in freshwater have been found to shift to different habitats in the winter. The type of habitat preferred differs among species. At the onset of winter the fish may select other microhabitats in the same stream reach or migrate to specific areas in the same watershed that provide refuge from extreme flow events, freezing and predators. Some characteristics of winter habitats are: deep water, cover, and lower water velocity. These conditions can be met in habitats such as: deep pools with cover, off-channel areas such as wall-based channels or spring-fed ponds, and coarse stable substrate.

These habitats have been historically abundant, but are now much diminished in many watersheds. Without these habitats, winter mortality can increase. The relative abundance of winter habitat is used as an indicator of resource condition in the Watershed Analysis fish habitat assessment module (Washington Forest Practices Board 1995). In stream segments where winter habitat is scarce, information on hydrology, sediment supply, channel conditions and human activities is examined to learn why the condition of scarcity exists. To support the Watershed Analysis effort, there is a need to improve the methods used during the initial habitat assessment and to develop a standard method to measure changes in winter habitat condition over time.

Purpose

The purpose of this report is as follows: 1) summarize information from the literature that describes the characteristics of winter habitat; 2) identify key issues that must be resolved in developing a winter habitat monitoring methodology in the context of Watershed Analysis; 3) describe how winter habitat has been identified and measured in other studies; and 4) recommend Watershed Analysis monitoring methods to measure changes in winter habitat availability.

Background Information on Winter Habitat

Of the regular and cyclical changes that occur in the winter, increased water volume and velocity and decreased temperature have the most impact on the overwintering juvenile salmonids. In western Washington, the highest precipitation levels are experienced in the winter months of November through February. This increases the volume of water in the stream systems and creates freshets, periods of sudden dramatic increases of water volume. The increased water volume causes an increase in water velocity and an expanded channel area (Swanston 1991). The lowest water temperatures also occur during this period. These low temperatures cause concomitant changes in the metabolism, growth, and digestion rates of the fish (Bustard and Narver 1975a, Groot et al. 1995).

The juvenile salmonids react to these changing conditions in a couple of different ways. Their behavior could be categorized simply as running (migrating to a different area of the watershed) or hiding (moving into areas where the effects of the changes are moderated) (Bjornn 1971, Bustard and Narver 1975a&b, Shirvell 1994). This behavior can provide protection from increased possibilities of mortality associated with winter condition changes in interior river systems: stranding and freezing, or low dissolved oxygen levels (Bustard 1984). Protection is provided in coastal systems from the mortality to juveniles associated with storm events (Onodera and Ueno 1961). Habitat preferences are not static and change in response to the activity, i.e., eating, avoiding displacement, or avoiding predators (Shirvell 1994). Another possible factor in the winter habitat shift is a photonegative response (avoidance of light) by juvenile salmonids concurrent with the falling temperatures (Campbell and Neuner 1985, Cunjak 1988).

A variety of winter habitats are used by different species depending on habitat availability, species preferences, and competition. Winter habitat areas share certain common physical characteristics, i.e., deep water, cover, and lower water velocity. There are a variety of areas that combine these characteristics in various ways. Table 1 shows winter habitat areas and how they are defined in the literature surveyed. Although each of the types of winter habitat has characteristic features, exceptions are abundant.

Much of the existing research has focused on detecting what guides species' choices of winter habitat. For example, Swales et al. (1986) found that side channels and off-channel ponds are preferred overwintering habitats for juvenile coho salmon. They observed that chinook salmon juveniles occupied deep pools with large debris cover, and steelhead sheltered in rock crevices or beneath large substrate material. McMahon and Hartman (1989) noted that preferred habitat differed by species, fish size, temperature, and hydrologic regime.

Table 1. Juvenile salmonids winter habitat types and definitions by researcher.

Habitat Type	Definition	Researcher	Species
Main channel	Area of main river flow (>30 cm/sec)	Murphy et al. 1989	sock/chin /coho
Braid	Shallow channel across mudflat or channel bar (10-30 cm/sec)	Murphy et al. 1989	sock/chin /coho
Alcove	Area of slack water along the channel margin separated from the main channel by streambanks or large obstructions such that it remains quiet even at high flows	Nickelson et al. 1992b	coho
Channel Edge	Margin of main channel (<30 cm/sec)	Murphy et al. 1989	sock/chin /coho
Slough / Percolation channel	Side channel formed when sediment and organic debris block the head of a braid or branch of main channel. Water velocity varies.	Murphy et al. 1989 / Peterson and Reid 1984	sock/chin /coho
Overflow channel	Usually only carries water during floods. Often formed in abandoned main channel or repeatedly scoured depressions of floodplain.	Peterson and Reid 1984	coho
Backwater	Slack water behind obstructions, such as a point bar in the main channel.	Murphy et al. 1989	sock/chin /coho
Terrace tributary	Stream flowing across valley floor to river	Murphy et al. 1989 / Sedell & Swanson1984	sock/chin /coho
Tributary mouth	Lower reach of a tributary affected by the river; often has slack water.	Murphy et al. 1989	sock/chin /coho
Beaver Pond	Terrace tributary impounded by beaver dam.	Murphy et al. 1989	sock/coho
Upland slough / wall-based channel	A slough fed by spring or terrace tributary; has outlet to the river.	Murphy et al. 1989 / Peterson & Reid 1984	sock/coho

Table 1. Juvenile salmonids winter habitat types and definitions by researcher.

Habitat type	Definition	Researcher	Species
Intermit. trib.	Subject to winter water velocities capable of scouring away fine materials and rooted vegetation. Substrate consists of exposed sand and gravel. Rooted vegetation, where present, covers less than 25% of the surface. Standing water is always present but during summer isolated pools are all that remain.	Hartman and Brown 1988	coho/ cutthr/ steelhd
Ephemeral swamp	Water levels are seasonally variable, but are always within 25cm of the surface, thus through capillary rise, the surface may appear wet even in the summer. Substrate consists of an organic muck blanket which may be exposed or covered.	Hartman and Brown 1988	coho
Small runoff trib.	Small runoff tributaries with abundant woody debris and gravel substrate	Cederholm and Scarlett 1981	coho/ cutthr/ steelhd
Wallbase channels	Springfed ponds and swamps with mud bottoms	Cederholm and Scarlett 1991	coho/ cutthr

Species Preferences

Several Pacific salmonid species, such as pink (Oncorhynchus gorbuscha), chum (O. keta) and ocean type chinook (O. tshawytscha) emigrate from freshwater before the start of winter. Many others have life histories that involve overwinter rearing in freshwater, including stream type chinook (O. tshawytscha), coho (O. kisutch), steelhead (O. mykiss), cutthroat (O. clarki), bull trout (Salvelinus confluentus), and Dolly Varden (S. malma). Sockeye salmon (O. nerka) overwinter in lakes, which are outside the scope of this literature review.

The preferred physical characteristics of the winter habitat and the behavior that influences the selections are examined by species in the following sections.

Chinook

Behavioral Influences on Winter Habitat Selection

Chinook use of winter habitat is strongly influenced by behavioral factors. Juveniles have been broadly categorized as exhibiting either "ocean-type" or "stream-type" life histories. The ocean-type juveniles migrate to the saltwater environment before the end of the first year of life. Stream-type juveniles migrate to the marine environment during their second year of life (Taylor and Larkin 1986). Winter habitat, therefore, is only of concern for the stream-type juvenile chinook. Taylor and Larkin (1986) found that stream-type juveniles from Slim Creek, B.C. exhibited a strong positive rheotaxis (upstream movement), high aggression, and notable fin coloration and development. These factors contribute to a territorial spacing of the juveniles during overwintering. Shirvell (1994) found that the juvenile chinook salmon in Kloiya Creek, B.C. tended to move offshore and downstream in response to increased water volume and velocity. Researchers have noted the use of interstitial space in the substrate by stream-type chinook increases during periods of cold stream temperatures (Hillman et al. 1987).

Physical Characteristics of Preferred Winter Habitat

The physical habitat preferences of juvenile chinook salmon have not been well documented. The results of some research show that the interstitial spaces between rocks and cobble are used as overwintering habitat by chinook in some systems. Hillman et al. (1987) examined juvenile distribution after placing cobble under overhanging banks in the Red River, Idaho. Overwintering juvenile chinook were predominantly found in the areas of added cobble with associated bank cover. Levings and Lauzier (1991) found that juvenile chinook in the Fraser River, Canada overwinter along the margins of the mainstem river and feed throughout the winter. Bjornn (1971) found the movements of juvenile chinook in the Lemhi River, Idaho correlated best with the amount of cover provided by large rubble substrate. In both field and laboratory tests more fish remained in troughs or stream segments with large rubble substrate than in troughs or sections with gravel substrate. The factor that correlates with the entry into the substrate was stream temperatures declining to 4-6° C. A suitable substrate providing adequate interstices appeared necessary or the fish migrated (upstream or downstream) in search of more suitable habitat as the temperature dropped. Healey (1991) summarized the available information on chinook freshwater overwintering and found correlation between increased juvenile size and movement downstream from the tributaries to the mainstem.

Coho

Behavioral Influences on Winter Habitat Selection

McMahon and Hartman (1989) observed behavioral influences in the winter habitat preferences of coho juveniles. First, they found a strong preference for structurally complex cover. Second, they observed the coho reacting to increased water velocities by shifting to the nearest available low-velocity microhabitat. These shifts were noted to be in the upstream direction in response to increased water volume and velocity (Skeesick 1970, Shirvell 1994). Nickelson et al. (1992a&b) found that coho juveniles preferred off-channel pools in the winter over pools in the main channel, possibly due to the decreased water velocities. Cederholm and Scarlett (1981) assert that the fall immigrations into winter habitat coincide with fall freshets, while spring immigrations seemed to be more a behavioral response to summer territorial redistribution. Scarlett and Cederholm (1984) found that the distribution and survival of coho juveniles overwintering in the Clearwater River system were size related. The larger coho occupied preferred habitat and had better apparent survival than the smaller coho.

Physical Characteristics of Preferred Winter Habitat

The physical characteristics of preferred winter habitat for juvenile coho salmon have been examined in several studies. Water depth, velocity, and cover appear to be important factors in winter habitat selection. Temperature also influences habitat use patterns. Reeves et al. (1989) observe that coho use a narrower range of habitat types as water temperatures decrease. In streams where mean winter water temperature is <7° C, coho used areas typified by water depths of >50 cm and velocities of <30 cm/sec. Tschaplinski and Hartman (1983) in their work at Carnation Creek, B.C., also found that coho fry and yearlings preferred water velocities <30 cm/s.

Bustard and Narver (1975a), also at Carnation Creek, found that beaver ponds were an important overwintering area for juvenile coho, with a survival rate of roughly twice that of the entire stream system. Bryant (1984) observed more coho captured in association with cover in beaver ponds than toward the open water areas of the ponds. Bustard and Narver (1975b) noted that the coho preferred "bays" (alcoves) with clean rubble and overhanging bank cover over those with silted rubble and no cover. Swales and Levings (1989) found coho preferred off-channel ponds as winter habitat. Cederholm and Scarlett (1981) and Peterson (1982a) found that a significant portion of the juvenile coho in the Clearwater River system along the Olympic Peninsula coast used two springfed riverine ponds off the mainstem and two small runoff tributaries. Swales et al. (1988) observed greater numbers of coho juveniles in two small shallow lakes than in the main river in the Keogh River system of British Columbia. Distribution patterns were size related. The mean length of coho in the lakes was greater than that of coho in the streams and main river.

McMahon and Hartman (1989) found that coho abundance increased as cover complexity increased, with only the most complex structures supporting many fish during simulated freshets. They also found that slow current velocities were important to coho in winter habitat selection, but only when shade and three-dimensional complexity was provided.

Cutthroat

Behavioral Influences and Physical Characteristics of Preferred Winter Habitat

Cutthroat winter habitat preferences have not been well documented. Boulders, log jams and root wads seem to be the preferred types of cover within stream channels. Heggenes et al. (1991) found that the fish selected habitat with a variety of substrate sizes, preferred areas with mean water velocities <20 cm/s, and used large pools less in the winter than in the summer. Swales et al. (1988) found cutthroat overwintering in two small shallow lakes and their inlet and outlet streams in the Keogh River, Vancouver Island, B.C. Bustard and Narver (1975b) found that 46% of the cutthroat moved to artificially constructed bays along the main channel (the other 54% remained in the main channel) as water temperatures fell. The majority of the cutthroat in the bays preferred clean rubble to silted rubble and overhanging bank cover rather than no cover. Cederholm and Scarlett (1981) found that a substantial portion of the cutthroat population in the Clearwater River system in western Washington overwintered in two springfed riverine ponds and two small runoff tributaries. Murphy et al. (1986) found that winter densities of cutthroat parr in several southeastern Alaska stream systems correlated with the area of undercut embankments and with fine sediment distribution patterns. Reaches with extensive undercut embankments and low levels of fine sediment had more parr during the winter.

Steelhead

Behavioral Influences on Winter Habitat Selection

Campbell and Neuner (1985) observed juveniles high in the water column at night and inferred that winter hiding behavior in the substrate during the day was a function of predator avoidance. Researchers have noted the use of interstitial space by juvenile steelhead increases during periods of cold stream temperatures (Hillman et al. 1987).

Physical Characteristics of Preferred Winter Habitat

The physical factors important for steelhead winter habitat appear to be cover and coarse substrate. Bustard and Narver (1975a&b) found preferred habitat for age 0+ (fry) and 1+ (parr) steelhead in Carnation Creek, B.C. to be a rubble bottom with associated large woody debris cover. Steelhead of age 0+ were associated with water depths shallower than 15cm and rubble substrate, while age 1+ were associated with depths greater than 15cm and LWD (most frequently logs and rootwads). Johnson et al. (1986) found that steelhead parr would move out of stream sections that had been clearcut (areas of high summer densities) and into areas of old growth forest or areas of buffered streams with more pools and LWD in the winter. Hartman and Brown (1987) found, also in the Carnation Creek system, that cutthroat and steelhead were only associated with gravel and nonvegetated sand substrate portions of three tributaries. The juvenile trout did not enter the less permanently flooded swamp areas with muck or vegetation bottoms or the tributaries characterized by muck bottom only.

Environmental Effects on Winter Habitat Selection

Temperature and Discharge

Annual cycles of temperature and discharge differ from coastal river systems and glacial or snowpack fed interior systems. Coastal river systems have their peak flows in the winter. In the interior systems, the annual pattern of low flows occurs in the winter. The combination of low flows and low temperatures can have several different results: stranding and freezing of the juveniles; lowered dissolved oxygen in the off-channel areas; and increased risk of predation (Bustard 1984). The juvenile salmonids migrate in response to the changing conditions, though the movement varies between watersheds (Bustard 1984, Swales et al.

1986). Swales et al. (1986) compared the winter habitat used by juvenile salmonids in two interior rivers in British Columbia with two coastal rivers. They found similar habitat preferences by species in the two different systems Coho preferred side channels and off-channel ponds with cover, chinook preferred mainstem deep pools with large woody debris, and steelhead preferred rock crevices or large substrate material. The advantages gained from these habitats differ from interior systems to the coastal river systems. They found that off-channel areas with groundwater inflow maintain higher mean water temperatures than the mainstem, which reduces the severity of icing and raises survival rates for the interior systems.

Winter habitat preferences are similar in coastal systems, but for reasons more attributable to avoidance of high water velocity than to avoidance of freezing temperatures. The off-channel and interstitial microhabitats provide lower water velocity for the overwintering juvenile salmonids (Swales et al. 1986).

Turbidity

Murphy et al. (1989) found, in their study on the glacial-fed Taku River, that water velocity was the primary factor in habitat selection by juvenile salmonids and turbidity was a secondary factor. Bjornn and Reiser (1991) noted that while turbidity doesn't seem to affect large juvenile and adult fish, smaller juveniles appear to actively avoid turbid waters.

Winter Habitat Features and Geomorphic Processes

The key features of winter habitat for juvenile salmonids seem to be substrate, cover, and lower water velocity. These features are affected by natural and landuse processes, and characteristics of a watershed such as gradient, geology, and hydrologic regime. Hartman and Brown (1987) found that winter salmonid distribution was influenced by stream drainage area, stream permanence, flushing characteristics, and stream bottom type.

Substrate

Species that utilize substrate for winter habitat hide within the interstitial spaces (cracks and voids) between larger particles (gravel, cobble, and boulders). These spaces afford protection to the juveniles from high water velocities and predators.

Characterizations of substrate in winter habitat study areas have been done by several researchers. In the lower Taku River, Alaska, the chinook juveniles were most abundant in the channel edges of the lower mainstem where the substrate was characterized as 61% and 36% fines in the two study areas (Thedinga et al. 1988). Bjornn (1971) found fewer trout and salmon left troughs with rock substrate than with gravel substrate as water temperatures decreased. Cunjak (1988) observed Atlantic salmon juveniles (5-15 cm fork length) overwintering in the spaces beneath rocks (mean diameter = 16.8 to 23.0 cm)or within redd excavations. Hillman et al. (1987) studied winter habitat selection by juvenile chinook in a heavily embedded Idaho stream. The fish used areas in association with undercut banks. When cobble substrate was added, eight times more chinook juveniles used the cobble substrate than the year before. Observations on two interior rivers (the Coldwater and Nicola rivers in British Columbia) showed that rainbow trout were generally more abundant in riprap bank protected areas over other potential winter habitat areas (Swales et al. 1986). Coho and cutthroat overwintering juveniles tend to use mud bottomed winter habitats, while steelhead and chinook favor gravel and cobble substrates for overwintering (Cederholm pers. comm.).

To produce this type of habitat, large particles must be present and the spaces between them must be free of fine sediment. The availability of large particles varies with supply and transport capacity; requiring a source of large particles, delivery to channel and adequate stream power to carry them into the reach. If the lithology does not produce particles of gravel size or larger, there is a lack of this type of habitat. If it does then distribution depends on slope, discharge, roughness and sediment supply.

The intrusion of fine sediment depends on availability and transport. Increased availability or input of fine sediment can fill the interstices and reduce the survival of juvenile fish (Furniss et al. 1991). Human impacts or land uses that increase erosion (e.g., roads, drainage ditches, agriculture) can increase the input of fine sediments (Cederholm and Reid 1987; Swanston 1991).

Forest management has been implicated as a source of change in the sediment storage and equilibrium in streams throughout the western United States. The most common result has been loss of LWD and accelerated routing of sediment through fluvial systems (Everest et al. 1987). In short high gradient streams, sediment suspended during storm flows may pass completely through the channel system without being deposited unless a major reduction in stream energy occurs. When energy is reduced, most commonly at obstructions and channel bends, suspended sediments settle to the channel floor. Intrusion of fine sediments (primarily sand) is limited initially to the upper 10-15 cm of the streambed (Beschta and Jackson 1979) and subsequent higher flows may flush the fine sediment from the gravel. If the source of fine materials persists, however, and if flows of sufficient energy to flush the sediments do not occur, increasing amounts may settle deeper into the gravel. Studies at Carnation Creek, B.C. (Hartman and Brown 1987) indicated that sudden pulses of fine sediment entering a stream tend to be deposited and then cleaned away in a few years, provided that the stream system is not overloaded with sediment and that erosion sources have revegetated. If sediment sources are persistent and fine sediments intrude deeper into the streambed, it may take many years for them to be cleaned out (Swanston 1991).

Cover

Cover for overwintering juvenile salmonids can take several forms. Bustard and Narver (1975a, b) found that coho juveniles in Carnation Creek, B.C., were most often found in association with overhanging banks, rootwads, woody debris jams, and other large woody debris (LWD). Bisson et al. (1987) found that LWD fulfills several functions in the stream system and can provide various benefits to the juvenile salmonids. It acts as a structural component of channel formation and stabilization. In this role it affects pool formation, sediment movement, organic matter storage and energy dissipation. When the stream system becomes too large to be spanned by the debris, accumulations along the banks can cause meander cutoffs and create well-developed secondary channel systems.

Juvenile salmonids in stream systems with higher percentages of LWD show higher overwinter survival than those in streams with less LWD (Murphy et al. 1984a&b). Shirvell (1990) studied the role of rootwads as cover habitat at varying streamflows. He found the variables affected by the rootwads (listed in order of fish preference) were as follows: 1) water velocity, 2) water depth, and 3) light intensity for both coho fry and steelhead parr.

The input processes for LWD depend on the age and composition of the riparian forest and localized land use practices. Buffer strips and the types of trees left surrounding a stream will determine if the stream system has sufficient wood in the succeeding decades. Wider buffer strips and coniferous trees make for a more sustained LWD presence in the stream (FEMAT 1993, Cederholm 1994).

Low Water Velocity

Sullivan (1986) found, in a study relating hydraulic patterns to availability of habitat through changing seasons and to the distribution of fish within stream reaches, that the overwintering juveniles shifted locations to low velocity microhabitats in response to the changing hydraulic characteristics of the channel units.

As shown in Table 1, low water velocity microhabitats can be created by a variety of conditions in the main channel: large woody debris, large boulders, deep pools, edges of the main channel, undercut banks, and alcoves. Larger areas (macrohabitats) of low water velocity are provided by side channels, wall-based channels, terrace tributaries, and ponds. Side channels or off-channel areas have not been studied thoroughly, though their importance has been documented (Cederholm and Scarlett 1981, Peterson 1982a&b, Peterson and Reid 1984, Scarlett and Cederholm 1984). Off-channel habitats or side channels can be formed by old channel beds that have been abandoned due to lateral channel migration, downed trees that trap water and sediment, springs flowing into lower elevation areas, and beaver dam construction. Sedell et al. (1983) defined side channels as follows:

> "Side channels are subsidiary channels to the main river located within the active exposed lower flood plain. These channels are not the obvious braided channels; they carry a very small percentage of the flow of the main channel. Some are caused by woody debris accumulations on bars in the main channel. Some side channels are the result of channel migration of the point bar. Other off-channel areas are intermittent overflow channels that receive ground water from the main river and nearby terrace. Most are subject to direct flows during freshet periods; others become completely isolated during summer low flow periods. Flow velocities are lower than the main river and water percolated through berm gravel carries reduced suspended sediment."

Wall-based channels are usually found along the back edge of a river terrace or floodplains, or at the base of the abutting slope (Peterson and Reid 1984). Their profile is often broken by the presence of a pond or swamp. At some sites the channelized flow begins at the outlet of the depression, while at other sites channelization occurs below springs emanating from the terrace wall above. Some wall-based channels receive most of their flow from the drainage of similar features on older terraces above. Wall-based channels can be formed from abandoned river channels, overflow scouring, or point bar accretion. Peterson and Reid (1984) found that most of the wall-based channels in the Clearwater River system shared the following characteristics: silt substrate, small catchments (usually less than 50 ha), and outlet water darkly stained by organic leachates. Since the channels are small and of low gradient and their catchments are of low relief and heavily vegetated, they carry relatively little suspended sediment even during peak flows. Hartman and Brown (1987) found that coho, cutthroat and steelhead use small ephemeral tributaries and off-channel ponds or swamps. Peterson (1982b) noted that pond morphometry in wall-based channels could influence coho overwintering survival rates. In his research on two ponds contributing to the Clearwater River, Washington, one study pond was deeper and had higher survival (78%), but average fish weight increased by only 49%. The other, shallower pond had lower survival (28%), but a higher average weight gain of 94%.

Beechie et al. (1994) found that approximately 58% of the historical production capacity of winter rearing habitats for the Skagit River system was in side channel and distributary sloughs. There has been a loss of over 115 km of Skagit River side channel and distributary sloughs over the past century. On a percentage basis, losses of the smolt production capacity have been 45% in side channel sloughs and 64% in distributary sloughs. Most of the slough losses have been in the floodplain and delta areas. In nearly all cases, losses of both side channel and distributary sloughs are due to diking of the Skagit River to protect lands zoned for agricultural, rural residential, or urban uses. There was also a 6% loss of smolt production from loss of off-channel winter habitat due to blocking culverts.

Landuse Consequences

Landuse practices can have diverse consequences for winter habitat features in streams. The landuse practices that have been most studied as causes of fluvial change are logging practices, urbanization, and landscape alterations due to beaver dams.

There are many geomorphological effects on stream systems and fish habitat from logging practices. Logging practices often lessen recruitment of large woody debris and increase sediment input (Chamberlin et al. 1991). The effect on winter habitat is one of reduced channel complexity, cover, and substrate stability. Several researchers have found that stream reaches where riparian vegetation was cut (as opposed to buffered or old-growth reaches) have significantly less pool habitat and LWD (Tschaplinski and Hartman 1983, Johnson et al. 1986, Heifetz et al. 1986, and Murphy et al. 1986). Murphy et al. (1986) also noted a reduction in the area of undercut banks in the main channel in logged stream reaches. Hartman and Brown (1988) identified several possible effects of "operational forestry activities on off-channel habitat": altered natural drainage patterns; increased sediment input; altered runoff from storm events leading to greater incidence of scour; reduced access; altered water quality; and disappearance of off-channel habitat due to reduced water levels.

Urbanization can also create many geomorphological changes in streams. Among these are increased runoff volume from precipitation and increased speed of transmission of the water to and through the channels (Booth 1990, Booth and Jackson 1994). Sediment delivery and channel configuration are also changed, however, the change continues over time and little research has been done on the long term effects of these changes on entire river systems (Dunne and Leopold 1978). The detrimental effect that has been most studied is that of channelization (Cederholm 1972, Cederholm and Koski 1977, Simpson et al. 1982). The most notable effect is the reduction in areas suitable for winter habitat.

Beaver

More than any other animal except humans, beavers geomorphically alter the landscape through their dam building and related activities. In forested environments, beavers build dams to create a pond environment in which to live. Damming of streams by beaver can completely alter the drainage pattern of the local area. Beaver dams can cause many hydrological effects: creation of ponds, diversion channels, and multiple flow paths; alteration of discharge during high flows; and expanded riparian habitats. In some cases they cause an increase in the level of the water table (Butler 1995). Beaver dams also trap sediment, but more study is needed .

The effects of beaver and beaver dams on the winter habitat of juvenile salmonids are to increase potential habitat. Bryant (1984) found beaver ponds provided a large and complex volume of water for anadromous fish habitat and produced densities of coho generally higher than those reported in other systems of southwest Alaska. Bustard and Narver (1975a) reported coho using beaver ponds for overwintering showed a survival rate about twice as high as the 35% estimated for the entire stream system.

Key Issues To Consider In Developing A Monitoring Approach

We have identified several important issues that need to be considered in developing a method for monitoring winter habitat (WH) for Watershed Analysis. These issues have been expressed as a list of questions related to the purpose of monitoring, the data needed, how the data will be interpreted, how monitoring studies should be designed and what sampling methods will be used.

What is the purpose of a Watershed Analysis methodology to monitor winter habitat?

What data are needed to assess and monitor WH for Watershed Analysis?

1. What parameters are most useful to assess and monitor WH?
2. What additional information is needed to help interpret WH data?

What is a valid design for sampling WH?

1. How should a sampling program be designed to characterize WH on a watershed scale appropriate for Watershed Analysis?
2. How should variation in stream flow be addressed?

What sampling methodologies should be used to collect WH data?

1. How accurate and repeatable are WH measurement techniques?
2. How does the feasibility (logistics, time and cost of sampling) of methods compare?
3. What methods are suitable for assessment?
4. What methods are suitable for monitoring?
5. How should data on discharge and physical channel characteristics be collected?

How will the data be interpreted?

1. How will WH be interpreted in the context of discharge?
2. How will WH be interpreted in the context of species needs?
3. How will WH data be interpreted in the context of physical channel reach characteristics? watershed characteristics?

These questions have been used to focus our efforts in developing a winter habitat monitoring method.

How The Key Issues Have Been Addressed In Other Studies

In this section of the review, we examined existing studies to determine how the key issues listed above have been addressed in other studies.

Purpose of studies assessing and monitoring Winter Habitat

Past studies of winter habitat have been conducted for several purposes:

1. to examine the differences between summer preferred habitat and winter preferred habitat (Hartman 1965, Murphy et al. 1984b, Hillman et al. 1987, Reeves et al. 1989, Heggenes et al. 1991, Nickelson et al. 1992b);
2. to observe specific habitat types and their use by overwintering juvenile salmonids (Cederholm and Scarlett 1981, Peterson 1982a&b, Bryant 1984, Murphy et al. 1984a, Peterson and Reid 1984, Scarlett and Cederholm 1984, Hartman and Brown 1987, Murphy et al. 1989, Swales and Levings 1989, Shirvell 1990, Levings and Lauzier 1991);
3. to evaluate the effectiveness of restoration and enhancement efforts (Cederholm et al. 1988, Cederholm and Scarlett 1991, Nickelson et al. 1992a);
4. to attempt to learn which environmental factors trigger the seasonal change in habitat use (Bjornn 1971, Cederholm and Scarlett 1981, Campbell and Neuner 1985, Taylor and Larkin 1986, Chisolm et al. 1987, McMahon and Hartman 1989, Shirvell 1994);
5. to study forestry impacts on overwinter production (Tschaplinski and Hartman 1983, Heifetz et al. 1986, Johnson et al. 1986, Murphy et al. 1986, Hartman and Brown 1988); and
6. to study the key factors influencing winter habitat selection by creating habitats and studying the choices made by the juvenile salmonids (Bustard and Narver 1975a&b, Swales et al. 1986, Cunjak 1988, Swales et al. 1988).

Parameters used to assess and monitor Winter Habitat

The types of winter habitat used by juvenile salmonids hinge on the types available. Winter habitat has not been studied thoroughly over time, the studies have all taken place in discrete times and spaces. Most of the studies have identified a location as winter habitat by the presence of juvenile salmonids in the winter. A monitoring study or method for specifically examining winter habitat over time has yet to be undertaken according to our research.

Oregon is using a model developed to meet their statutory mandate to manage salmonid populations for sustainability and to assess carrying capacity and limiting habitat for streams (Nickelson et al. 1992c). The data required for the model include the rearing density for each habitat type (spring, summer, winter). Winter habitat carrying capacity is obtained from the total surface area of each habitat type (e.g., alcove, backwater pool, dammed pool) and the average density of juveniles per the habitat type. The authors are currently attempting to refine the model to include a factor relating the amount of in-channel LWD to the carrying capacity of winter habitat.

Some other variables related to winter habitat have been measured, they include: overhanging bank cover (Bustard and Narver 1975), amount of LWD in the stream (Murphy et al. 1984b), water velocity (Shirvell 1990, 1994), water temperature (Bustard 1984), wall-based channel location (Belknap and Naiman 1994), and substrate composition (Bjornn 1971, Hillman et al. 1987, Cunjak 1988, Thedinga et al. 1988). The watershed analysis fish habitat assessment module defines the parameters of winter habitat in terms of macrohabitats: change in the abundance of large, deep pools with cover; change in the availability or suitability of off-channel habitat; or loss of interstitial hiding area (increased cobble embeddedness).

Study design and sampling methods

As noted above, the variable most often measured is number of fish in a defined area during the winter. Attempts to measure the number of juveniles who could potentially use an area by using the mainstem as a control have not fared well, as it is difficult to detect the degree of immigration and emigration. Nickleson et al. (c) start their study with a set list of winter habitat types, from Nickleson et al. (1992b), and divide the observed habitat into these categories. They then measure the surface area for each defined type. Sullivan (1986) found morphologic characterization by channel unit surveys to be an effective quantitative measure of available space for winter habitat. Belknap and Naiman (1994) detail a methodology for locating, detecting, and mapping wall-based channels in western Washington. The method uses present digital elevation and stream models to locate areas where a high percentage of wall-base channels are likely to be found. Then an aerial mounted thermal infra-red scanner is used for remote detection. The scanner output video tape can then be used to map wall-base channels for inventory purposes.

Data interpretation

The data interpretation from these studies of juvenile salmonid use of winter habitat ranges from an acknowledged designation of an overwintering site to comparative survival rates. Nickleson et al. (c) and Reeves et al. (1989) use the data generated on winter habitat abundance to estimate the carrying capacity of winter habitat and the limiting habitat for coho salmon in a particular stream system. First, the total surface area of the various habitat types in the specific stream system is measured and converted to a usable habitat figure by multiplying by a habitat equivalent coefficient. Next, these figures are multiplied by a smolt production factor to produce the smolt potential figure. The life stage associated with the lowest smolt potential is then identified as the limiting habitat. The carrying capacity of the stream is then considered to be equal to the maximum potential smolt yield from the available habitat for this life stage. Belknap and Naiman (1994) created maps of wall-base channels for use as baseline inventory data. Detection and mapping of wall-base channels by this method, when field checked, proved to be 88% effective in the Clearwater River system and 92% effective in the South Fork Stillaguamish River system. The watershed analysis fish habitat assessment module interprets data on winter habitat in broad terms of habitat change. This is a useful method for rapid assessment on a watershed level.

Recommended Monitoring Approach

Purpose

We recommend that the winter habitat monitoring method be designed to accomplish the following purposes:

1. To assess current winter habitat on a stream reach scale.
2. To monitor changes and trends over time.
3. To interpret winter habitat in the context of channel conditions and watershed input processes.
4. To interpret the expected effect of winter habitat amounts and quality on fish production trends.

Parameters to assess and monitor winter habitat

We recommend that the following variables be assessed and monitored to gain a good base knowledge of winter habitat:

1. surface area of in-channel winter habitat;
2. surface area of off-channel winter habitat;
3. LWD abundance;
4. abundance/quality of rubble substrate; and
5. area of overhanging bank cover.

Study design and sampling methods

Our proposed approach is as follows:

I. Identify the species present.

A. Office remote option

1. To determine the type and locations of species present, refer to sources such as: A Catalogue of Washington Streams and Salmon Utilization (Williams et al. 1975), spawning ground survey database and Washington River Information System (WARIS) from the Washington Department of Fish and Wildlife. Other sources include personal communications with biologists and fisherman familiar with the areas and tribal records.

B. Field intensive option

1. Use appropriate sampling methods (e.g., box traps, spawning ground surveys, snorkel surveys, electroshocking) to determine the species present in the target stream reach.

Table 2. Suggested Winter Habitat Parameters by Species

Species	Habitat Types	Reference	Type of Method
coho	Alcove, beaver pond, slough, overflow channel, backwater, terrace trib., wall-based channel, intermittent trib., ephemeral swamp	Nickleson et al. 1992a,b,c; Peterson and Reid 1984; Murphy et al. 1989; Hartman and Brown 1988	Remote
chinook	Main channel, braid, channel edge, percolation channel, backwater, terrace trib., beaver pond, upland slough, large, clean cobble	Murphy et al. 1989; Bjornn 1971; Hillman et al. 1987; Levings and Lauzier 1991; Shirvell 1994; Swales et al. 1986; Swales and Levings 1989; Taylor and Larkin 1986	Field
cutthroat	Wall-based channels, intermittent trib., small runoff trib.	Cederholm and Scarlett 1981; Cederholm and Scarlett 1991; Hartman and Brown 1987; Heggenes et al. 1991	Remote
steelhead	Intermittent trib., small runoff trib., pools with cover, large clean cobble, riprap	Bjornn 1971; Cederholm and Scarlett 1981; Hartman 1965; Hartman and Brown 1987; Heifetz et al. 1986; Johnson et al. 1986; Murphy et al. 1986; Murphy et al. 1984; Murphy et al. 1984b;Shirvell 1990; Swales et al. 1986	Field

II. Identify the type of habitats utilized by the overwintering juvenile salmonids of the species determined to be present in Step I and determine the portions of the watershed likely to contain them.

A. Office remote option

1. Refer to the information gathered in Table 2 and compare to Geographic Information Systems (GIS) information (e.g., hydrology, geology, topography, etc.) and aerial photos to determine the off-channel locations (beaver ponds, wall-base channels, sloughs, and small tributaries) likely to be used by overwintering juvenile salmonids. Likely in-channel locations with abundant habitats can be roughly located by assessing confinement (in-channel winter habitat is scarce in confined channels) and gradient. High gradient streams characteristically have high water velocities during winter high flows making them less suitable for winter habitat.

B. Field intensive option

1. As in number one above, compare the information from Table 2 to available information on the targeted watershed or stream system to roughly locate the likely overwintering locations.

2. Test these hypothetical locations by field checking for the presence of juvenile salmonids.

III. Assess the current conditions and abundance.

A. Office remote option

1. Locate off-channel habitats through examination of aerial photos, maps, and GIS information and estimate surface area.

2. No method for assessing in-channel winter habitat from remote sources was found.

B. Field intensive option

1. Field check to verify the presence and surface area of off-channel habitat identified from remote sources. Determine if off-channel habitats are present that were not visible from remote sources.

2. Conduct field surveys to assess the abundance and quality of in-channel habitat used by the species present such as LWD, alcove pools, rubble substrate, and area of overhanging bank cover. Confer with a statistician to develop an appropriate sampling plan.

IV. Follow-up monitoring

A. Office remote option

1. For off-channel area monitoring, examine new aerial photos for large scale changes such as landuse changes, mass wasting events, channel changes, etc. Any changes on this scale would signal a need for field checking. If no large scale changes have occurred, assumptions can be made about the continuing quality of identifiable (in the photos, etc.) off-channel features.

B. Field intensive option

1. Do regular field checks on the identified winter habitat in the targeted stream reaches using the data collected in Step III as the monitoring baseline. Aim for similar conditions in scheduling the field check cycle. The relationship between high flows and winter habitat is fluid and changes at each successive high flow level. As the water inundates regions further and further removed from the main channel, the juveniles will venture greater distances to reach low water velocities. Winter habitat, therefore, changes as discharge changes (Sullivan 1986). Sample or subsample according to your sampling plan.

Data interpretation

We recommend interpreting winter habitat in the context of a limiting factor to production as in Nickelson et al. (c). This can be detected by changes in survival rates and any corresponding habitat changes. By learning the species, location, and number of fish present at the first stage, more conclusions can be reached concerning the extent of limitation on production when done in the context of the watershed's potential.

Recommendations for future research

Winter habitat for salmonids is a recent idea and research topic. More research needs to be done on the following aspects:

1. How does the abundance, hydraulics, and utilization of winter habitat change as flows change?

2. How do geomorphic processes affect winter habitat?

3. What is the natural variation in winter habitat?

4. Winter habitat utilization patterns of both cutthroat and chinook;

5. Effects of high flows on cobble and rubble substrate (scour and fill); and

6. Causes of mortality or displacement of juvenile salmonids during peak flow.

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