Spawning Habitat

Substrate

Nest gravel dominated by 3-15 cm ϕ gravel and cobble	Raleigh et al. (1986)
Spawning channel gravel specification of 1.3 - 3.8 cm (80%) with grains up to 10.2 cm (≤20%)	Bell (1990)
Gravel composition = 2 - 10 cm preferred for spawning channels	Reiser and Bjornn (1979)
Gravel = 59 - 86%	Raleigh et al. (1986)
Cobble = 8 - 35%	Raleigh et al. (1986)
Fines ≤ 6% (in redd)	Raleigh et al. (1986)
Spawning bed composition = 7.6 - 25.4 cm preferred in area prior to spawning (Deshutes River)	Huntington (1985)
Spawning bed composition = gravel particles with D_{50} ≤ 10% of body length	Kondolf and Wolman (1993)
Spawning bed composition = 24.4 mm in mean D_g, with 12.9% fines reduced to 8.3% in redd	Kondolf and Wolman (1993)
Spawning bed composition = 12-26% fines (<1mm), with 30% fines reduced to 7.2% in redd	Everest et al. (1987)
Spawning bed dominated by gravel/cobble mixture 2.5 cm - 15 cm ϕ, with majority 5 - 7.5 cm (Battle Creek, CA)	Vogel (1982)
Spawning bed dominated by 5 - 10 cm gravel/cobble mixtures (Sacramento River, CA)	Gard (2003)
Spawning bed gravel with D_{50} ranging from 44 mm to 66 mm for Sacramento River stocks (BL=84cm)	Kondolf and Wolman (1993)
Spawning bed dominated by large gravel (50-75mm);	
subdominate small cobble (75-150mm) and medium gravel(25-50mm) (Trinity River, CA)	Hampton (1988)
Preferred gravel bed embeddedness before spawning < 40-50% (Trinity River, CA)	Hampton (1988)

Water depth

Minimum preferred depth = 0.2 m	Raleigh et al. (1986)
Minimum depth = 0.24 m (spring Chinook, Oregon)	Reiser and Bjornn (1979)
Preferred depth range 0.14 - 0.66 m (Battle Creek, CA)	Vogel (1982)
Preferred depth range 0.24 - 0.91 m for Sacramento River fall and late-fall run Chinook salmon (90% of observations)	Gard (2003)
Preferred depth range 0.25 - 3.0 m for Sacramento River winter-run Chinook salmon (90% of observations)	Gard (2003)
Preferred depth range 0.15 - 0.80 m for Upper Klamath-Trinity Chinook salmon	Hampton (1988)

Water temperature

Preferred/normative spawning range 4.4 - 18.0 °C	Raleigh et al. (1986)
	Marine (1992)
Low egg and fry survival (warm spawning) ≥ 16°C	Seymour (1956)
Low egg and fry survival (cold spawning) < 4.5°C	Combs and Burrows (1957)

Optimal spawning and incubation range = 10 - 12 °C	Bell (1990)
	Leitritz and Lewis (1980)
	Piper et al. (1983)
Low embryo survival (when spawning temp) ≥ 15 °C	Leitritz and Lewis (1980)
	Raleigh et al. (1986)
Water velocity	
Suitable velocity for spawning and egg/larval incubation 12 - 131 cm/sec	Raleigh et al. (1986)
Suitable velocity for spawning and egg/larval incubation 25 - 152 cm/sec (Sacramento R. winter-run Chinook)	Gard (2003)
Preferred velocity for spawning 23 - 111 cm/sec with 45 cm/sec most suitable (Battle Creek, CA)	Vogel (1982)
Preferred velocity for spawning 15 - 115 cm/sec with 40-65 cm/sec most suitable (Trinity River, CA)	Hampton (1988)
Habitat type	
Pool tailouts	Raleigh et al. (1986)
Pool tailouts	Sullivan et al. (1987)
Pool frequency = 40 - 60% for spawning and rearing	Raleigh et al. (1986)
Cover type	
Most preferred cover (in descending order): undercut bank, large wood, overhanging vegetation	Hampton (1988)
Gradient	
≤ 3% associated with WA Chinook spawning distributions, which is associated with alluvial reaches and scour limits	Montgomery et al. (1999)
≤ 4% selected as criterion for Baker River Chinook salmon	R2 Resource Consultants (200
Streams with spawning populations of Chinook salmon avg. 1.2% gradient	Cramer (2001)
Entrenchment	
Entrenched ratio = 1.0-1.4; moderately entrenched = 1.4-2.2; slightly entrenched >2.2	Arend (1999)

Egg Incubation Conditions

Bed surface fines

Optimal silt levels ≤5% (≤ 0.84 mm) (including in redds)	Raleigh et al. (1986)
	Everest et al. (1987)
Optimal sand levels ≤5% (≤3.0 mm) (including in redds)	Raleigh et al. (1986)
	Everest et al. (1987)
Optimal fines level < 15% (≤ 0.84 mm)	McNeil and Ahnell (1964), cited in Raleigh et al. (1986)
Decreasing survival > 15% fines (≤ 0.84 mm)	McNeil and Ahnell (1964), cited in Raleigh et al. (1986)
Oxygen permeability is high < 5% fines (≤ 0.84 mm)	McNeil and Ahnell (1964), cited in Bjornn and Reiser (1991)
Oxygen permeabilty is low > 15% fines (≤ 0.84 mm)	McNeil and Ahnell (1964), cited in Bjornn and Reiser (1991)
Normative fines (< 0.83 mm) threshold ≤20% for "natural system" survival	Everest et al. (1987)
Fines levels in undisturbed Oregon coastal rivers 22 - 28%	Koski (1966), cited in Iwamoto et al. (1978)
Normative fines (< 6.35 mm) threshold ≤30% for > 80% survival	Tappel and Bjornn (1983), cited in Bjornn and Reiser (1991)

Water temperature

Optimal incubation temperatures 6 - 14°C	Combs and Burrows (1957)
	Marine (1992)
	McCullough (1999)
Initial temp 16°C for <1 week, then declining, no significant loss	Olson and Foster (1955)
Initial temp 16.5°C, declining 0.2°C/day, (DO≥4ppt), no significant mortality	Geist et al. (2006)
Insignificant mortality from 6.4 - 14.2°C for Sacramento River fall Chinook	Healey (1979)
Insignificant mortality for Sacramento river winter-run Chinook <13.8°C	USFWS (1999)

Summer Rearing (Age 0 fry and parr)	
Substrate preference	
silt - 20 cm ϕ substrates	Everest and Chapman (1972)
sand and gravel	Hillman and Griffith (1987)
2 - 5 cm ϕ substrates	Bjornn and Reiser (1991)
boulders > 25 cm in riffles and runs	Hillman and Griffith (1987)
cobbles and boulders in pools, glides and runs	Cramer (2001)
10 - 40 cm ϕ substrates covering ≥ 15% of bed	Raleigh et al. (1986)
< 10% fines (<3mm ϕ) in gravel-cobble bed riffles and runs	Raleigh et al. (1986)
> 40% fines causing embeddedness reduces fish densities	Bjornn and Reiser (1991)
> 30% fines results in low probability of use	Raleigh et al. (1986)
embeddedness ≤20% no significant change in fish density	Bjornn et al. (1977)
Fry occur in slow depositional areas with dominant sand and silt bed;	
subdominate boulder (Trinity River, CA)	Hampton (1988)
Parr associate with variety of substrate, prefer boulder dominated bed (Trinity River, CA)	Hampton (1988)
Pool area	
< 50% pool area associated with higher fish densities	Platts (1974)
< 20% pool area associated with 59% of chinook in survey area	Platts and Partridge (1983)
40-50% pool area cited as preferred habitat ratio	Raleigh et al. (1986)
Habitat preference	
pools preferred habitat type	Platts and Partridge (1978)
90% of fry associated with pool and glides	Hillman and Griffith (1987)
pools preferred habitat type	Murray and Rosenau (1989)
pools, especially backwater, deep, low gradient areas	Jonasson et al. (1995-1998)
pools with willow margins and LWD	Johnson et al. (1992)
pools and eddies associated with highest fry densities	Everest and Chapman (1972)
pools, glides, and runs account for highest densites of parr	Cramer (2001)
Water temperature	
>24°C lethal	Brett (1952)
12-18°C preferred/normative	Raleigh et al. (1986)

15°C - optimum growth, 20°C - 50% of max, 21.5°C - no growth	Brett et al. (1982)
up to 19°C - high growth with abundant food	Myrick and Cech (2002)
up to 16°C - normal growth, smoltification, interactions	Marine and Cech (2004)
	Sullivan et al. (2000)
17 - 20°C - normal growth, with some impairment	Marine and Cech (2004)
>21°C - decreased growth and increased impairment	Marine and Cech (2004)
Depth	
prefer shallow, slow edge water	Vogel and Marine (1991)
	Bustard and Narver (1975)
enough depth to cover fry	Bjornn and Reiser (1991)
shift to deeper water as they grow	Chapman and Bjornn (1969)
	Everest and Chapman (1972)
	Healey (1991)
	Vogel and Marine (1991)
	Quinn (2005)
Most preferred by fry 0.15-0.75 m (Trinity River, CA)	Hampton (1988)
Most preferred by parr > 0.30 m (Trinity River, CA)	Hampton (1988)
Cover	
depths ≥ 15 cm	Everest and Chapman (1972)
preference 20% combined cover	Raleigh et al. (1986)
> 15% of substrates 10 - 40 cm ϕ	Raleigh et al. (1986)
	Cramer (2001)
pool complexity associated with highest fry densities	Platts (1974)
overhead bank cover of 32% preferred to no cover	Brusven et al. (1986)
Fry preferred cover in descending order : undercut bank, large wood, submerged vegetation	Hampton (1988)
Parr preferred cover in descending order: undercut bank, large wood, small wood	Hampton (1988)
Gradient	
< 4 -5%	Lunetta et al. (1997)
4% gradient associated with peak fry densities	Platts (1974)
≤ 3% associated with WA Chinook spawning distributions	Montgomery et al. (1999)
Entrenchment	
Entrenched ratio = 1.0-1.4; moderately entrenched = 1.4-2.2; slightly entrenched >2.2	Arend (1999)

Winter Rearing (Age 0 fry and parr)

Substrate preference	
large gravel-cobbles, free of excessive silt used for cover	Everest and Chapman (1972)
outmigrate if winter cover in the stream bed not available,or if silted and embedded	Everest and Chapman (1972)
	Stuehrenberg (1975)
	Raleigh et al. (1986)
	Hillman and Griffith (1987)
< 5% fines - optimal, > 30% fines - deleterious	Raleigh et al. (1986)
embeddedness < 20% no signficant effect on fish density	Bjornn et al. (1977)
Pool complexity	
≥ 20% pool area preferred	Raleigh et al. (1986)
Habitat	
pools, glides, and riffles, especially pools with cover	Jonasson et al. (1995 - 1998)
pools, glides, and riffles	Hillman and Griffith (1987)
associated with overhanging cover (brush and banks)	Reiser and Bjornn (1979)
associated with cover in pools and glides	Bjornn and Reiser (1991)
Cover	
> 15% of substrates 10 - 40 cm ϕ	Raleigh et al. (1986)
overhead bank cover of 32% preferred to no cover	Brusven et al. (1986)
undercut banks with vegetation associated with high fry densities	Hillman and Griffith (1987)
Water temperature	
12-18°C preferred/normative	Raleigh et al. (1986)
≤ 10°C significantly reduced growth and activity	Brett (1952)
	Shelbourn et al. (1995)
≤ 4°C associated with fry taking cover in bed rubble	Chapman and Bjornn (1969)
near 0°C can be tolerated for short periods seasonally	Bjornn and Reiser (1991)
	Raleigh et al. (1986)

Spring Rearing and Outmigration (Age 1+ parr and smolts)

Substrate preference

associated with mixed gravel ,large bed elements, boulders, LWD	Hillman and Griffith (1987)
preference for rubble (cobbles and small boulders)	Everest and Chapman (1972)

Depth

≥60 cm	Everest and Chapman (1972)
30 - 76 cm preferred by juveniles, range shifts shallower in turbid and deeper in clear waters	Raleigh et al. (1986)
40 - 58 cm	Bjornn and Reiser (1991)
< 61 cm	Bjornn and Reiser (1991)
55 - 60 cm	Bjornn and Reiser (1991)

Cover

associated with cover in pools, overhanging vegetation, undercut banks	Bjornn and Reiser (1991)
30 - 100 cm associated with mixed fines, gravel to boulder beds, and overhanging vegetation	Fris and DeHaven (1993)

Habitat

Rearing parr prefer pools > 61 cm deep with one or more combinations of cover components	Platts (1974)
	Raleigh et al. (1986)
	Fris and DeHaven (1993)