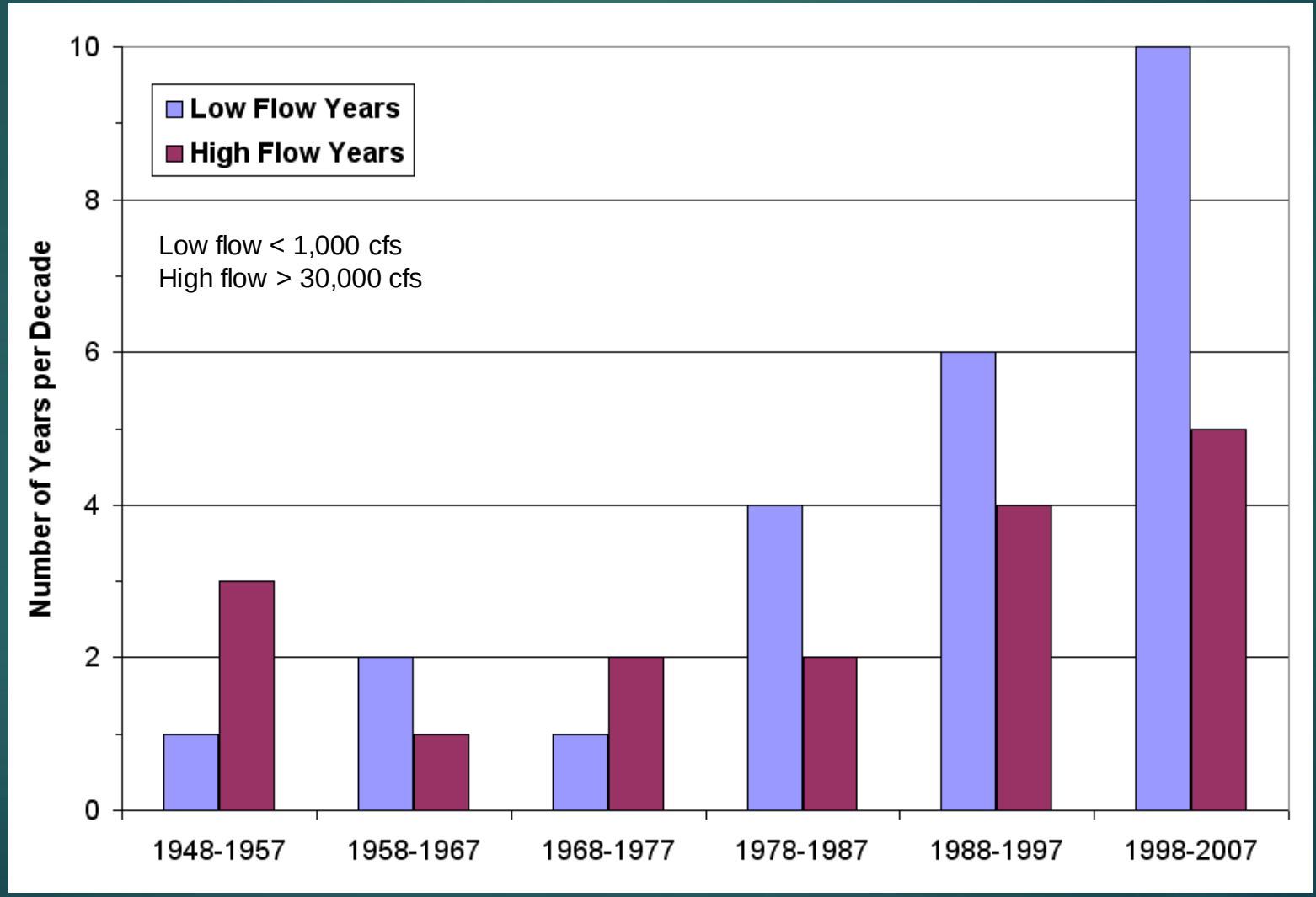
Challenges of aquatic invasive species and implications to upper Skagit reservoir fisheries under changing climatic conditions

JEFF FISHER, SEATTLE CITY LIGHT

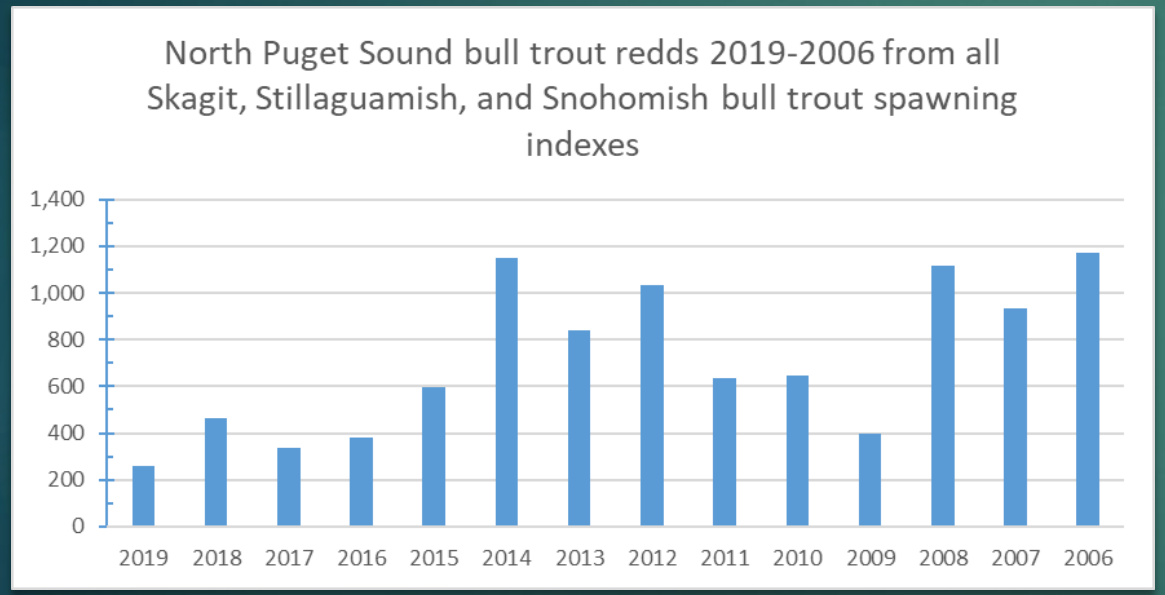
Processes likely to be influenced by climate change

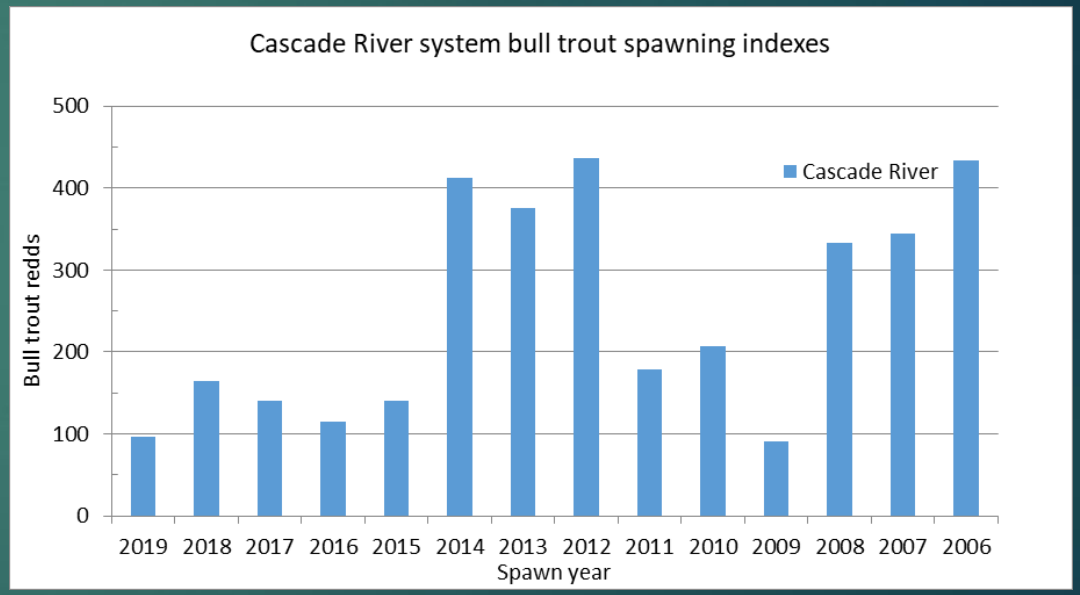
	Directional change in habitat characteristic	Predicted population effect
Incubation	↑ Winter flood magnitude	↑ Egg mortality
	↑ Winter temperature	↓ Emergence time
Freshwater rearing	↓ Summer flow	↓ Rearing area
		↑ Juvenile mortality
	↑ Summer temperature	↕ Growth rate
		↑ Juv./adult mortality
Estuary rearing	↑ Rearing temperature	↓ Residence time
	↑ Sea level	↓ Rearing area
Nearshore/ ocean rearing	↑ Rearing temperature	↕ Growth rate
	↓ Prey availability	↓ Growth rate
	↑ Winter temperature	↓ Juvenile mortality

Sauk River High and Low Flow Frequencies: 1948-2007



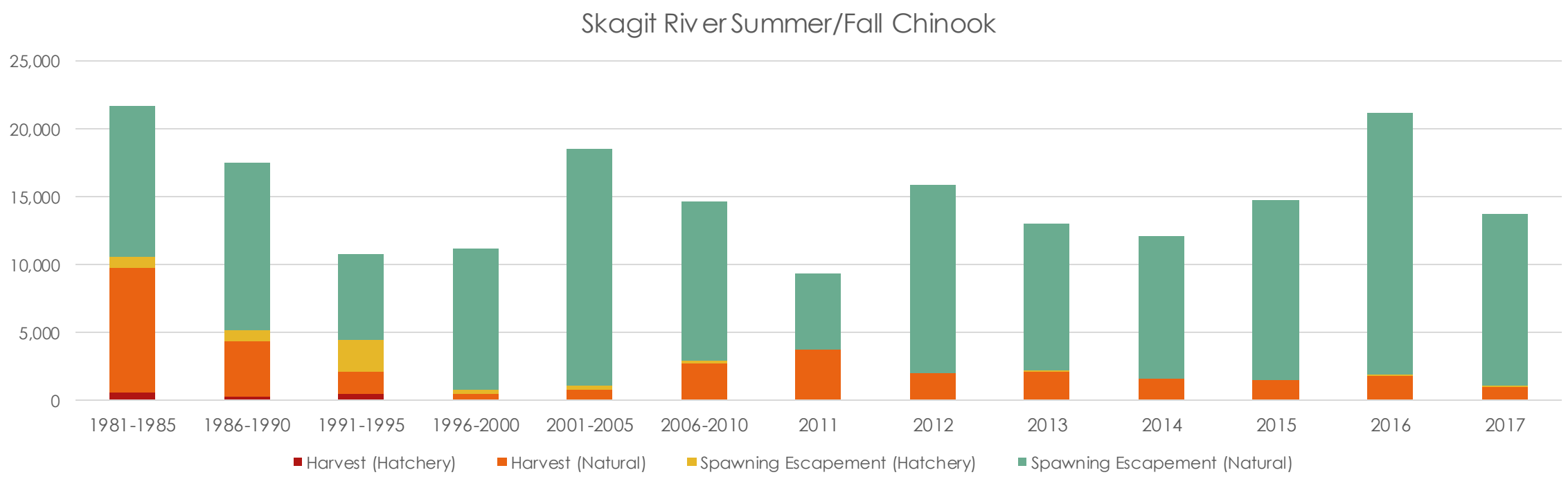
Recent returns indicate region-wide downward trends in spawning stocks, with some exceptions…





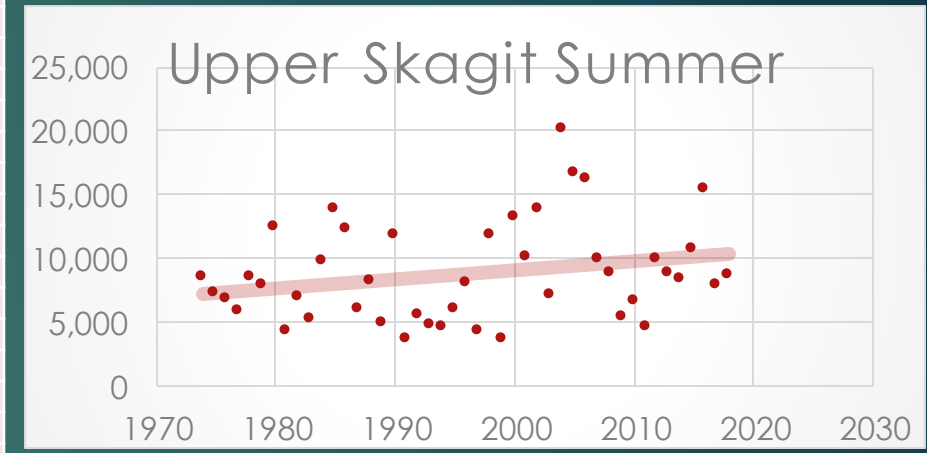
Source: A. Fowler, WDFW

Chinook trends data--PFMC



Skagit Tributary/Reach Chinook Escapement

Year	Upper Cascade Spring	Suiattle Trib. Spring	Upper Sauk Spring	Upper Skagit Summer	Lower Skagit Summer	Lower Sauk Summer	Skagit Spring Total	Skagit Summer/Fall Total	Percent Upper Skagit
1994	173	167	130	4,565	884	100	470	5,549	82.3
1995	225	440	190	5,948	666	263	855	6,877	86.5
1996	208	435	408	7,989	1,521	1,103	1,051	10,613	75.3
1997	308	428	305	4,168	409	295	1,041	4,872	85.6
1998	323	473	290	11,761	2,388	460	1,086	14,609	80.5
1999	83	208	180	3,586	1,043	295	471	4,924	72.8
2000	273	360	388	13,092	3,262	576	1,021	16,930	77.3
2001	625	688	543	10,084	2,606	1,103	1,856	13,793	73.1
2002	340	265	460	13,815	4,866	910	1,065	19,591	70.5
2003	298	353	193	7,123	1,161	1,493	844	9,777	72.9
2004	380	495	700	20,040	3,070	443	1,575	23,553	85.1
2005	420	518	308	16,608	3,320	875	1,246	20,803	79.8
2006	478	375	1,043	16,125	3,508	1,095	1,896	20,728	77.8
2007	223	108	282	9,845	1,053	383	613	11,281	87.3
2008	284	203	983	8,841	2,685	538	1,470	12,064	73.3
2009	338	273	367	5,290	1,439	250	978	6,979	75.8
2010	330	263	768	6,644	1,017	356	1,361	8,017	82.9
2011	265	215	345	4,480	820	237	825	5,537	80.9
2012	488	460	1,826	9,808	3,295	715	2,774	13,818	71.0
2013	310	620	1,080	8,801	1,551	530	2,010	10,882	80.9
2014	225	460	923	8,308	1,785	364	1,608	10,457	79.4
2015	188	478	743	10,705	2,203	406	1,409	13,314	80.4
2016	295	648	1502	15,406	2,840	1044	2,445	19,290	79.9
2017	323	898	1630	7,792	3,786	1001	2,851	12,579	61.9
2018	128	645	1603	8,602	1,923	378	2,376	10,903	78.9

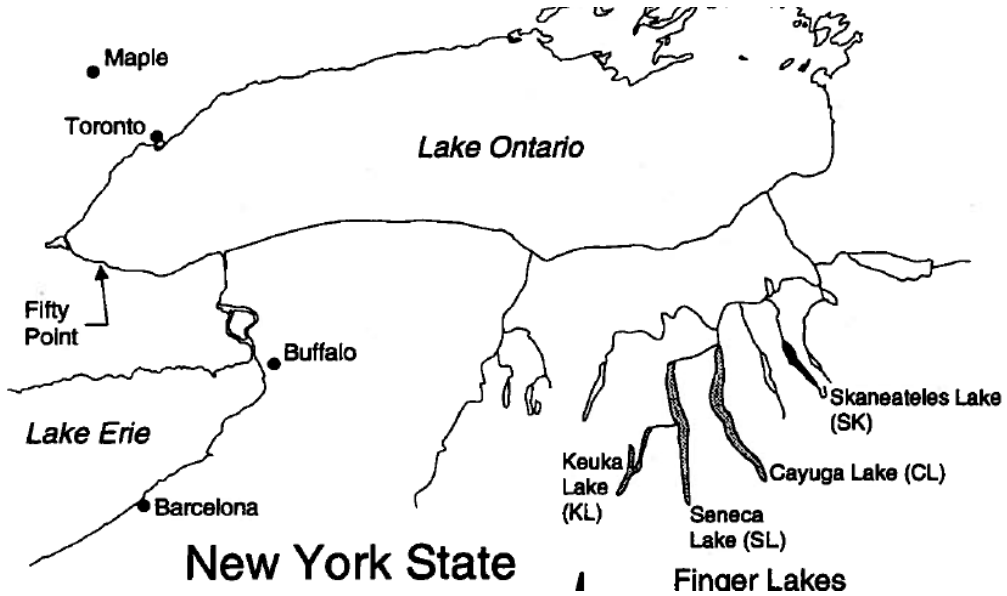


Climate change threats for Skagit salmonid species

	Pink	Chum	Chinook	Coho	Sockeye	Steelhead	Bull trout	Cutthroat
Spawning								
↑ Migration temp			Lower river		low tolerance	↓ summer run	low tolerance	
↓ Flow	Δ in redd depth		Δ in redd depth		Δ in redd depth	↓ summer run		
Incubation								
↑ Temp						summer run	low tolerance	
↑ Floods	scouring	scouring	scouring	scouring	scouring		scouring	
FW rearing								
↑ Temp			cold water	floodplains	lake rearing	tributaries	cold water	
↓ Summer flow			cold water	floodplains	lake rearing	tributaries	cold water	↓ habitat
Estuary rearing								
↑ Temp			↓ residence					↓ habitat
↑ Sea level		↓ habitat	↓ habitat					
Nearshore rearing								
↑ Temp	↓ habitat	↓ habitat	↓ habitat				low tolerance	
↑ Sea level	shoreline habitat	shoreline habitat	shoreline habitat					
↓ pH	plankton feeding	foodweb	foodweb	foodweb	plankton feeding	foodweb	foodweb	foodweb
Ocean rearing								
↑ Temp	summer habitat	summer habitat	summer habitat	summer habitat	summer habitat	summer habitat		
↓ pH	plankton feeding	foodweb	foodweb	foodweb	plankton feeding	foodweb		

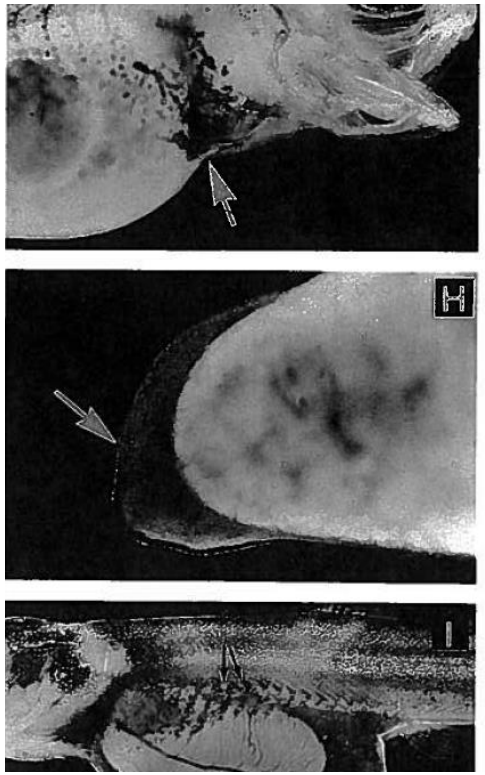
What's missing from the list of potential climate change effects?

- Invasive Species



Lessons to be learned from other systems: Atlantic salmon early mortality syndrome study area

Typical gross lesions in Atlantic salmon alevins from Cayuga Lake spawn



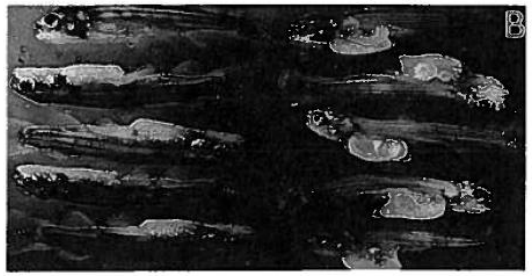
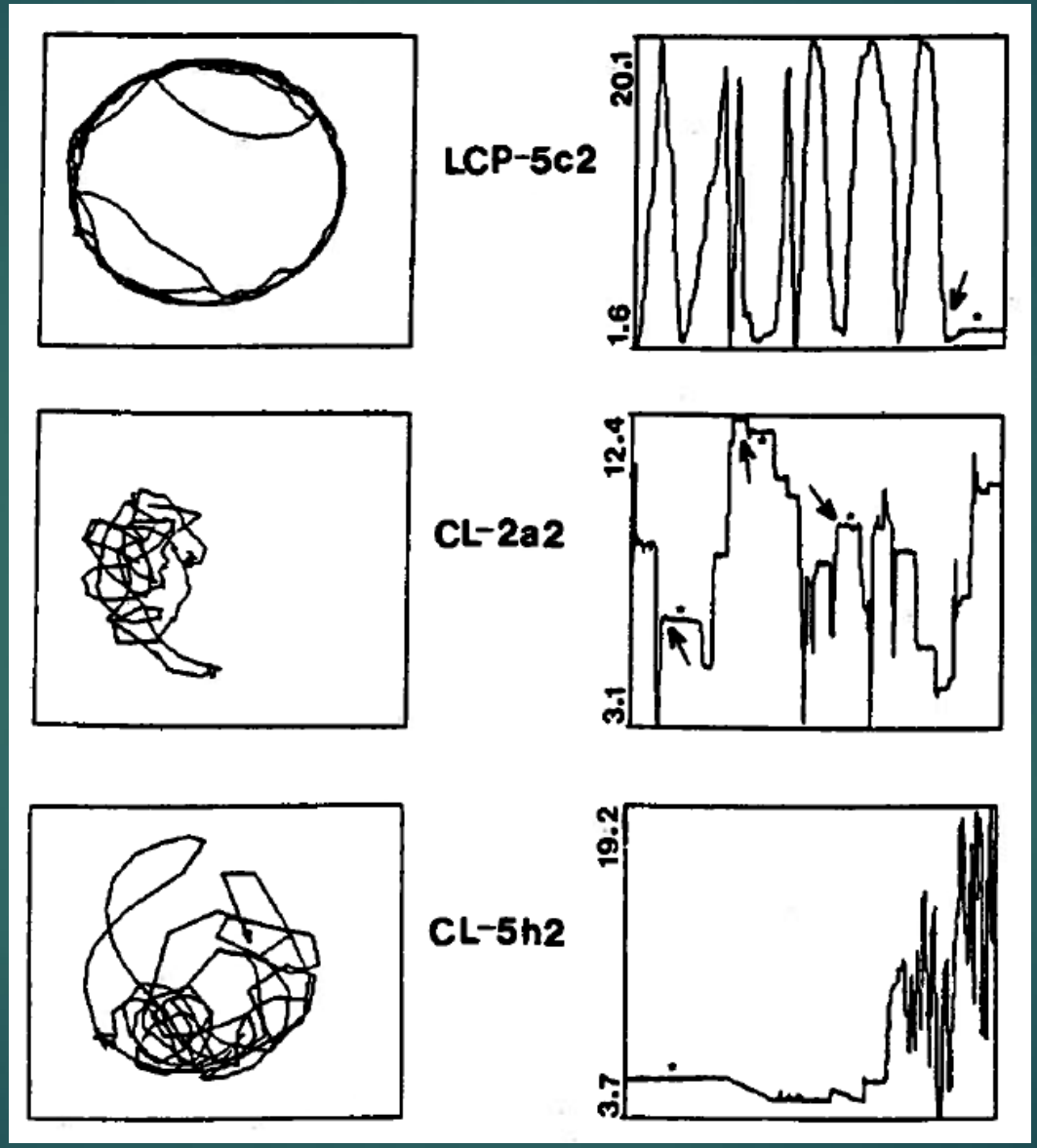


TABLE 1.—Gross lesion frequency in landlocked Atlantic salmon sac fry from Little Clear Pond (LCP), and syndrome-afflicted Cayuga Lake (CL) and Keuka Lake (KL). Results designated by female number (if cultured separately) are followed by year-class. Blank cells indicate that lesion frequency was not recorded. Standard errors are in parentheses.

Lesion or stage	Female number									
	LCP 90[a]	LCP 92[b]	CL 1-90[c]	CL 1-91	CL 1-92	CL 2-92	CL 3-92	CL 4-92	CL 5-92	KL 1-92
Lesion frequency (number of sacfry with lesions/number examined or percent)										
YSO[d]	2/40	0.0 (0)	32/40	9/18	15/22	19/21	22/22	20/20	21/21	19/20
SCE[e]	1/40	2.0 (2.2)	10/40	6/18	6/22	1/21	10/22	14/20	0/21	19/20
PCE[f]		0.0 (0)			4/22	0/21	6/22	8/20	0/21	16/20
RBE[g]	0/40	0.0 (0)	1/40	2/18	0/22	2/21	4/22	2/20	0/21	6/20
VCHM[h]	3/40	1.4 (7.6)	3/40	6/18	7/22	7/21	9/22	8/20	1/21	13/20
BCHM[i]	0/40	0.0 (0)	4/40	6/18	7/22	3/21	8/22	5/20	0/21	11/20
HC[j]	0/40	0.0 (0)	0/40	1/18	0/22	0/21	0/22	0/20	0/21	3/20
FM[k]	0/40	0.0 (0)	0/40	0/18	0/22	0/21	1/22	1/20	0/21	5/20
CC–CD[l]	0/40	0.0 (0)	1/40	1/18	7/22	0/21	4/22	15/20	0/21	12/20
SC[m]	1/40	0.0 (0)	0/40	0/18	0/22	1/21	0/22	0/20	0/21	0/20
Development reached (centigrade degree-days)										
DDays[n]	805, 834	678	750, 779	682	678	765	670	625	775	638
TTDO[o]	p	p	728 (11)	666	629 (24)	661	612	542 (0)	657 (35)	671 (12)
TTDC[q]	p	p	818 (11)	738	691 (6)	765	670	641 (0)	821 (0)	696 (0)

Typical stimulus-provoked swimming behavior in control (LCP) Atlantic salmon alevins and syndrome-affected alevins



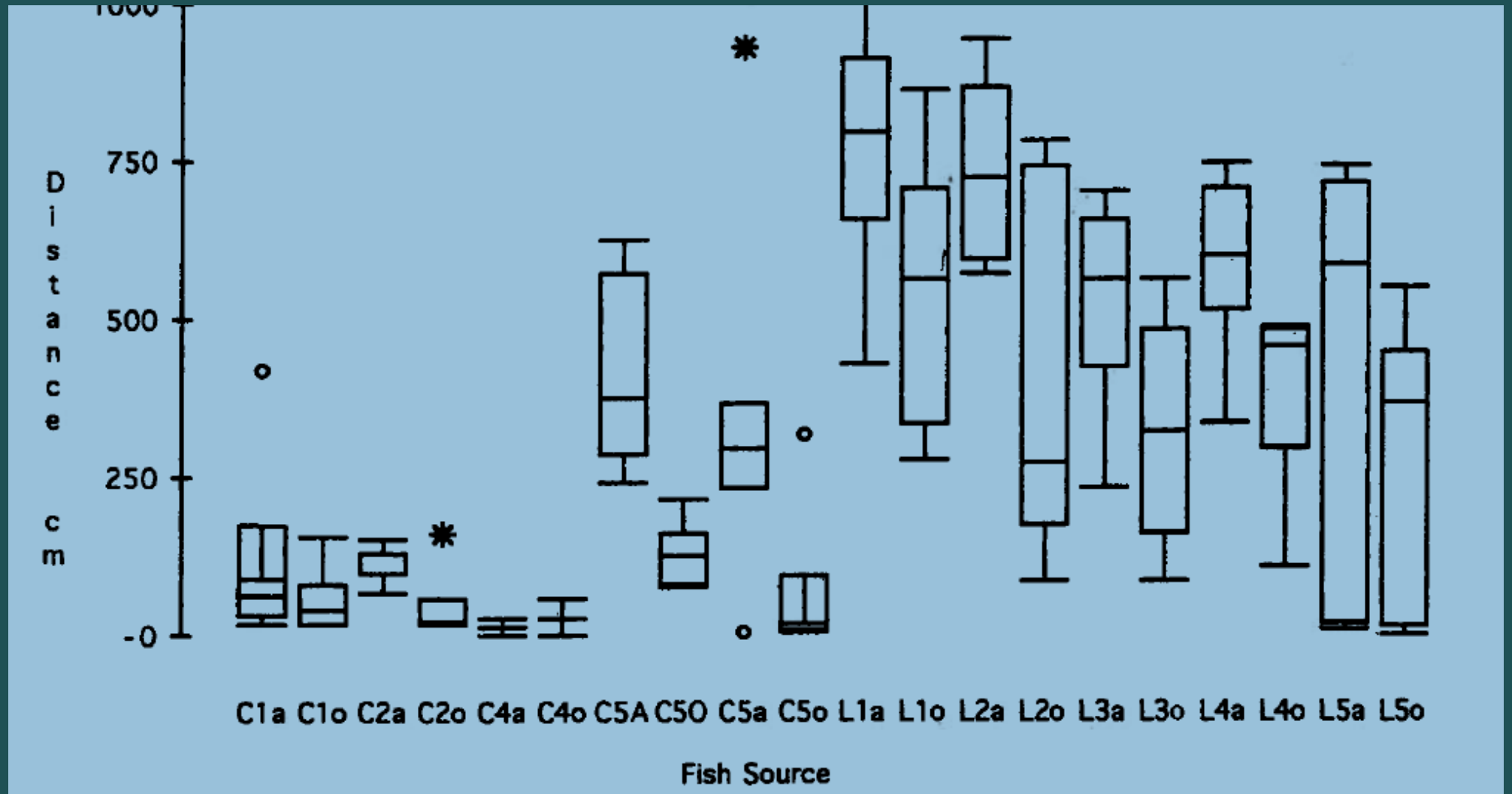


FIGURE 2.—Box plots of distance swum by Atlantic salmon sac fry from Cayuga Lake (C) and Little Clear Pond (L)

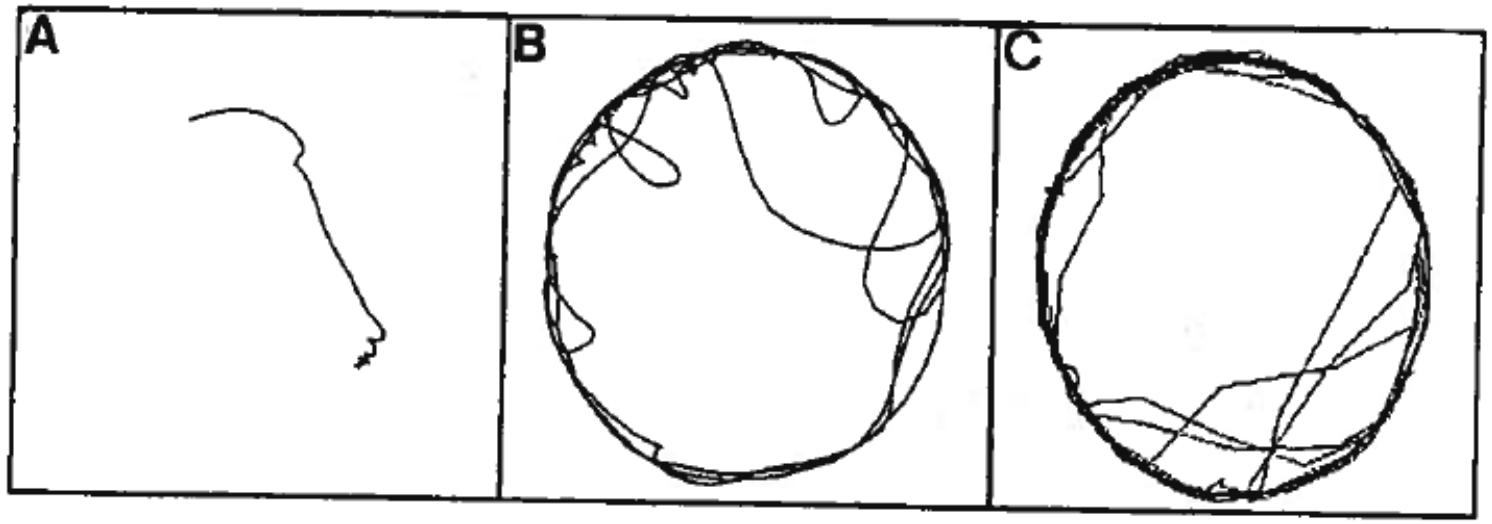
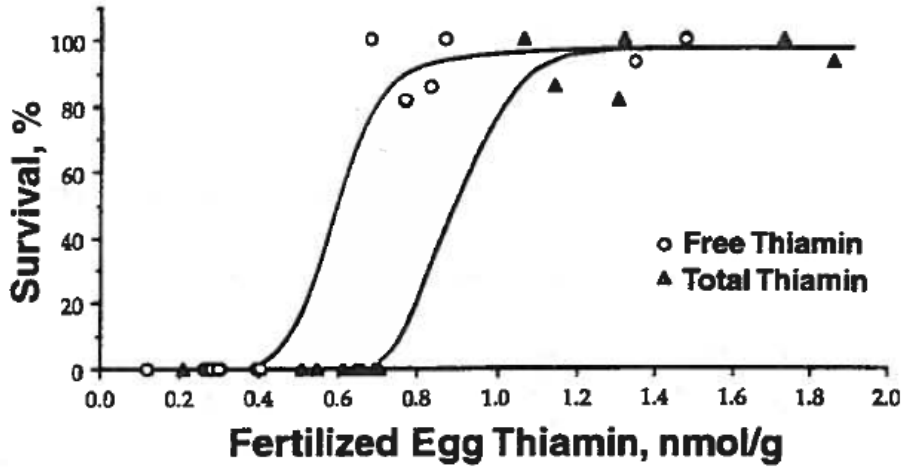


FIGURE 3.—Digitized swimming patterns of single Atlantic salmon sac fry from the control Little Clear Pond C) stock and from the syndrome-afflicted Cayuga Lake (CL) stock before and after thiamine bath treatment. awings indicate (**A**) representative syndrome-afflicted CL Atlantic salmon sac fry before thiamine bath treatment;) swimming pattern of the same CL sac fry 48 h after



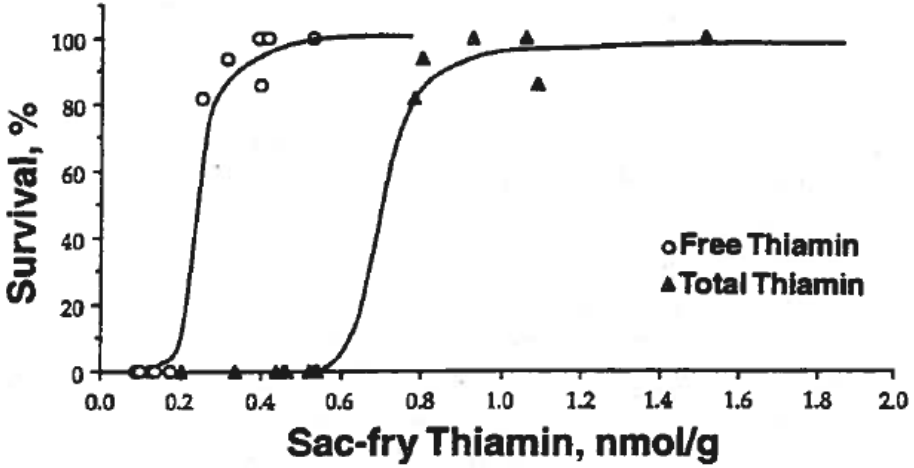


FIGURE 3 Interpolated best-fit curves of survival of landlocked Atlantic salmon through first feeding versus egg and sac-fry concentrations of free and total thiamine.

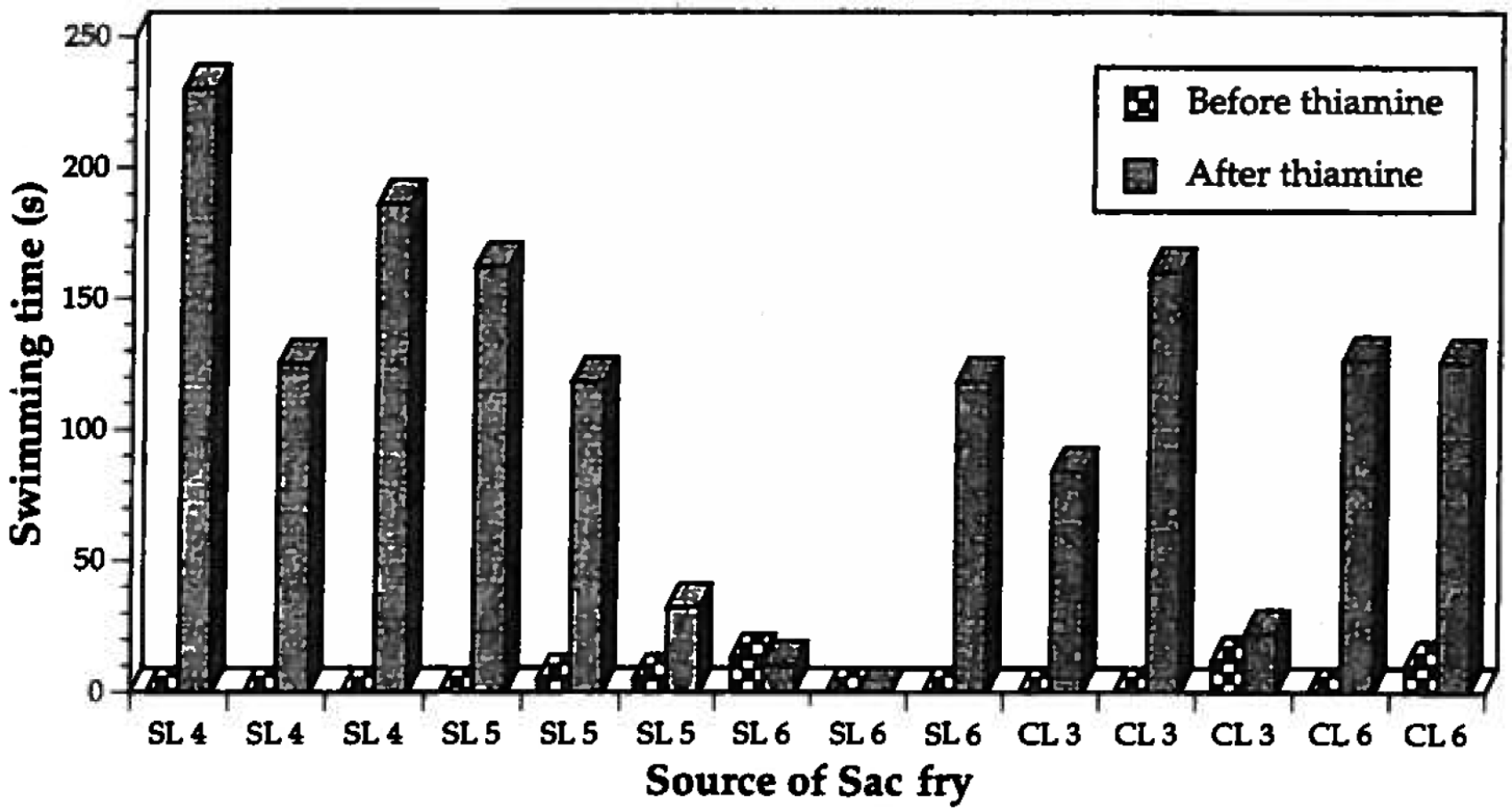


FIGURE 4.—Effect of a 1-h, 1% thiamine bath on the light-induced swimming behavior of Atlan
ry afflicted with the Cayuga syndrome. Each three-dimensional bar represents the swimming time of
fflicted sac fry during a 4-min observation before and 48 h after thiamine treatment. The source o

Factors Limiting Native Fishes Above Skagit River Mainstem Dams

USGS, Western Fisheries Research Center

- Goal: Identify and quantify factors limiting production of adfluvial salmonids that populate the reservoirs and associated tributaries

- OBJECTIVES:
- Reservoir & Tributary Food Web Interactions
- Redside Bioenergetics
- Geochemical Identification of Natal Tributaries
- Tributary Habitat Spawning & Rearing Capacity
- Distribution of Native & non-native Salmonids in Tributaries to Ross & Diablo Reservoirs
- Hybridization with Native Salmonids

USGS science for a changing world

Upper Skagit reservoirs

- Energy – 20% of Seattle's electricity
- FERC relicense and concern over native populations?

ESA-listed bull trout

Credit: NPS

Rainbow trout

Credit: Cameron Miller

Invasive redside shiner

Credit: NPS

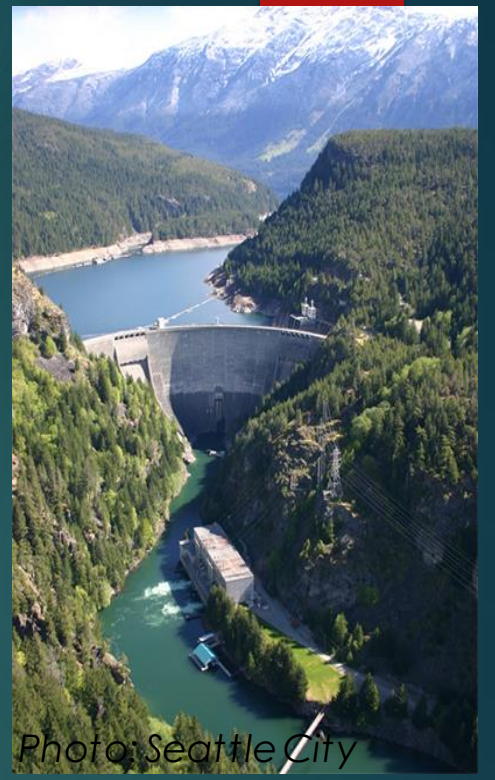


Photo: Seattle City Light

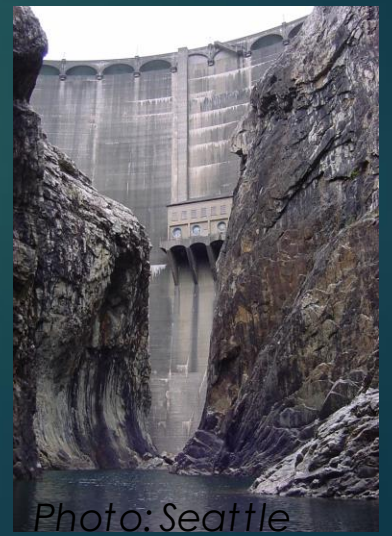


Photo: Seattle City Light

- **<u>What is limiting production of native fishes</u>?**
  - Temperature? Prey availability? Predation? Competition?

Quantifying food web interactions

bull trout/ Dolly Varden

Brook trout

Rainbow trout - adult

Top predators

(-)

Competition?

?

Redside shiner

Rainbow trout - juvenile

Zooplankt

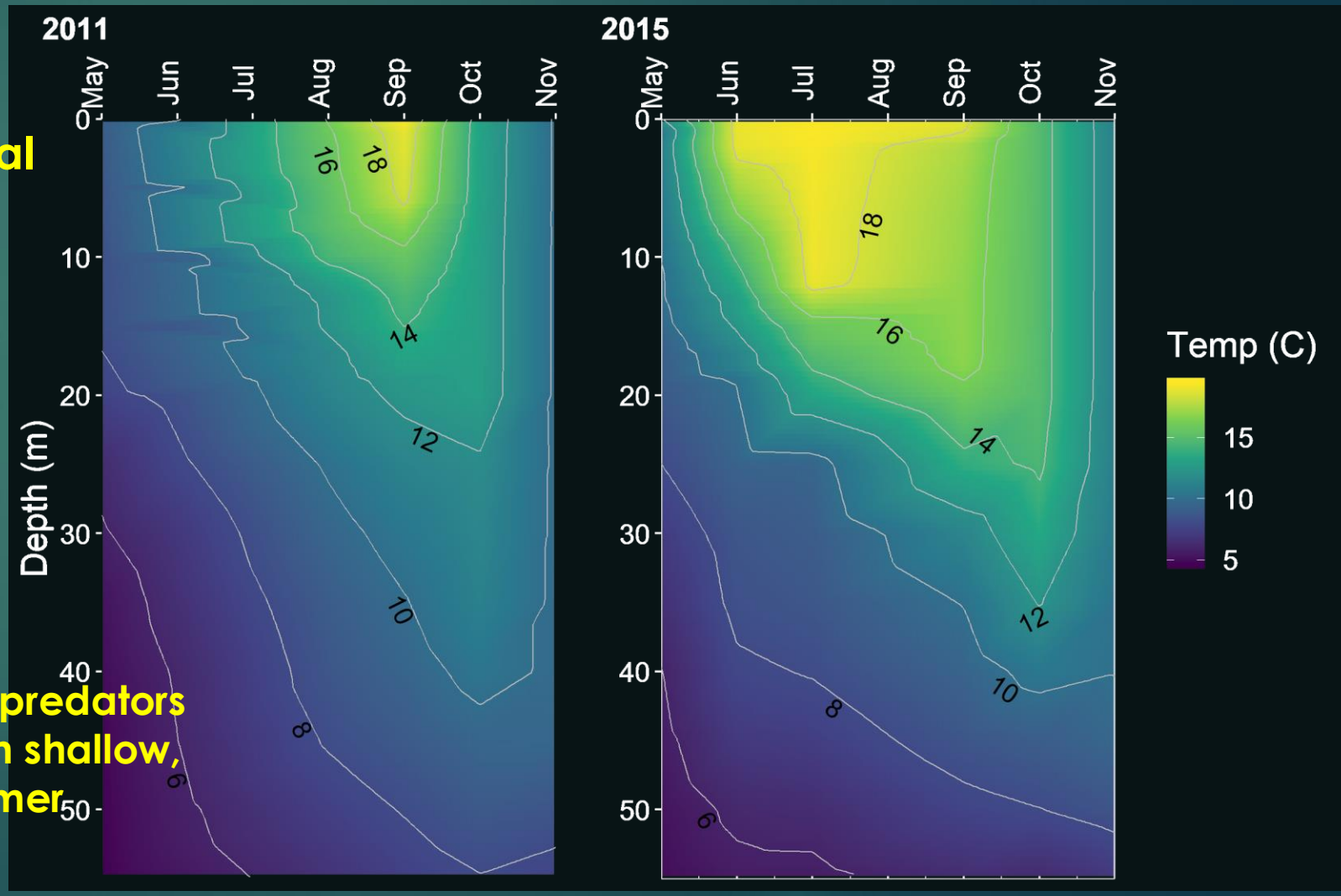
Benth

Thermal structure of Ross Lake

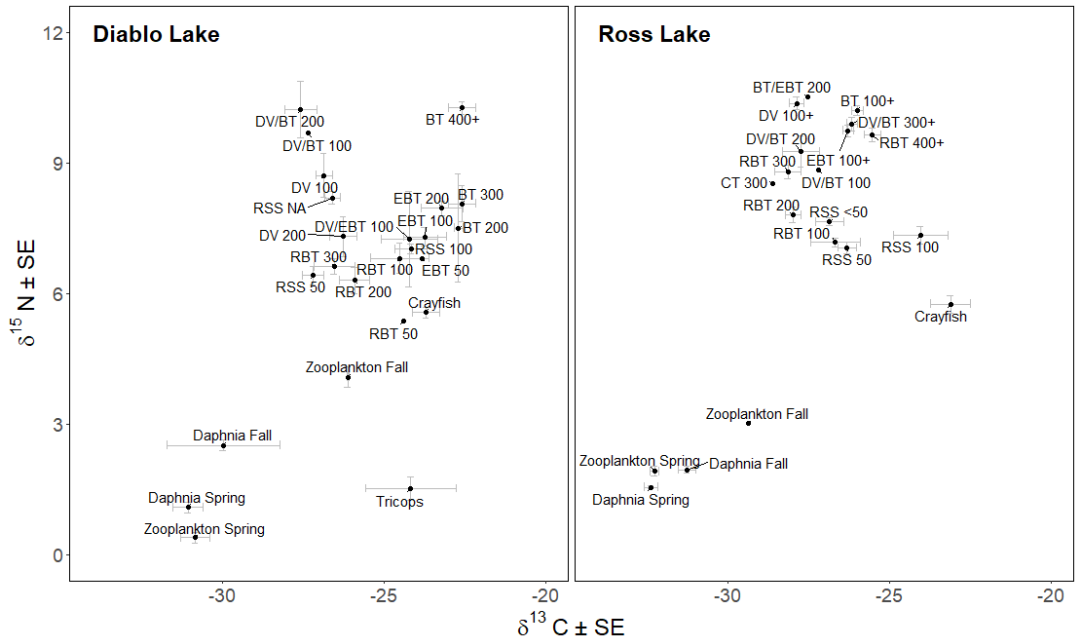
Thermal structure influences spatial overlap and trophic interactions among species

-Invasive Redside shiners have Higher thermal tolerance & optimal temperatures for growth than native salmonids

Warmer climates:
-increase segregation of shiners from predators
-reduce access of juv. Salmonids from shallow, high-density zooplankton during summer



Food web structure: stable isotopes



Bull trout

Rainbow trout - adult

Brook trout

Dolly varden

Native char hybrids

Top predators

Redside shiner

Rainbow trout - juvenile

?

Predation quantified

How many fish?

At a mean prey size of 70 mm (3.5 g)…

	Prey species	
Predator	RSS	Unid. Fish
DV	880	5,303
EBT	61,307	26,477
Hybrids	208,730	142,201
BT	233,574	203,287
RBT	383,196	246,802
Total	**887,687**	**624,070***

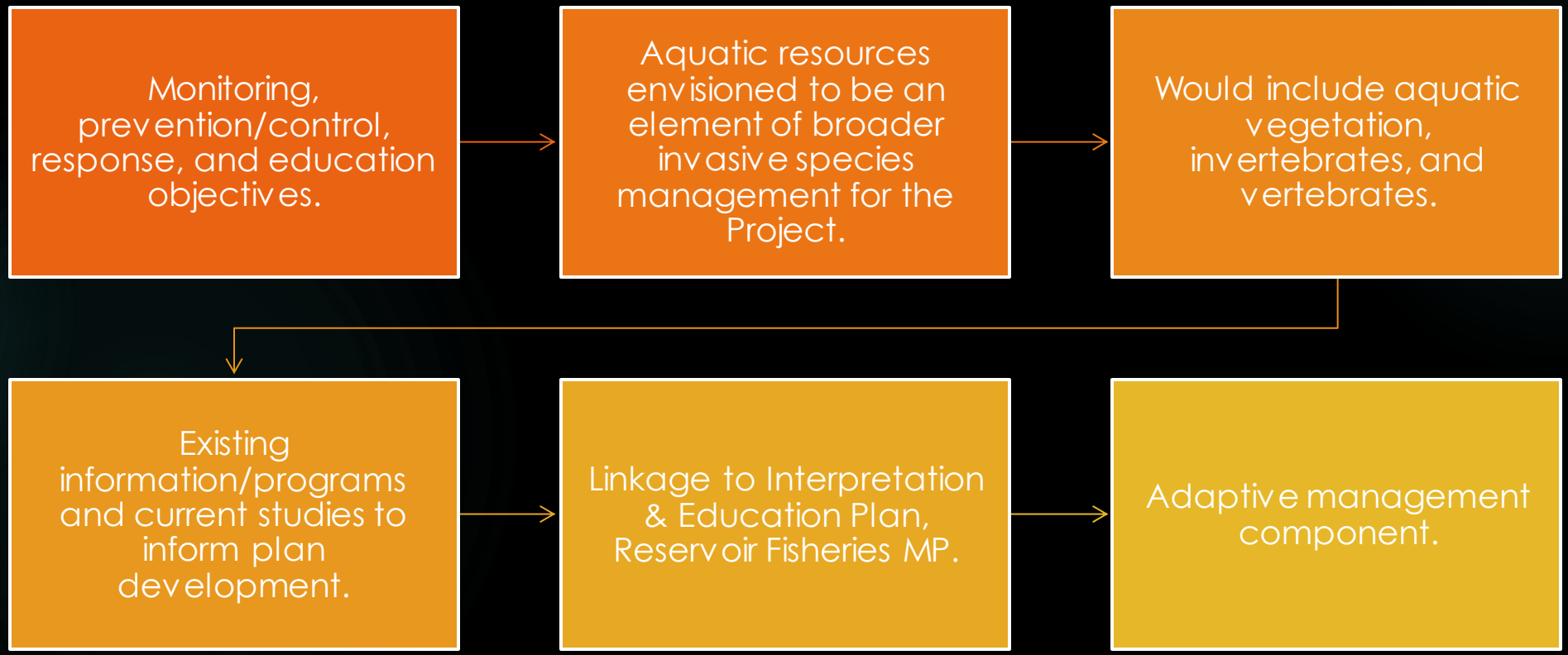
*If just 1% of these unidentified fish were salmonids, that would mean annual predation mortality of approx. 6,240 fish

Next steps

- More robust diet data
  - Stable isotope mixing models
- Estimating redside shiner population densities
  - Hydroacoustic surveys
- Resource competition: quantifying redside shiner consumption
  - Parameterizing a bioenergetics model (in progress)

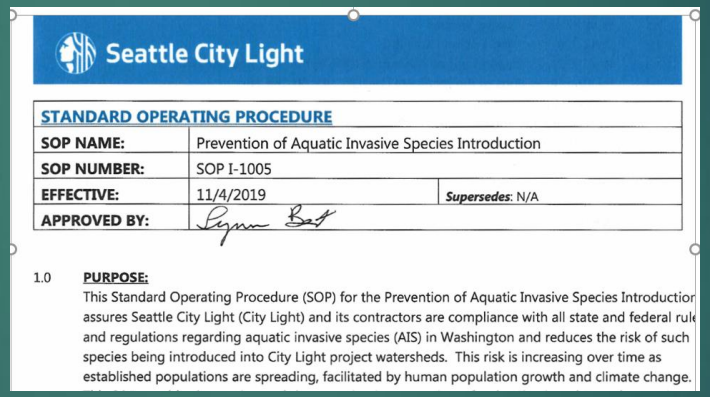
Bull trout in British Columbia credit: Joel Sartore

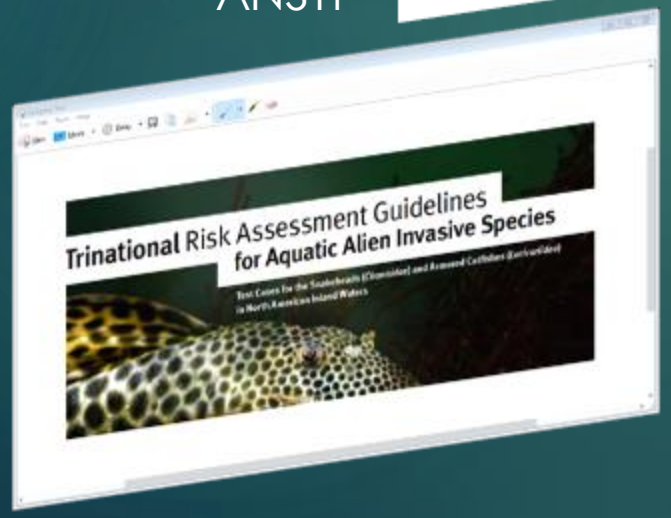
Aquatic Invasive Species Mngt Plan



LOTS OF GUIDANCE AND POLICY OUT THERE SAY 'HOW' AND SET CRITERIA…

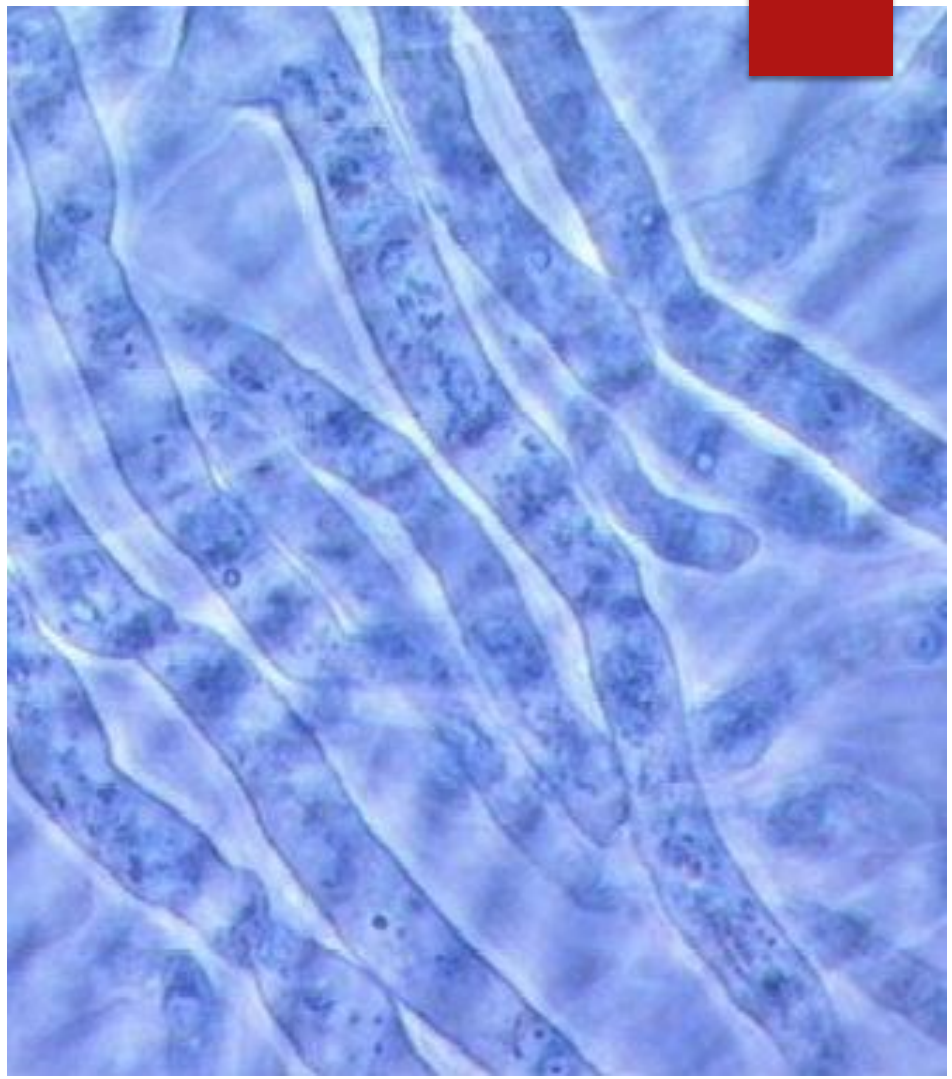
- CBD Art. 8(h)--"*prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.*"
- IMO-Ballast Water Convention--First standards developed to replace first voluntary guidelines for ballast water: 10 orgs/ml ballast (^{3} (>50 um)
- OIE
- ANSTF





Crayfish Plague

- Crayfish Plague – causative agent is oomycete *Aphanomyces astaci* – type of water mould – 5 Genotypes
- Clinical signs – behavioural changes-scratching & day-time activity, melanisation
- Survives outside host – water, mud, damp clothes, fur, equipment/gear – up to 21 days
- Fatal disease for White-clawed Crayfish with up to 100% mortality in populations



Potential pathway

- Carrier species – Signal crayfish/Red swamp crayfish, Otters, other Wildlife species
- Movement – Stocked fisheries, Ornamental & Pet trade
- Possible transfer via water and mud on damp clothes, footwear, bike tyres, fishing or boating equipment or any machinery
- Human activities - Water sports & recreational activities such as angling, kayaking, dog walking

ONE POSSIBLE MANAGEMENT ACTION WHEN RISKS ARE CONSIDERED TOO HIGH …

(A.K.A. WHAT *REALLY* HAPPENED TO NEM0)

Acknowledgements

- Ed Connor, Seattle City Light (retired)
- Rachelle (Shelley) Johnson, USGS
- Dave Beauchamp, USGS
- Alan Fowler, WDFW
- NPS--NOCA

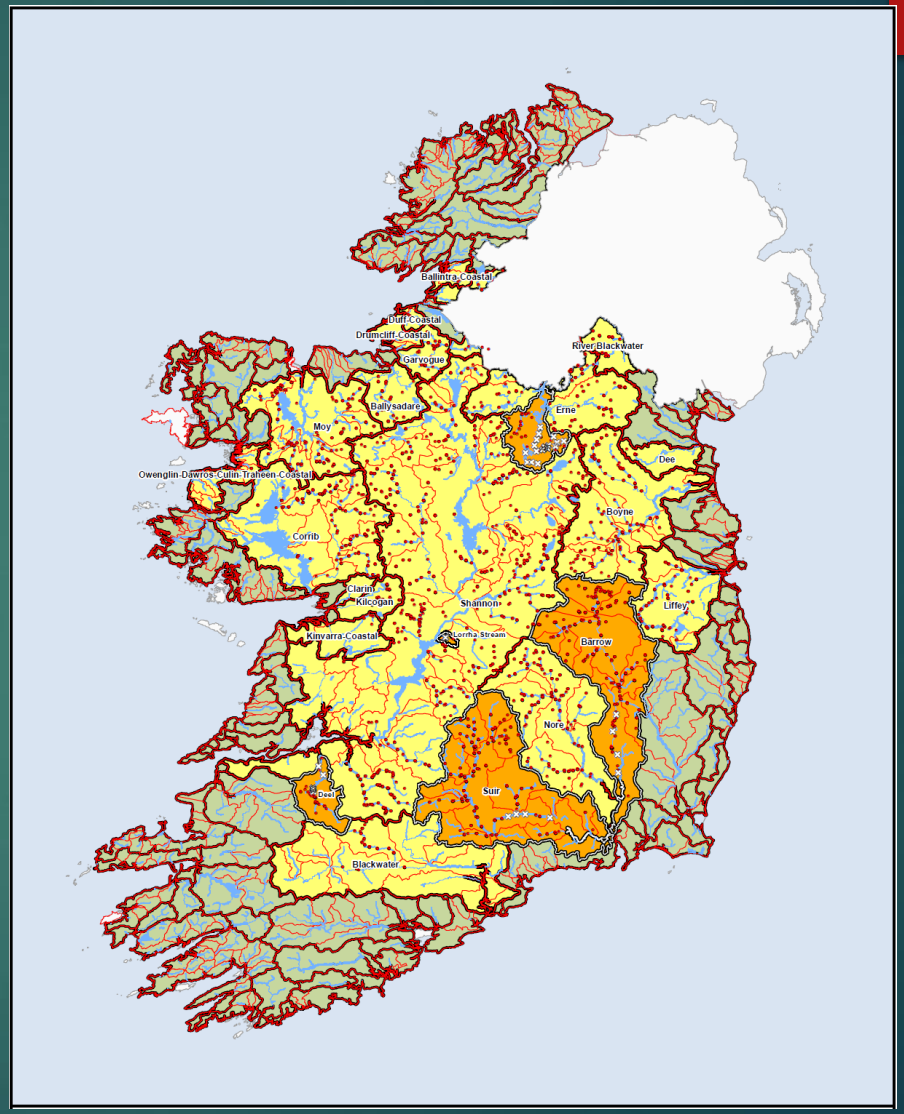
Climate Adaptation and Instream Flows

- SCL reservoirs currently reduce peak flows by average of 17% in lower Skagit
- Reservoirs have limited additional capacity to offset increased peak flows caused by climate change (55% of Skagit Basin is unregulated)
- SCL reservoirs currently increase minimum annual flows by 36% on average
- Fish management flows provide protections from low flow events down to Skagit estuary
- Flow augmentation of 1,650 cfs by SCL reservoirs will become more important under future low flows

Recent Outbreaks

- 2015 – Bruskey, Co. Cavan
- 2017 –
  - River Suir, Co. Tipperary
  - River Deel, Co. Limerick
  - Lorrha River, Co. Tipperary
  - River Barrow, Co. Waterford

- Suspected cases – Negative for Crayfish plague; No further mortality reported.



Management Procedure

(For Import Pathways)