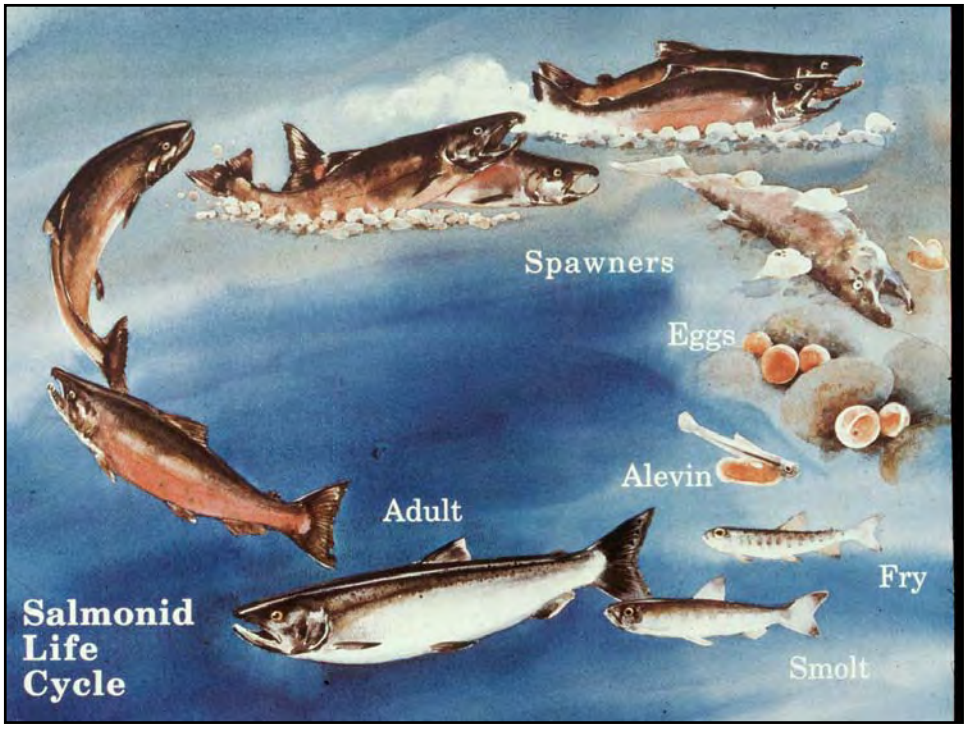
The production of anadromous salmonids in streams: behavioral and population-level perspectives

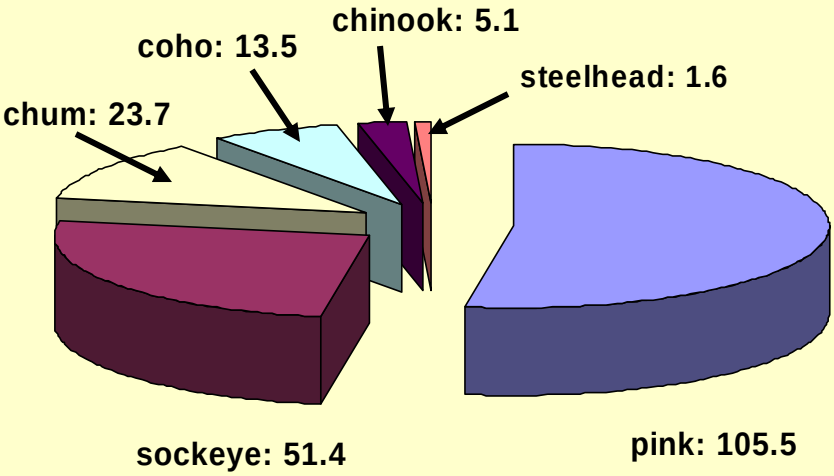
Thomas Quinn
School of Aquatic and Fishery Sciences
University of Washington



Streams: the crux and the curse of salmonid life histories

- The exclusive or primary spawning habitat for virtually all species, *and*
- The exclusive or primary rearing habitat for most species, *but*
- The growth of individuals and density of populations depends on leaving the stream
- Pink, sockeye, and chum salmon liberated themselves from stream rearing, and are the most numerous species.

Abundance of North American anadromous salmonids (millions of adults)

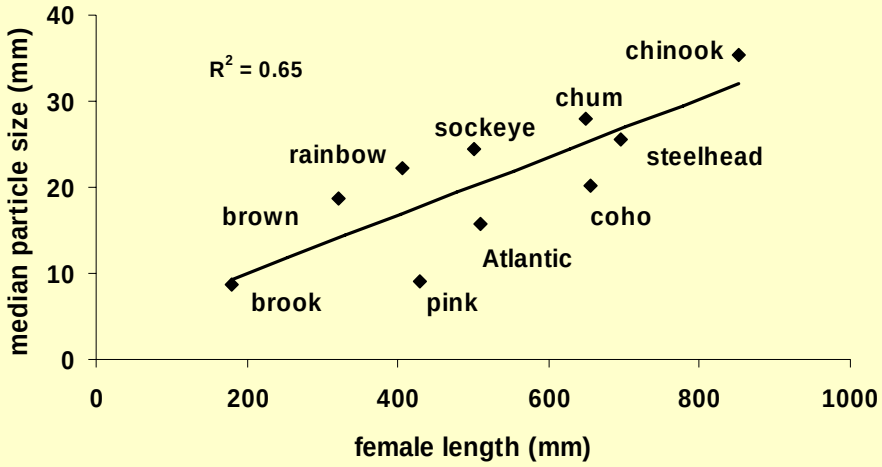


Salmon: Rogers (2001) 1951 – 2001;
steelhead: Burgner et al. (1992)

Talk outline:

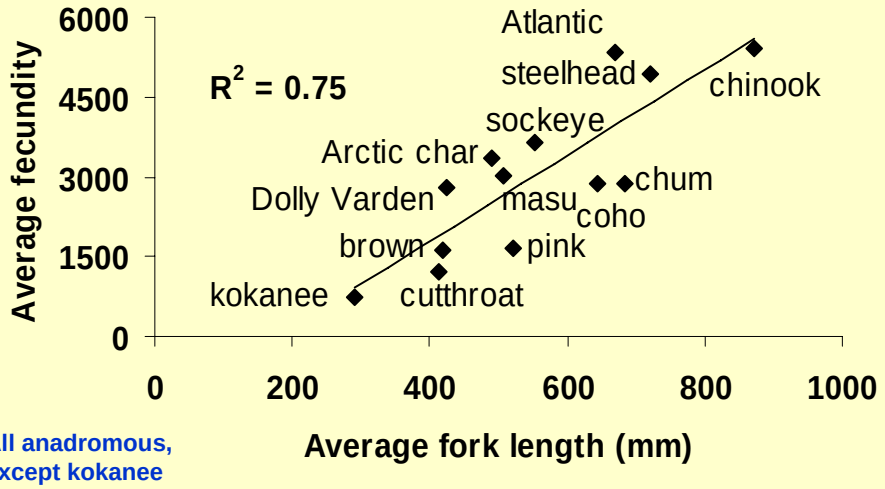
- **Parental influences: habitat selection, fecundity, and egg burial depth**
- **Survival of embryos to emergence**
- ***Population and behavioral perspectives on the production of smolts from streams***

Gravel size at the redd site scales with female size



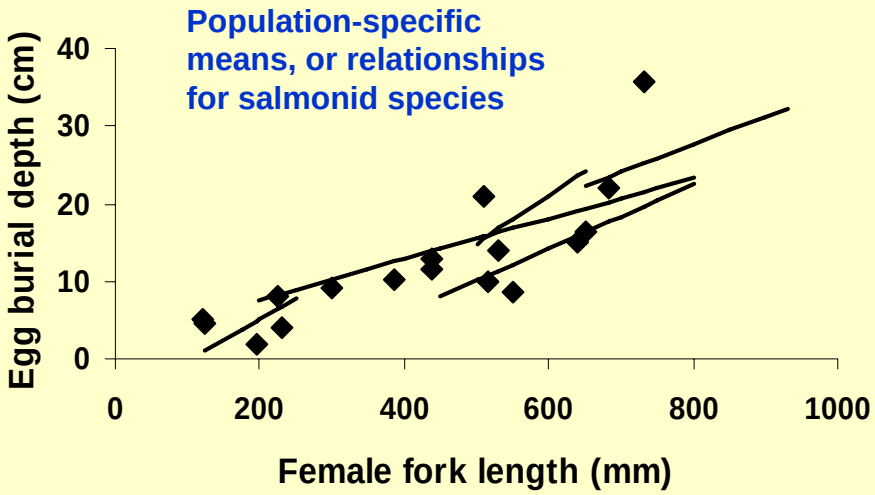
Kondolf and Wolman (1993)

Egg production varies with female length, and with species-specific tradeoffs between egg size and fecundity



All anadromous, except kokanee

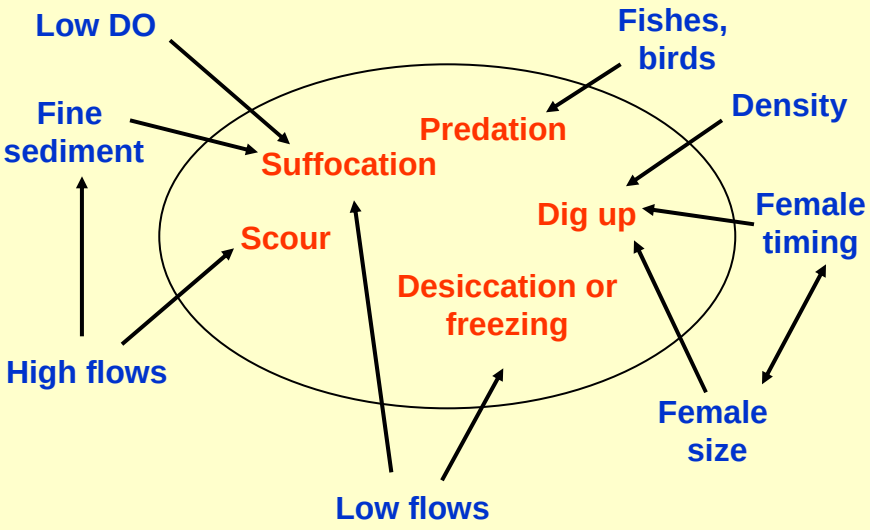
Redd depth protects embryos from dig-up and scour, and increases with female size



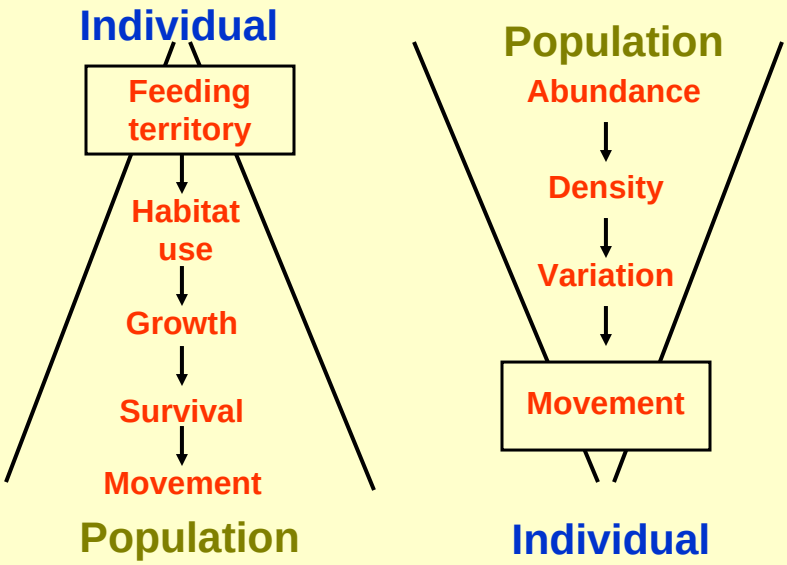
What percentage of the eggs survive to emerge as fry?

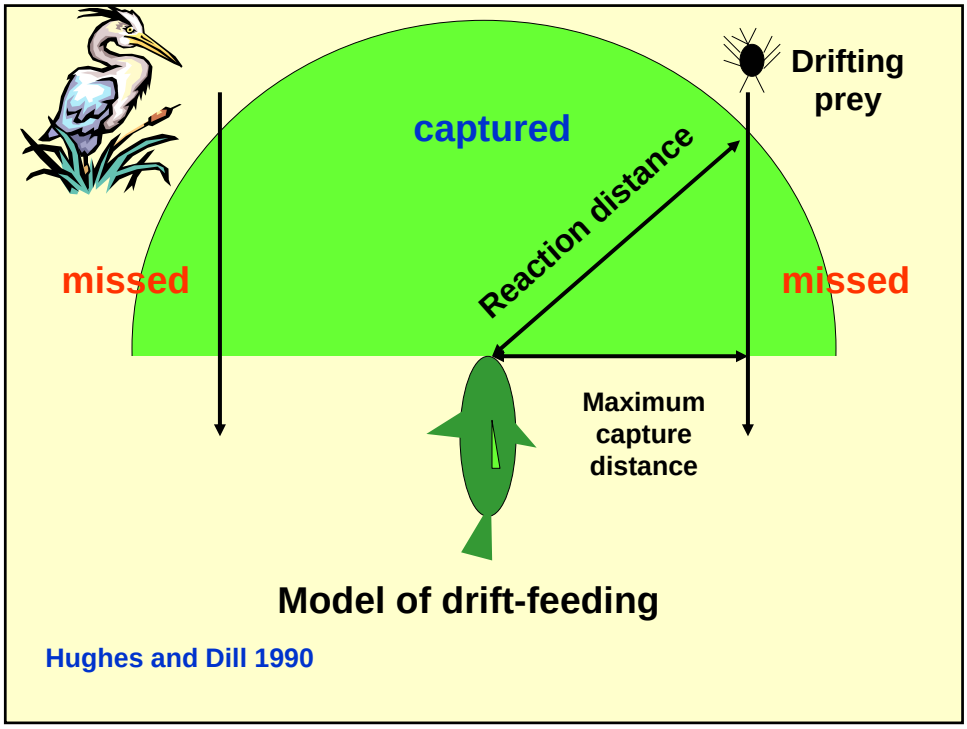
Species	Survival (%)	# of studies
Pink	11.5	22
Sockeye	12.7	16
Chum	12.9	15
Coho	25.3	8
Steelhead	29.3	2
Chinook	38.0	5

Sources of Embryo Mortality



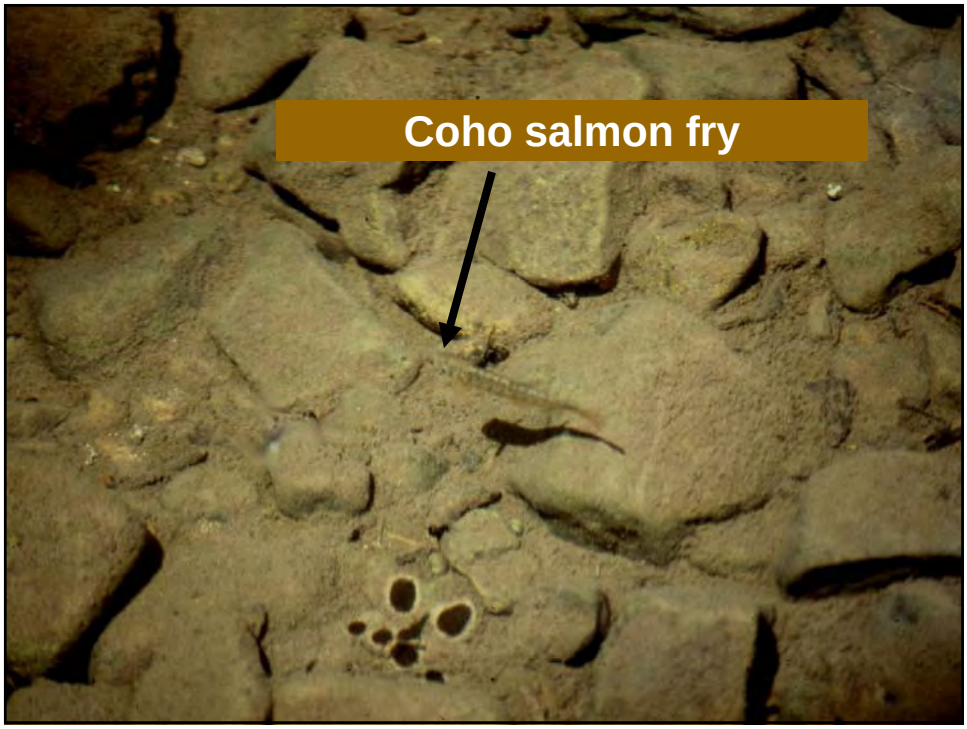
Behavioral and population-level perspectives on abundance, density, growth, and survival of salmonids in streams



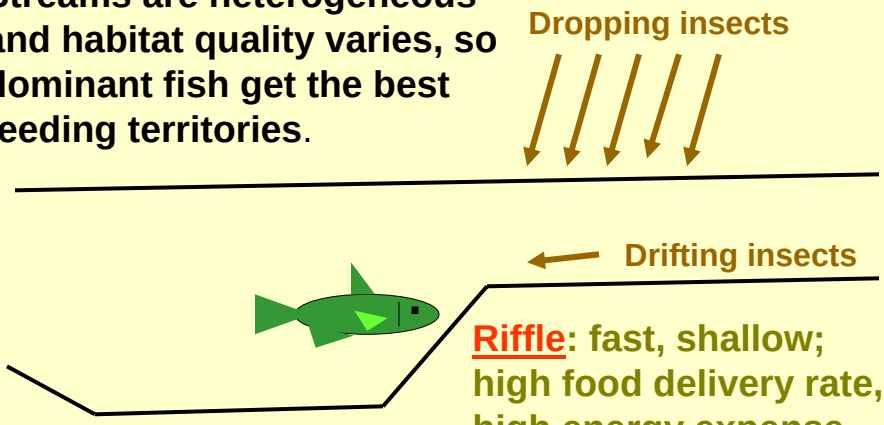


Model of drift-feeding

Hughes and Dill 1990



Streams are heterogeneous and habitat quality varies, so dominant fish get the best feeding territories.



Riffle: fast, shallow; high food delivery rate, high energy expense, predation risk?

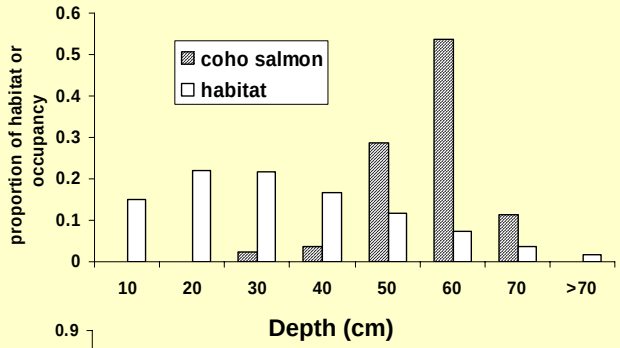
Pool: slow, deep water; low food delivery rate, low energy expense, predation risk?

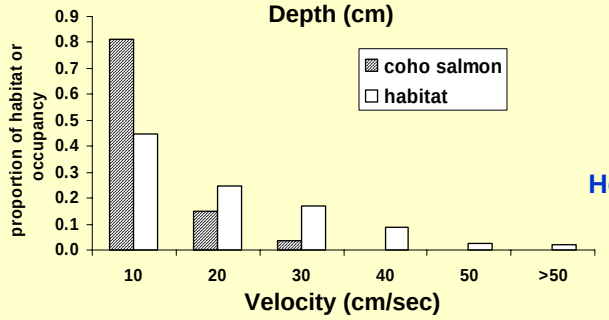
Factors affecting dominance relationships among salmonids

- Body size
- Metabolic rate
- Prior claim
- Experience
- Individual recognition
- Sibship
- Inter-specific interactions

Foraging success of juvenile coho salmon as a function of social status (Nielsen 1992)

Attribute	Dominant	Subdominant	Floater
Size (mm)	64	55	50
Foraging rate (bouts/min)	2.7	1.8	1.7
Aggression per min	0.77	0.42	0.16
Submissive acts per min	0.05	0.21	0.33
Available food (drift + drop)	0.29 + 0.14	0.22 + 0.13	0.06 + 0.15
Growth (mg/d)	5.5	3.2	2.1



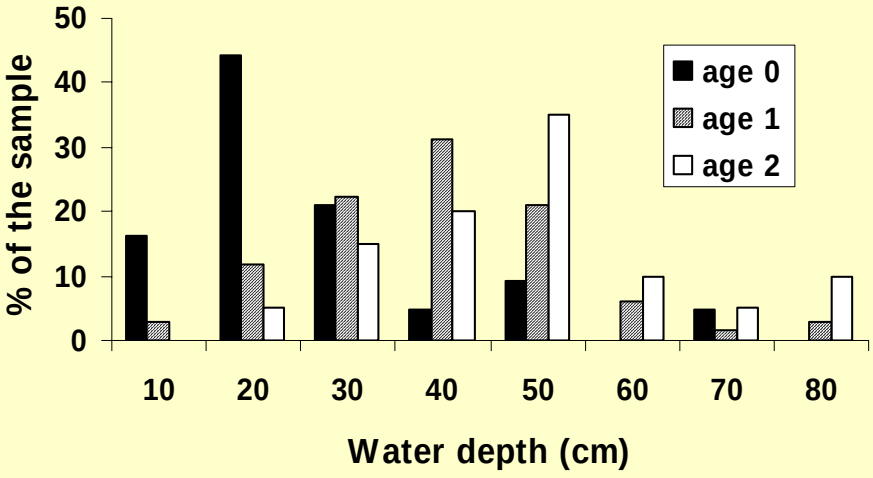


Juvenile salmonids use available habitat selectively.

Coho salmon tend to occupy slow, deep water (pools).

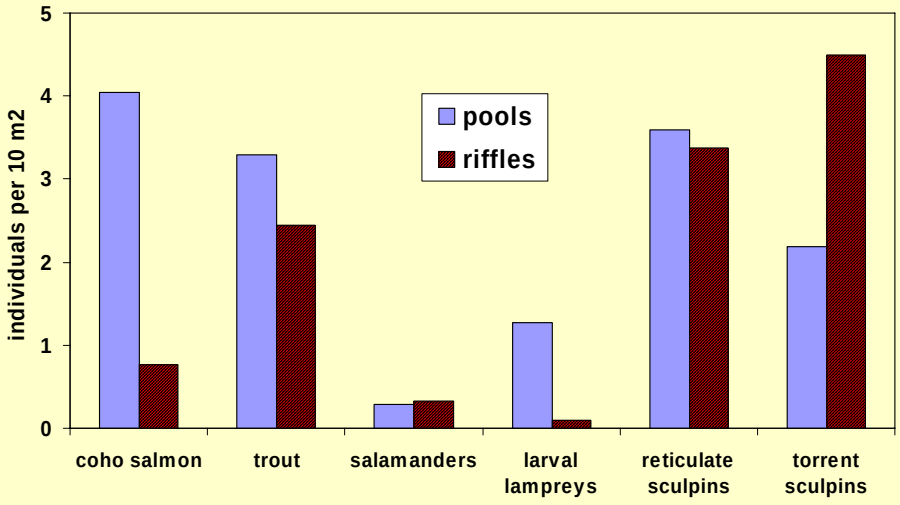
Healy and Lonzarich 2000

Ontogenetic shifts in habitat: Issaquah Creek cutthroat trout

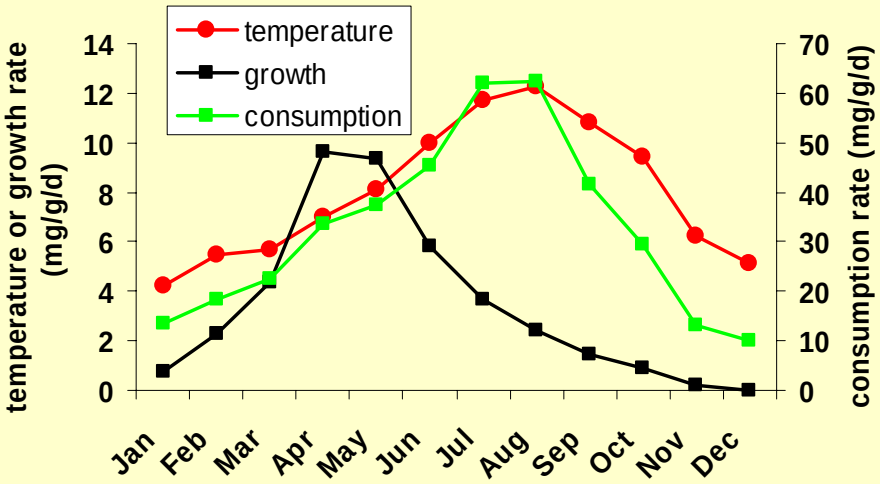


Habitat use patterns vary among salmonids (and other fishes), reflecting choice and competition

Roni 2002

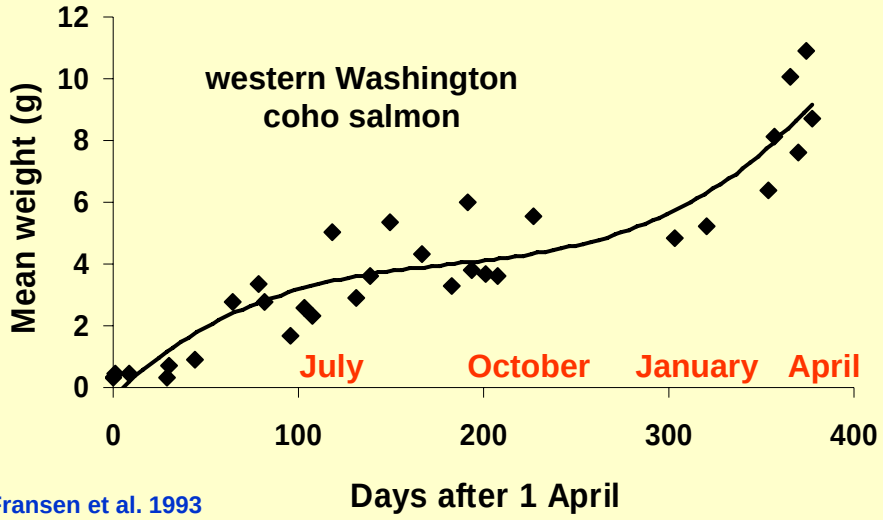


Seasonal processes affecting salmonid growth: age 1 cutthroat trout on the Olympic Peninsula



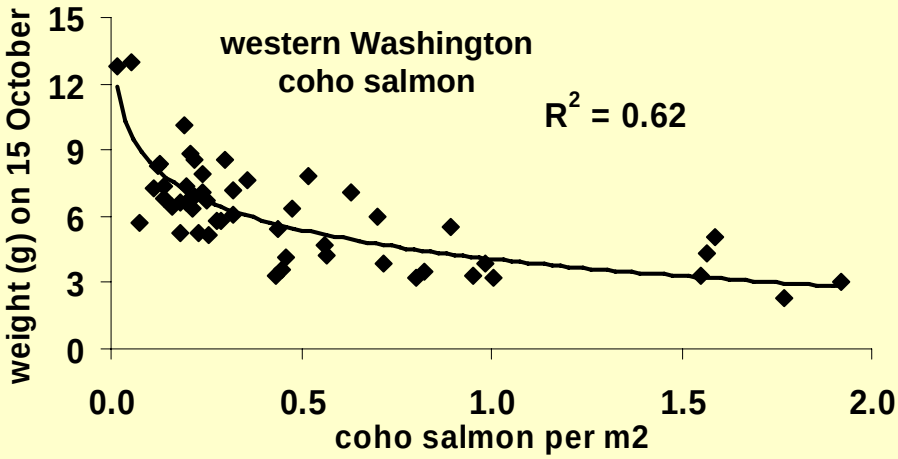
Martin 1985

Growth in streams is seasonal



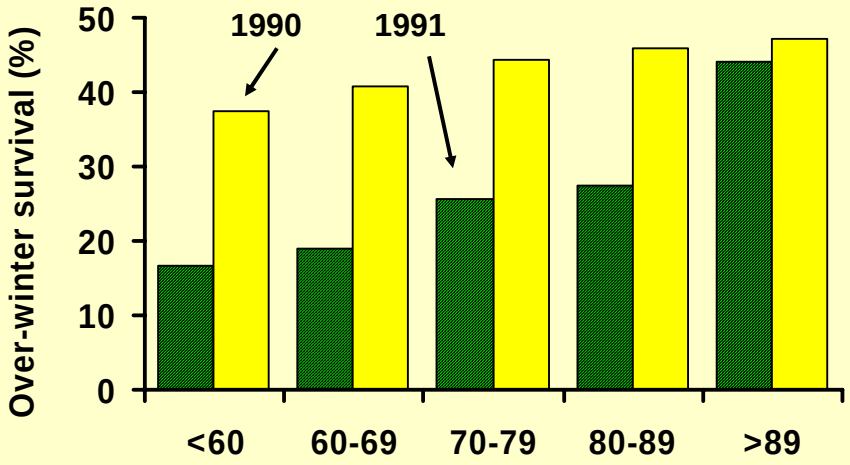
Fransen et al. 1993

Growth in streams is density dependent



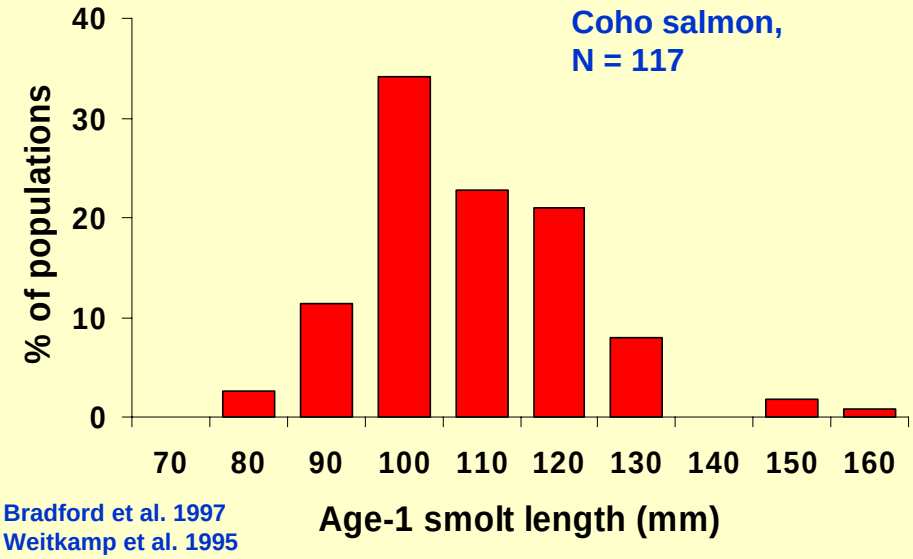
Fransen et al. 1993

Large fish (e.g., coho salmon) are more likely to survive the winter than smaller fish



Quinn and Peterson 1996

Variation in smolt size among populations



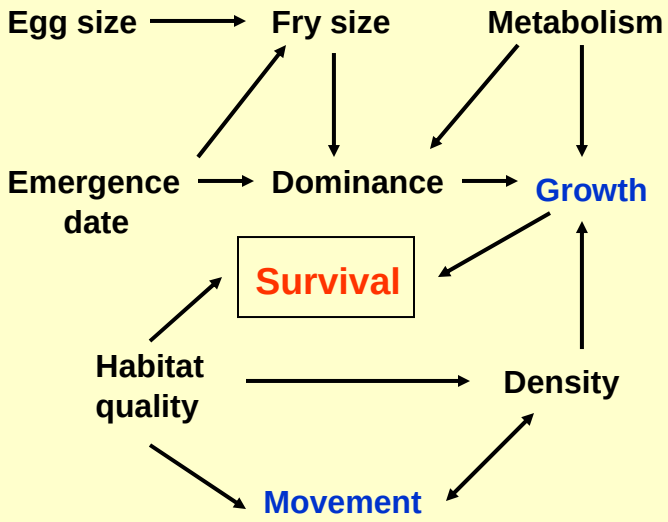
Bradford et al. 1997
Weitkamp et al. 1995

Movement: escape for losers or a chance for the adventurous to get ahead?

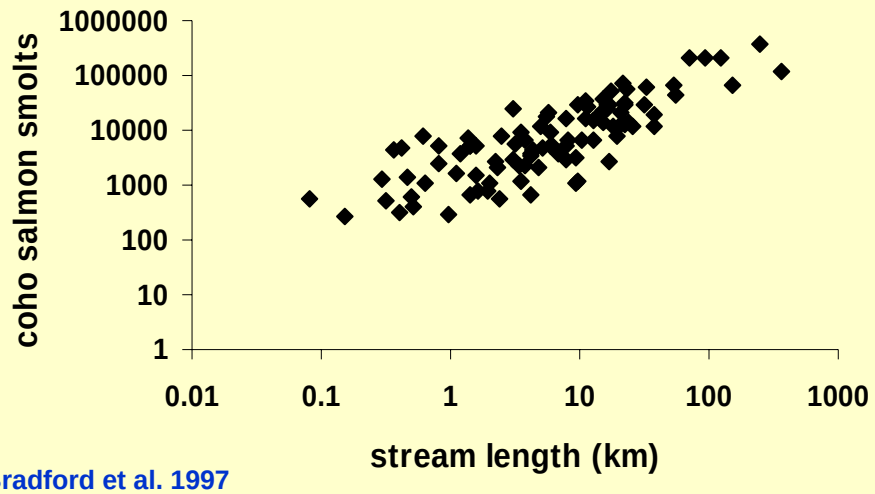
Conventional wisdom: small, weak, or late-emerging fry cannot obtain territories and move downstream, finding territories or perishing.

Recent results: Movement, especially upstream, is common, and reflects poor quality habitat rather than density. Fish may tolerate high density in good habitat and grow slowly. Fish in poor habitat may leave, even if density is low.

The perspective of individual salmonids in streams

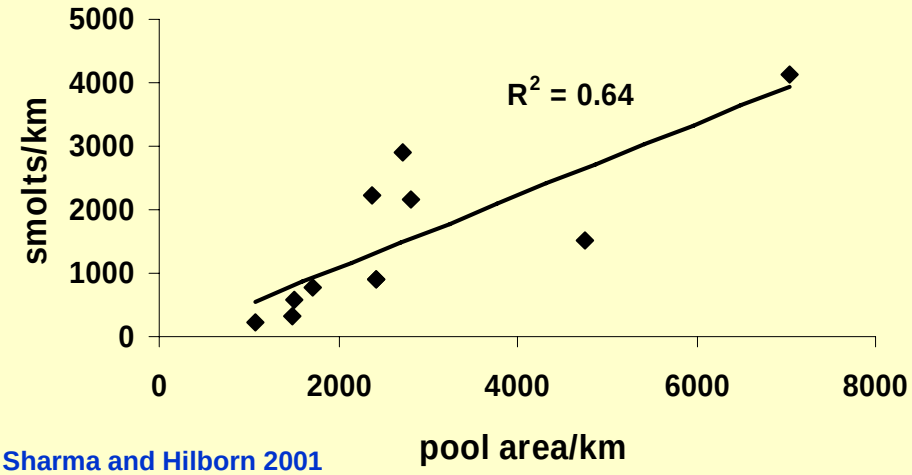


Stream length is the best predictor of coho salmon smolt yield



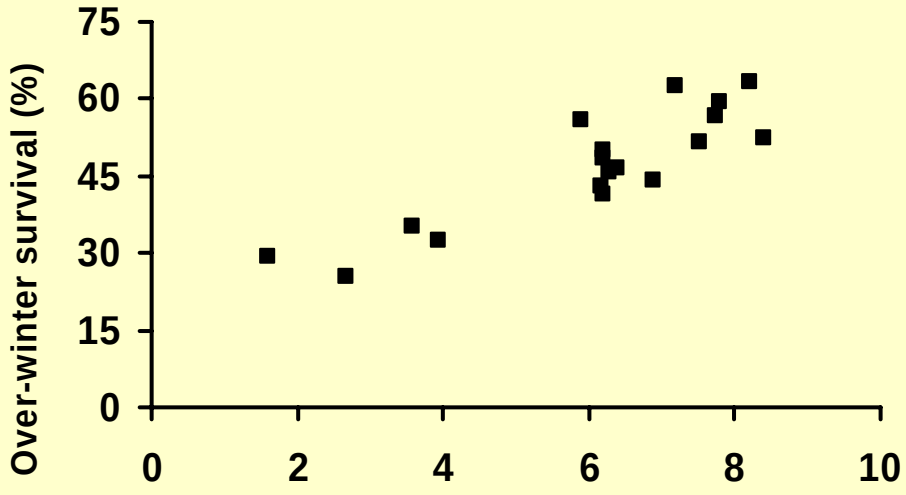
Bradford et al. 1997

Coho smolt production per km of stream is related to physical habitat variables (gradient, pond and pool density, etc.)



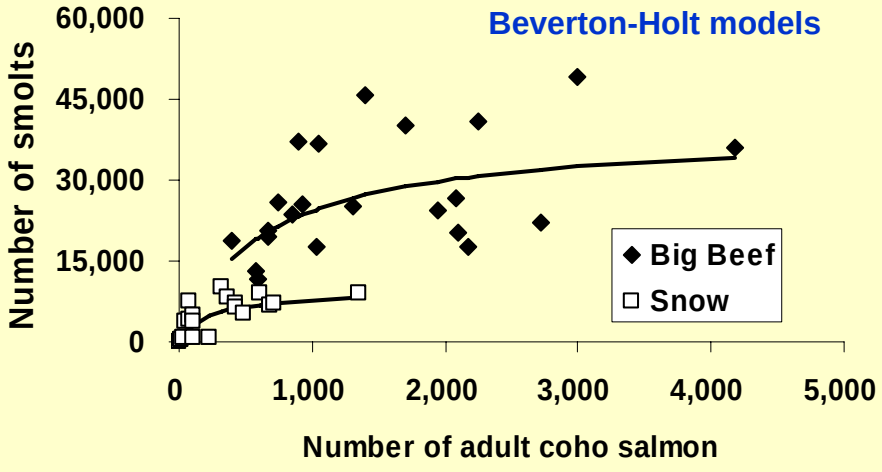
Sharma and Hilborn 2001

Tagging studies reveal higher over-winter survival rates in more complex reaches of stream for coho salmon

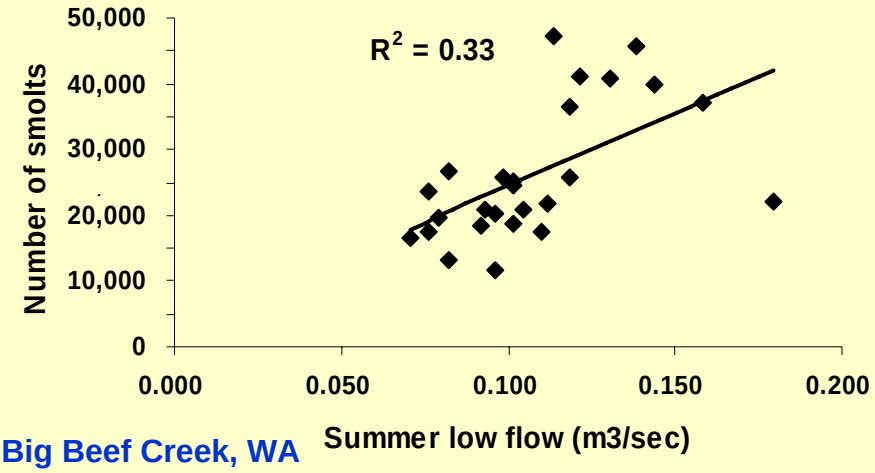


Quinn and Peterson 1996

When streams reach their carrying capacity, more spawning adults do not produce more smolts



Given adequate escapement, smolt production may be limited by low flow or other physical features



Big Beef Creek, WA
coho salmon

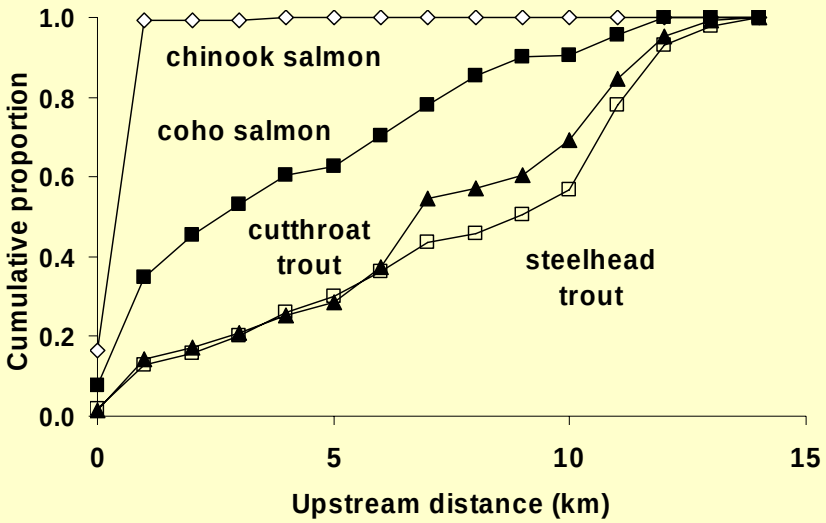
Species composition and density of juvenile salmonids (fish/m2) is affected by stream gradient, reflecting juvenile and adult ecology

Fish density

Gradient (m/km)	0+ coho	0+ trout	1+ steelhead	1+ cutthroat
High (24.1)	0.03	0.49	0.10	0.03
Low (10.9)	0.46	0.14	0.03	0.01

Averages of 5 high and 5 low gradient streams in Oregon; Hicks and Hall 2003

Species-specific fry distributions may reflect adult as well as juvenile ecology



Sitkum River, Quileute River basin; John McMillan, unpublished

The perspective of salmonid populations in streams

Variation among sites

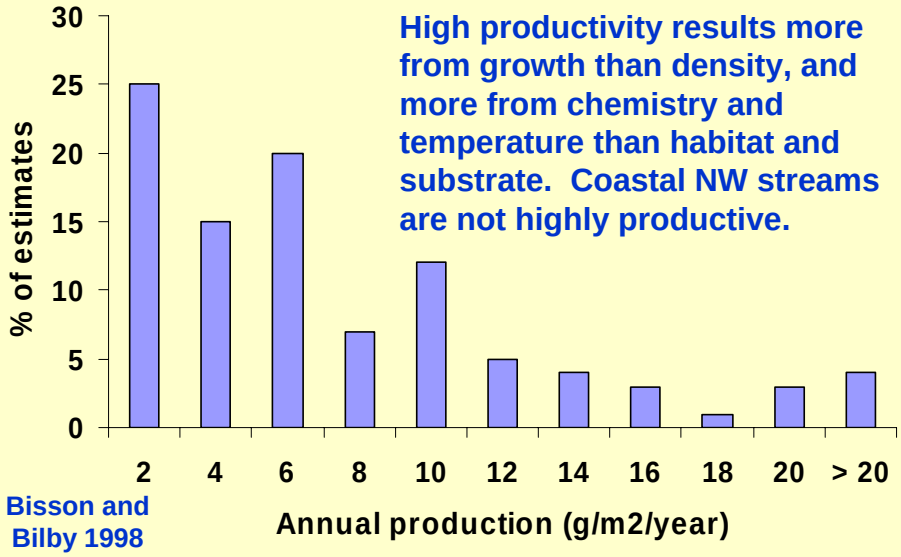
- Stream length (smolts/creek)
- Fixed attributes (smolts/km)

Variation among years

- Density (smolts/year)
- Physical conditions (smolts/female)

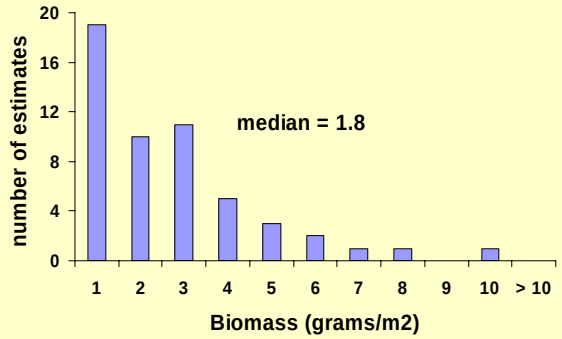
Within- and between-species effects

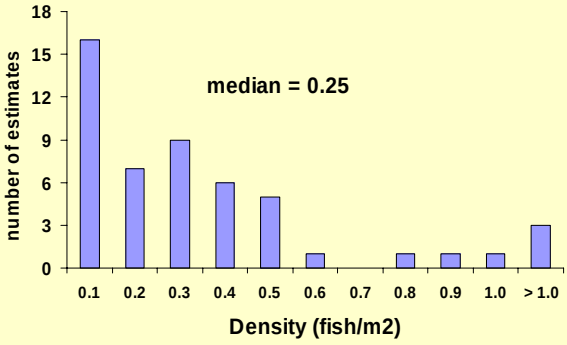
World-wide, the distribution of stream productivity for salmonids is very skewed.



High productivity results more from growth than density, and more from chemistry and temperature than habitat and substrate. Coastal NW streams are not highly productive.

Bisson and Bilby 1998



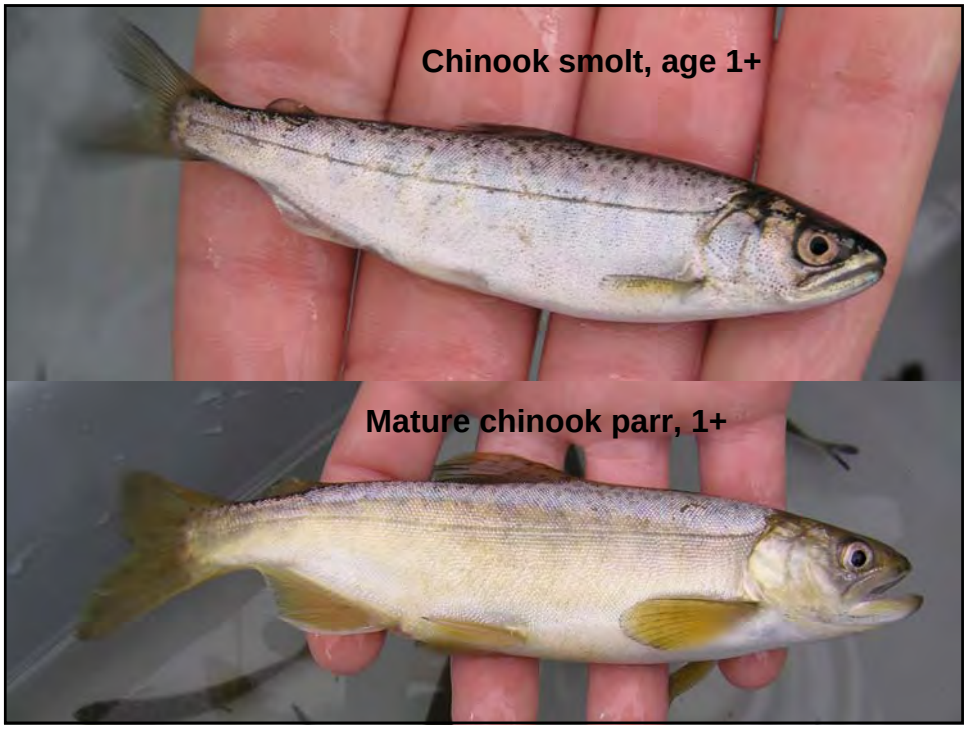


Estimates of biomass and density of trout and char in western Washington, Oregon and California are generally low.

Platts and McHenry 1988

Because streams in our region are unproductive, salmonids face a fundamental dilemma each year: stay, grow slowly but be safe, or go to sea, grow fast, and face the sharks!

Anadromy or residence: Should I stay or should I go now?



Typical (++) and less common (+) smolt ages

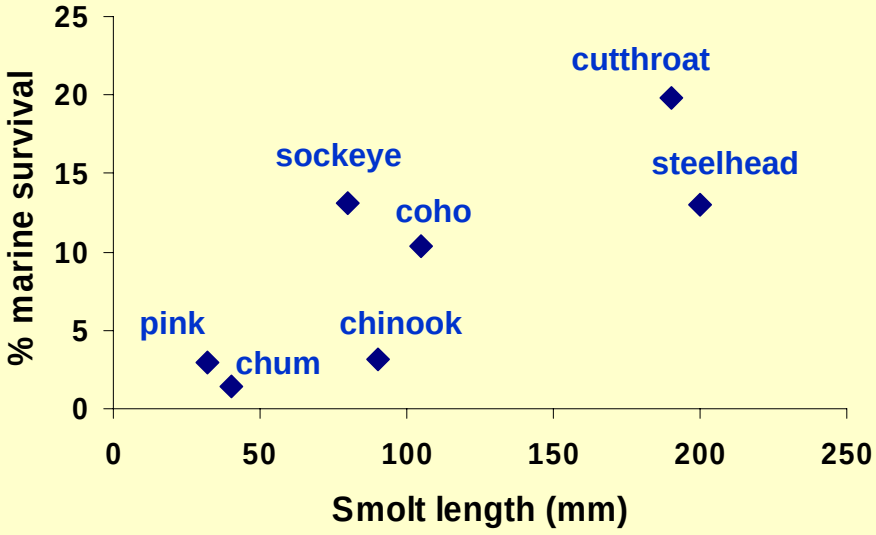
	0	1	2	3	4	5	6	7	8
Pink salmon	++								
Chum salmon	++								
Chinook salmon	++	++	+						
Coho salmon	+	++	++	+					
Masu salmon		++	++	+					
Steelhead trout		+	++	++	+				
Cutthroat trout		+	++	++	++	+	+		
Dolly Varden			+	++	++	+	+		
Arctic char		+	+	++	++	++	++	+	+

Age at seaward migration (e.g., steelhead smolts) seems to reflect the tradeoffs of growth and mortality in fresh water and at sea.

	1	2	3	4
Alaska	0	15	74	11
British Columbia	1	35	60	4
Washington	6	86	8	0
Columbia River	4	79	17	1
Oregon	4	79	16	1
California	23.3	69.0	7.5	0.3

Busby et al. 1996

Species with larger smolts tend to have higher survival at sea, though duration of residence at sea seems to also play a role



Conclusions:

- Stream are the primary if not exclusive breeding habitat for salmonids; most features (fecundity, site selection, nest depth) scale with fish size
- Survival to emergence varies with biotic and abiotic factors, often mediated by density
- The intrinsic capacity of streams for rearing stems from limited food and space
- Stream-rearing can be studied from individual and population-level perspectives but common themes emerge from both approaches