Monitoring hatchery-wild introgression in Puget Sound steelhead

Bethany Craig, Kenneth Warheit, Joseph Anderson, and Todd Seamons

The Washington Department of Fish and Wildlife

Pacific Coast Steelhead Management Meeting, March 16-18,

Puget Sound steelhead segregated hatchery programs

- Support recreational and tribal harvest opportunities
- Intentional selection of early maturing fish to advance spawn timing
- Designed to minimize reproduction with wild steelhead

Early Winter Hatchery stock (EWH) developed from Chambers Creek in south Puget Sound, “Chambers”

Early Summer Hatchery stock (ESH) developed from lower Washougal River in lower Columbia River, “Skamania”

Puget Sound steelhead segregated hatchery programs

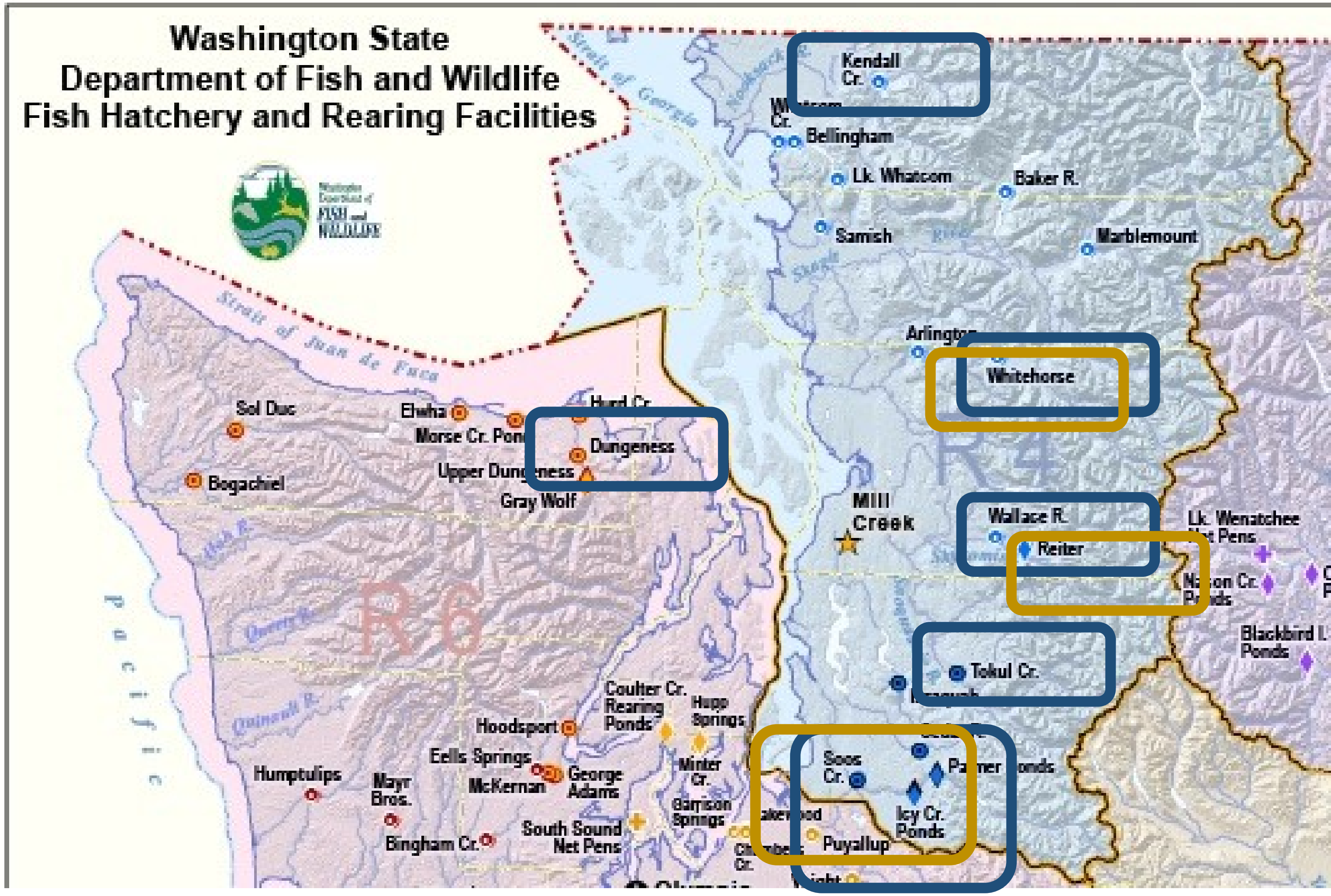
EWH

- Nooksack, Stillaguamish, Skykomish, Snoqualmie, and Dungeness, *authorized 2016*
- Green, *terminated, last release 2014*

ESH

- Green, *authorized 2019*
- Skykomish, *phasing out, proposal to transition to local stock*
- Stillaguamish, *terminated, last release 2019*

BiOps stipulate < 2% gene flow from hatchery programs into wild population



Genetic risks of hatchery programs

- Earlier spawn timing of early run hatchery steelhead may be insufficient to prevent spawning with wild fish, Seamons et al. 2012 *Evol App*

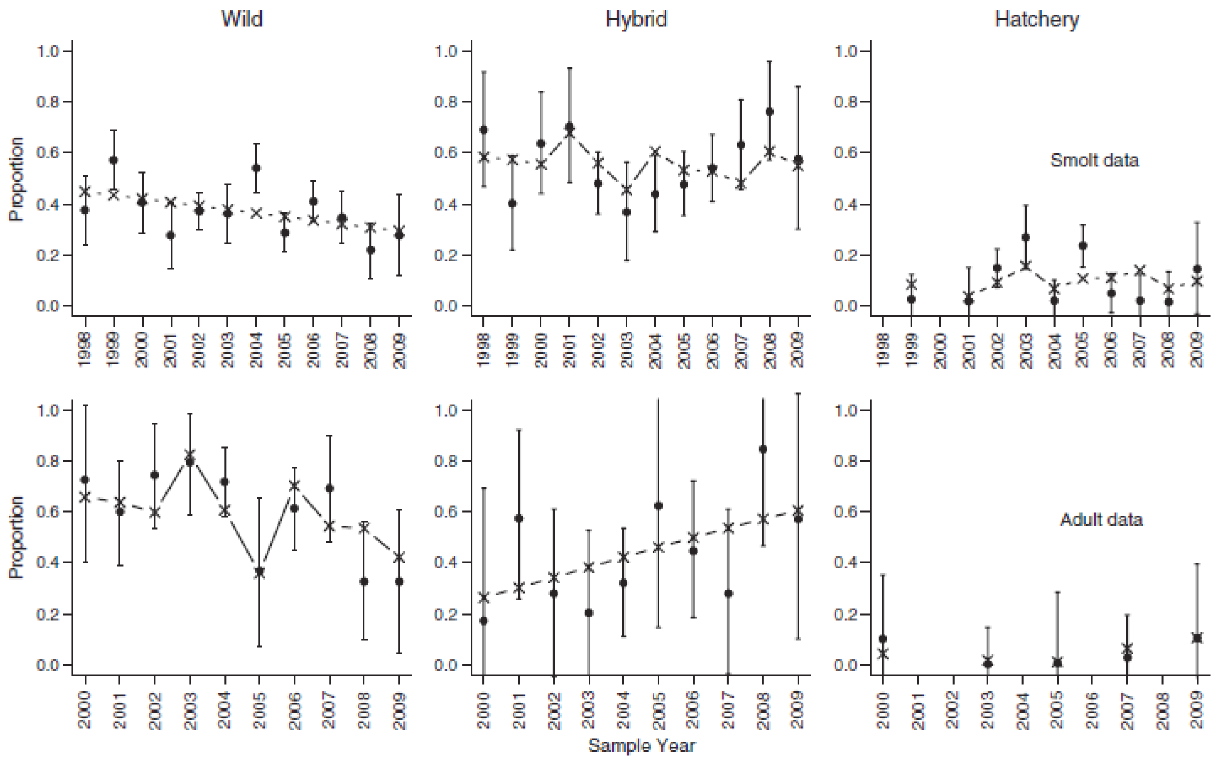


Figure 4 Time series of estimates of true proportions of wild, hatchery, and hatchery/wild hybrid smolt and adult individuals (black) and expected values from the best fit models (-x-; Table S4). Error bars represent 95% confidence interval of true estimates based on distributions of observed hatchery and wild mixture proportions bootstrapped across individuals.

Seamons et al. 2012 *Evol App*

Genetic risks of hatchery programs

Evidence that hatchery-origin fish have lower reproductive fitness than natural-origin fish, Araki et al. 2008 *Evol App,* Araki et al. 2009 *Biol Letters*, Christie et al. 2014 *Evo Apps*

elative Reproductive Success of non-native, segregated steelhead hatchery programs

STUDY	POPULATIO N	HATCHERY	WILD	SEGMENT	SEX	RRS (MAX)
Chilcote et al. 1986 Ledier et al. 1990	Kalama River	Summer *(Skamania)*	Summer	Lifetime	F, M	0.13
McLean et al. 2003	Forks Creek	Winter *(Chambers)*	Winter	Lifetime	F, M	0.11
Araki et al. 2007	Hood River	Winter *(Big Creek)*	Winter	Lifetime	F M	0.11 0.06
Araki et al. 2007	Hood River	Summer *(Skamania)*	Summer	Lifetime	F M	0.37 0.35

Adapted from Araki et al. 2008 *Evol App*, courtesy of Ken Warheit

Genetic risks of hatchery programs

TABLE 2

Unadjusted offspring proportions (C_h), observed frequencies of the G3PDH-1 A′ allele (f_o), and frequencies (f_o') offspring proportions (C_h') and reproductive success (RS_h') adjusted for the negative survival effects associated with the genetic mark in offspring of naturally spawning hatchery summer-run steelhead in the Kalama River, Washington

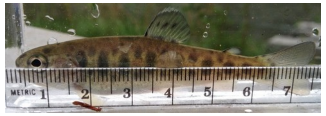
Values computed using potential egg deposition (PED) and potential gamete contribution (PGC) methods

Life history stage			Brood year 1979	1980	1981	1982	Mean
Subyearlings	C_h	PED	0.592	0.537	0.128	0.686	0.486
		PGC	0.533	0.531	0.031	0.606	0.425
	C_h'	PED	0.876	0.800	0.560	0.942	0.794
		PGC	0.848	0.796	0.465	0.922	0.758
	RS_h'	PED	0.924	0.801	0.278	1.149	0.788
		PGC	0.850	0.912	0.243	0.997	0.750
Smolts	C_h	PED	0.488	0.638	0.211	0.722	0.515
		PGC	0.429	0.633	0.108	0.648	0.455
	C_h'	PED	0.629	0.745	0.367	0.813	0.638
		PGC	0.572	0.741	0.262	0.757	0.583
	RS_h'	PED	0.221	0.586	0.127	0.307	0.310
		PGC	0.203	0.667	0.099	0.262	0.308
Adults	f_o		0.173	0.189	0.128	0.173	
	f_o'		0.231	0.234	0.161	0.221	
	N		56	112	112	160	
	C_h		0.345	0.310	0.096	0.277	0.257
	C_h'		0.502	0.456	0.256	0.457	0.418
	RS_h'	PED	0.131	0.168	0.075	0.059	0.108
		PGC	0.153	0.197	0.095	0.071	0.129

Leider et al. 1990 *Aquaculture*

Evidence of differential survival at all life stages for fish with hatchery ancestry,

Leider et al. 1990 *Aquaculture*



Puget Sound steelhead genetic monitoring Program goals

1. Ensure proportion effective hatchery contribution (PEHC) < 2%
2. Describe factors affecting PEHC
   - PEHC through the steelhead life cycle
   - Hatchery operations
   - Mechanisms of introgression

Estimating hatchery-wild introgression

Genetic methods required because direct observations of spawning rare or impossible

- No carcasses
- Winter/spring river conditions: turbid, high flows

Proportion effective hatchery contribution (PEHC)

- Use offspring DNA samples to identify hatchery vs. wild origin of parents

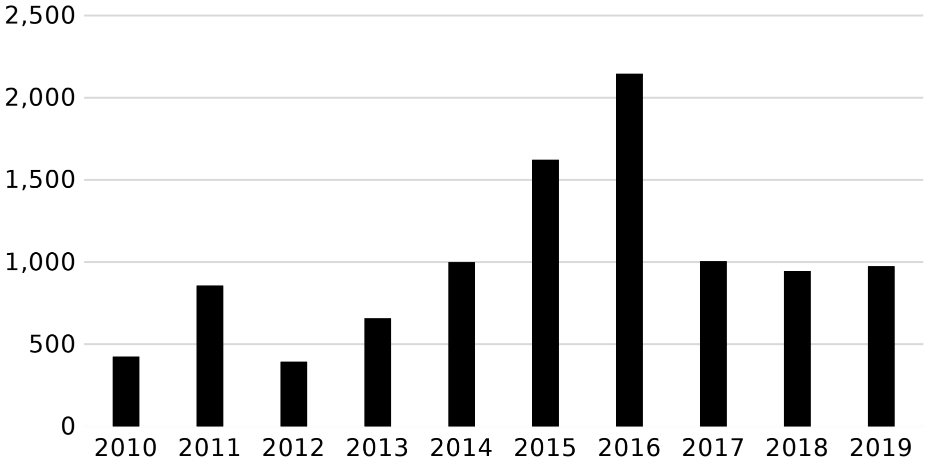
$$\textbf{PEHC} = \frac{\text{H-W} + 2 * \text{H-H}}{2 * N}$$

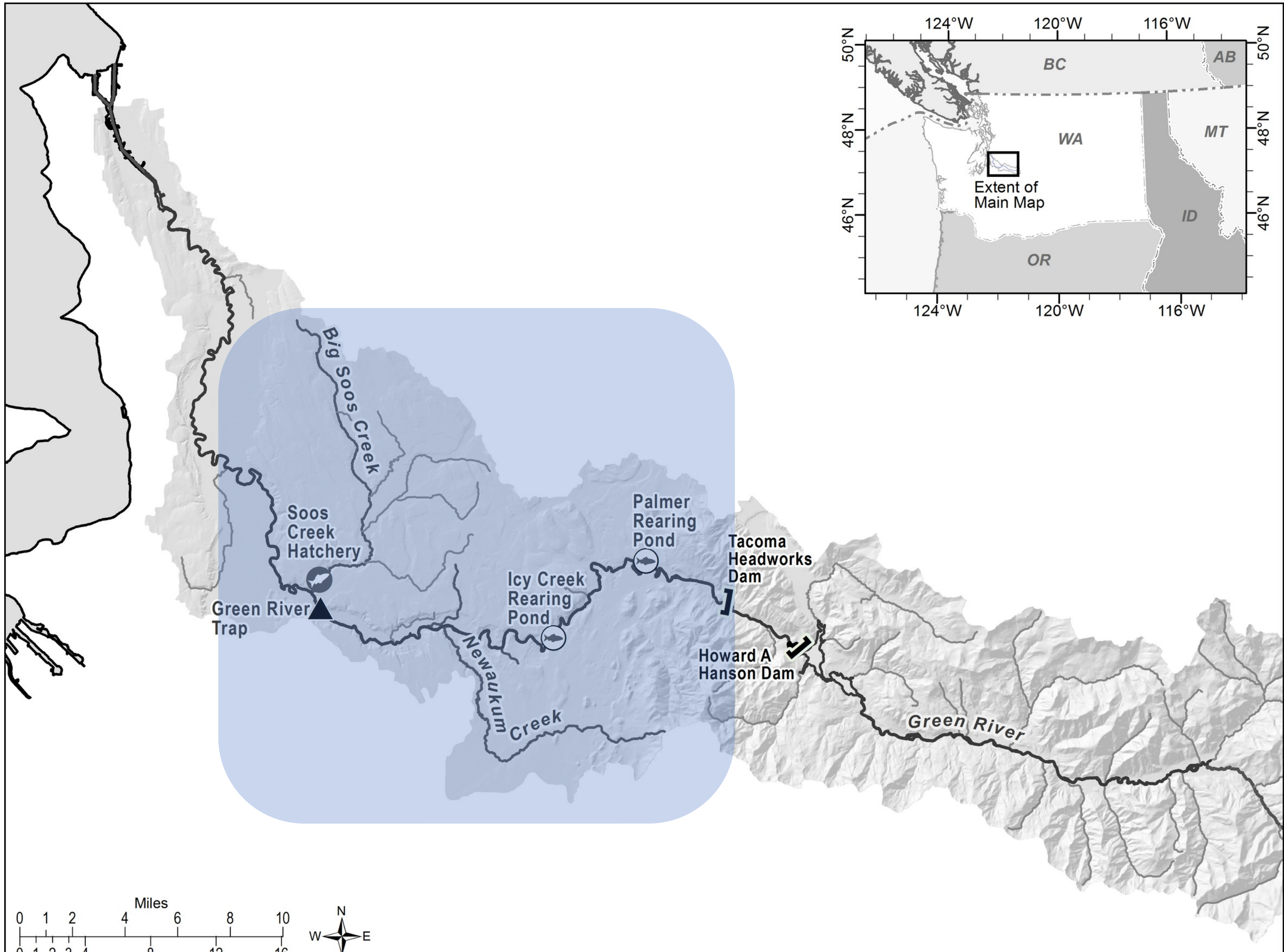
← Number of matings in each category (numerator)

← Total number of parents in sample (denominator)

Green River steelhead

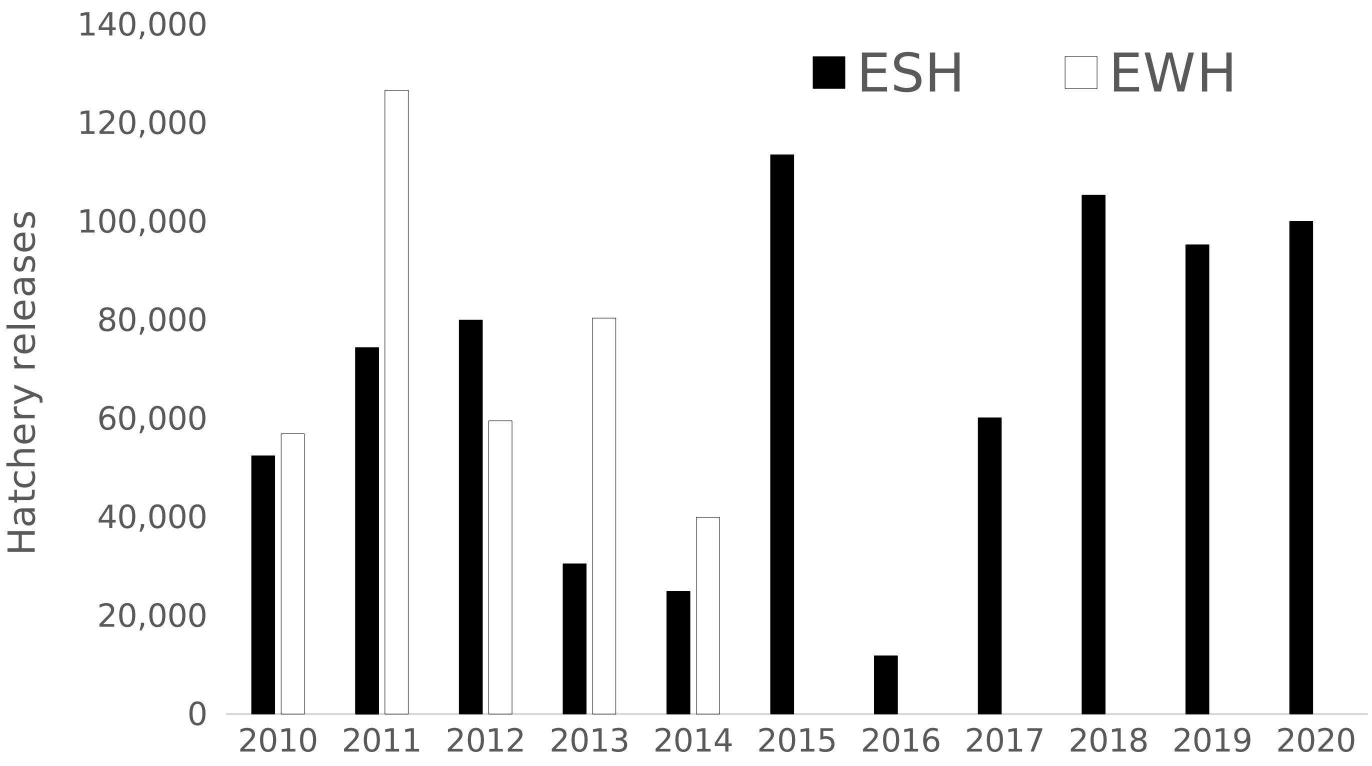
Natural steelhead spawning escapement

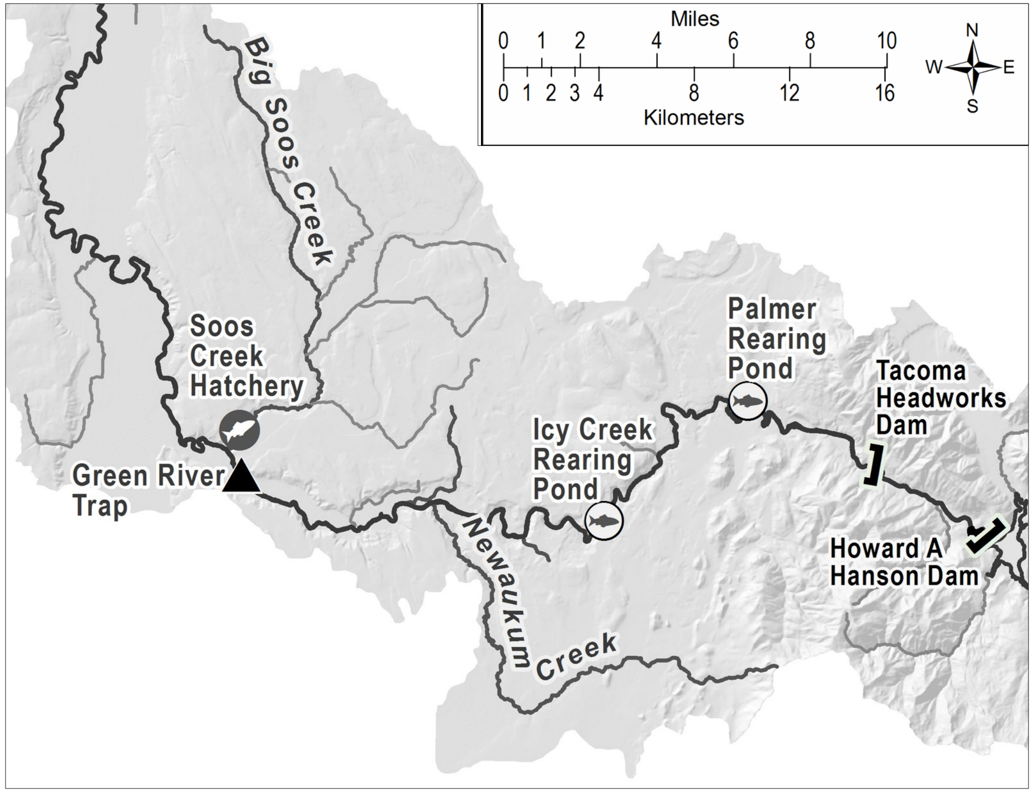




From Anderson and Topping 2018, *N Amer J Fish Man*

Green River steelhead hatchery programs





From Anderson and Topping 2018, *N Amer J Fish Manag*

Green River steelhead sample collections

Pre-smolts
2014-2017

Smolts
2014-2019

Adults
2014-2016, 2018-2020

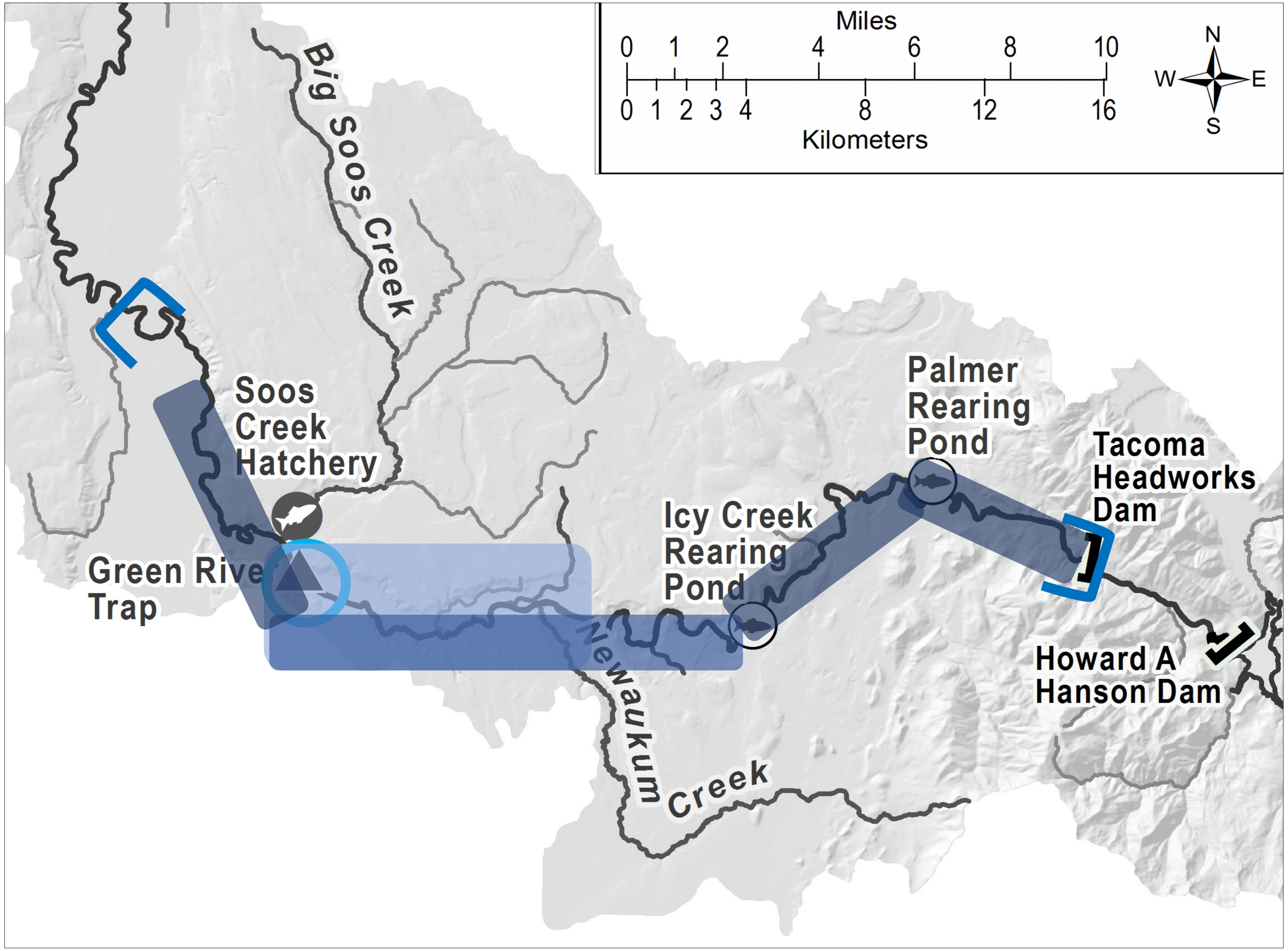
Green River steelhead sample collections

Adults

Smolts

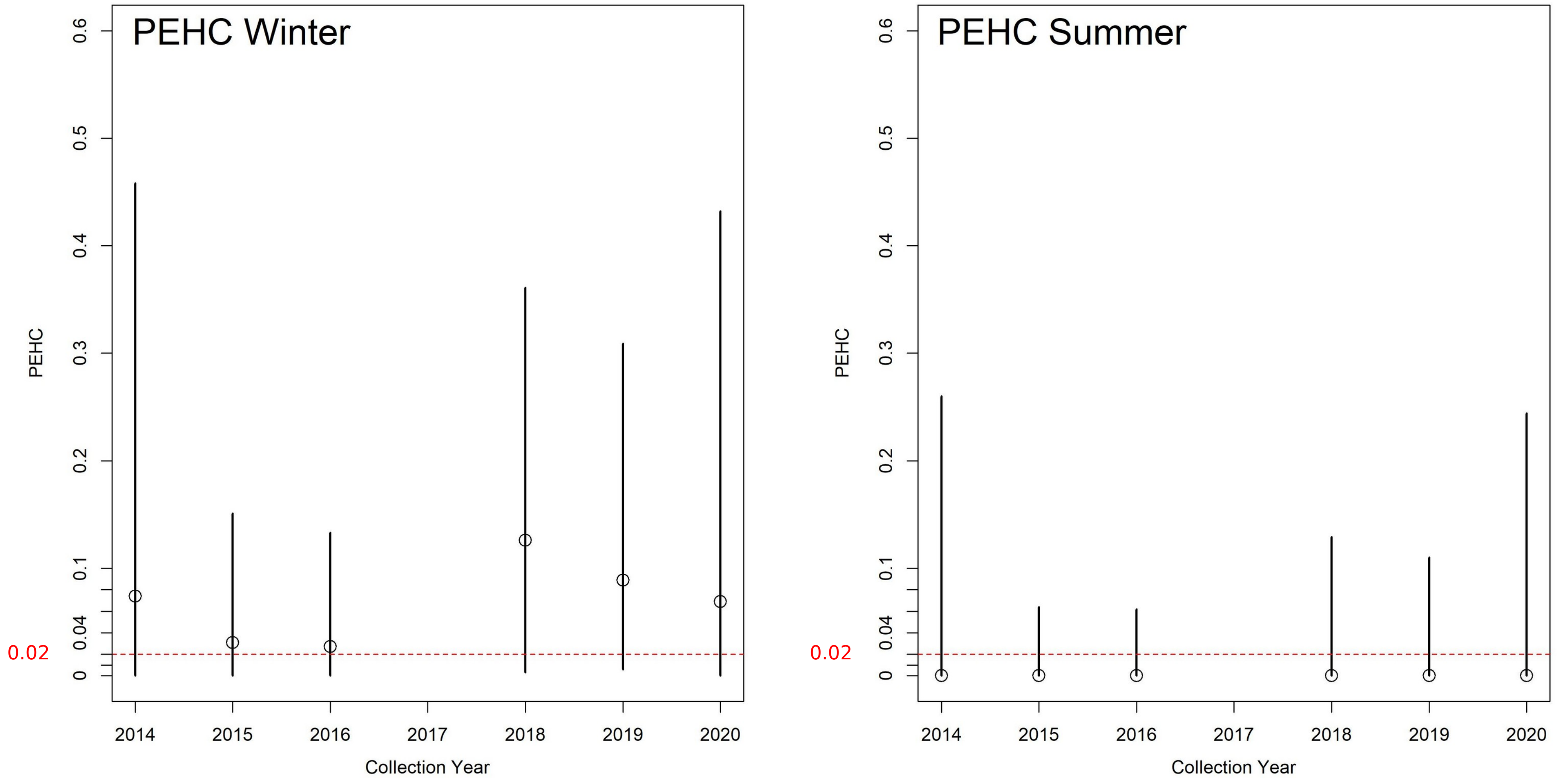
Pre-smolts

Spawning habitat



From Anderson and Topping 2018, *N Amer J Fish Manag*

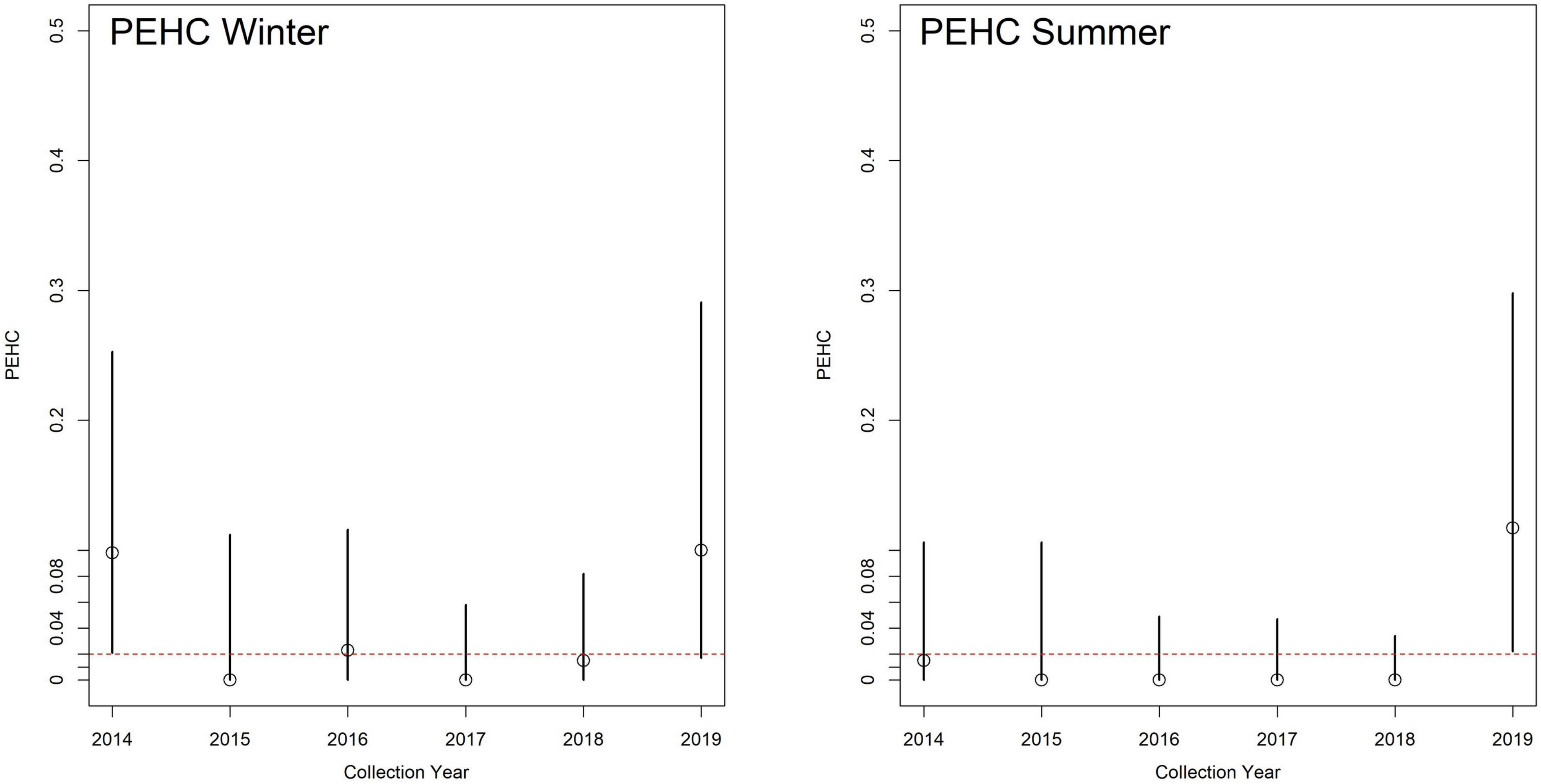
Adults: PEHC by Collection Year



Adults: Sources of PEHC

Collection Year	N	PEHC Winter (90% CI)	PEHC Summer (90% CI)	Sources of PEHC					
				EWH	EWH-Wild	ESH-Wild	ESH	Wild	EWH-ESH
2014	15	0.077 (0.00 - 0.448)	0.000 (0.000 - 0.260)	0.074	0.000	0.000	0.000	0.926	0.000
2015	66	0.031 (0.00 - 0.151)	0.000 (0.000 - 0.064)	0.031	0.000	0.000	0.000	0.969	0.000
2016	72	0.027 (0.00 - 0.133)	0.000 (0.000 - 0.062)	0.027	0.000	0.000	0.000	0.973	0.000
2018	33	0.126 (0.003 - 0.361)	0.000 (0.000 - 0.129)	0.038	0.177	0.000	0.000	0.786	0.000
2019	39	0.089 (0.006 - 0.309)	0.000 (0.000 - 0.110)	0.089	0.000	0.000	0.000	0.911	0.000
2020	17	0.069 (0.000 - 0.432)	0.000 (0.000 - 0.244)	0.069	0.000	0.000	0.000	0.931	0.000

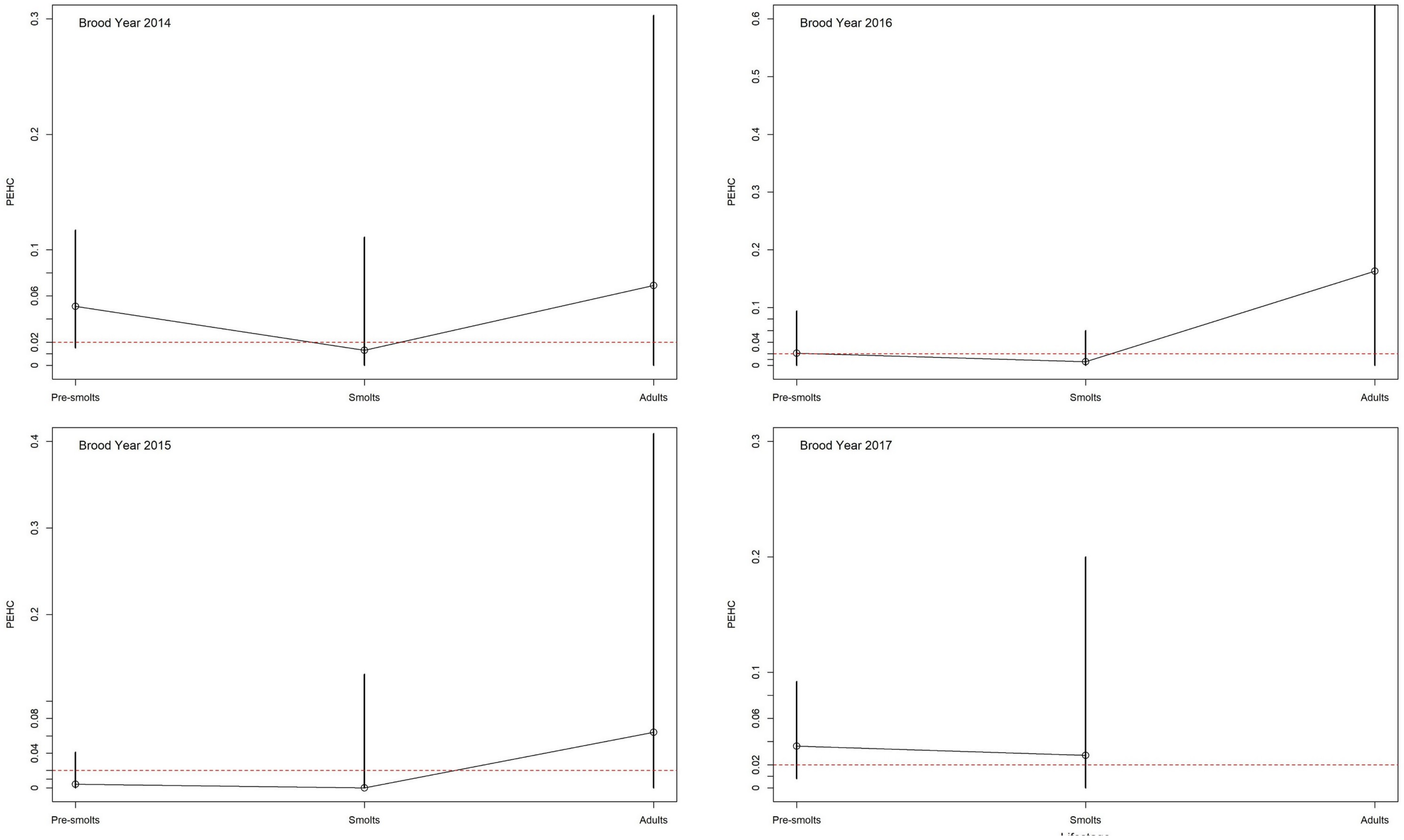
Smolts: PEHC by Collection Year



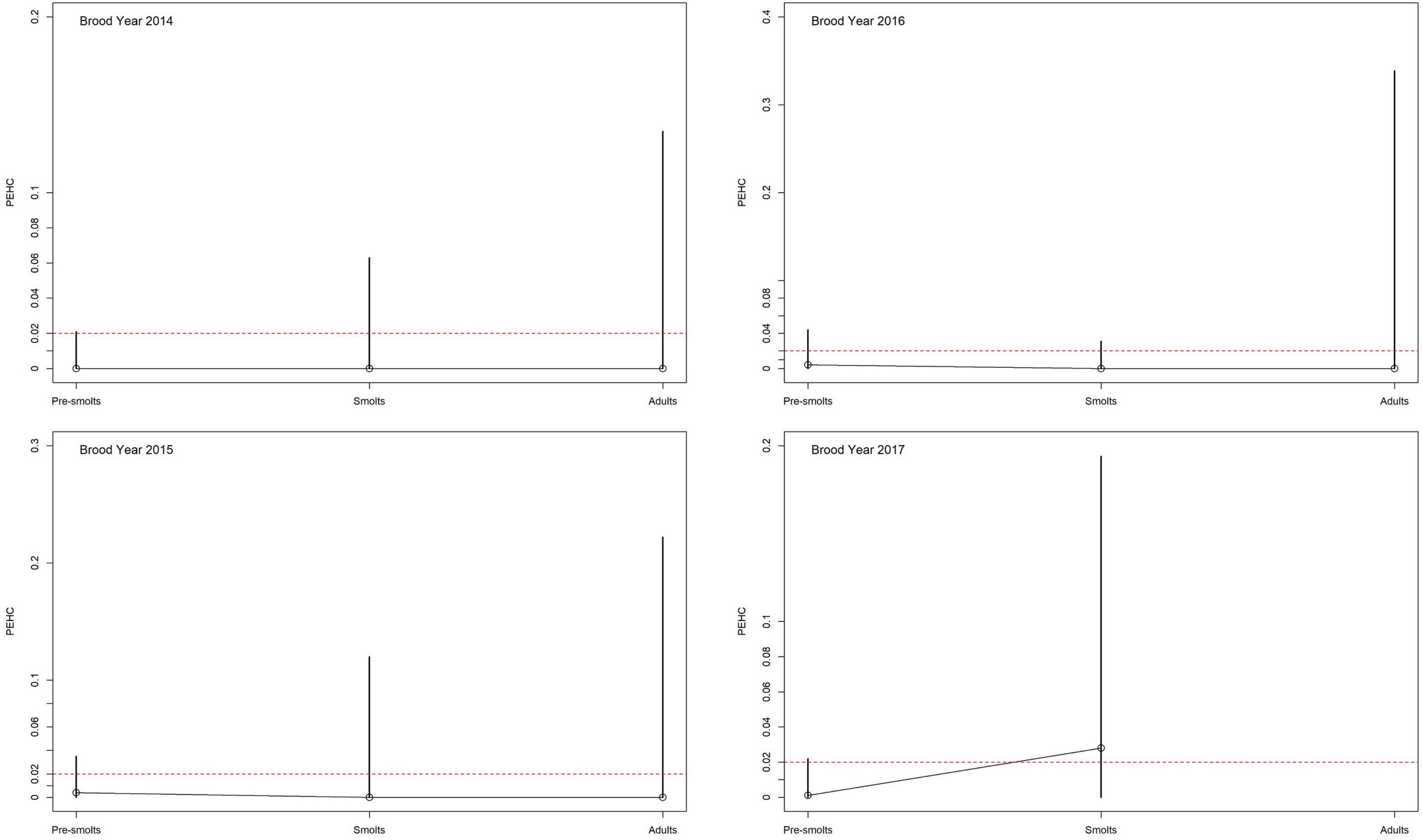
Smolts: Sources of PEHC

Collection Year	N	PEHC Winter (90% CI)	PEHC Summer (90% CI)	Sources of PEHC					
				EWH	EWH-Wild	ESH-Wild	ESH	Wild	EWH-ESH
2014	68	0.098 (0.021 - 0.253)	0.015 (0.000 - 0.105)	0.098	0.000	0.000	0.015	0.887	0.000
2015	42	0.000 (0.000 - 0.112)	0.000 (0.000 - 0.106)	0.000	0.000	0.000	0.000	1.000	0.000
2016	86	0.023 (0.000 - 0.116)	0.000 (0.000 - 0.049)	0.023	0.000	0.000	0.000	0.977	0.000
2017	95	0.000 (0.000 - 0.058)	0.000 (0.000 - 0.047)	0.000	0.000	0.000	0.000	1.000	0.000
2018	123	0.015 (0.000 - 0.083)	0.000 (0.000 - 0.034)	0.015	0.000	0.000	0.000	0.985	0.000
2019	42	0.100 (0.017 - 0.291)	0.117 (0.022 - 0.298)	0.078	0.000	0.000	0.095	0.783	0.044

Winter PEHC by Brood Year



Summer PEHC by Brood Year



Pre-smolts: Sources of PEHC

Collection Year	N	PEHC Winter (90% CI)	PEHC Summer (90% CI)	Sources of PEHC					
				EWH	EWH-Wild	ESH-Wild	ESH	Wild	EWH-ESH
2014	211	0.05 (0.02-0.12)	0.00 (0.00- 0.02)	0.051	0.000	0.000	0.000	0.949	0.000
2015	137	0.00 (0.00-0.04)	0.004 (0.00-0.04)	0.000	0.000	0.000	0.000	0.992	0.008
2016	119	0.02 (0.00-0.09)	0.004 (0.00- 0.04)	0.017	0.000	0.000	0.000	0.975	0.007
2017	218	0.04 (0.01-0.09)	0.001 (0.00- 0.02)	0.035	0.000	0.000	0.000	0.963	0.001

Conclusions

- Segregated hatchery programs have affected genetic structure of wild winter steelhead populations in the Green River
- Early winter hatchery fish have introgressed with wild winter population to a greater degree than early summer hatchery fish
- Sample size greatly influences precision of estimate
- Difficult to determine mechanism by which introgression is occurring
  - Pre-smolt PEHC indicates some H x H natural spawning
  - Smolts and Adult PEHC could be due to unclipped HORs, and/or natural spawning of H x H fish

Acknowledgments

- Pete Topping
- Robert Green
- Nathanael Overman
- David Smith
- Dan Estell
- Chris Frazier
- Aaron Bosworth
- Brodie Antipa
- Mike Wilson
- Soos Creek Hatchery staff
- Kate Olson
- Pete Lisi
- And others


Extras

Fin clip to PEHC estimate

1. Genotyped at 169 SNPs to confirm genetic species ID
2. Individuals assigned to a population via STRUCTURE
   - EWH, ESH, Wild, and F1 hybrids, (and No call)
   - Average q value from 5 iterations
   - Assignment thresholds determined from simulation modeling to minimize error rates
3. Individual assignments aggregated to estimate PEHC
   - Point estimate & 90% CIs are corrected via error matrix and maximum likelihood procedure (Knapp and Warheit 2016)

Adults: Scale ages

Collection Year	3	4	5	6	Total
2014		5	5		10
2015	4	31	21	4	60
2016	2	41	19	3	65
2018	6	10	7	2	25
2019	4	9	18	2	33
2020		9	6	2	17
TOTAL	**16**	**105**	**76**	**13**	**210**
TOTAL	**7.6%**	**50.0%**	**36.2%**	**6.2%**	**1**

Adults: Brood Year

	Brood Year								
Collection Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
2014	5	5	1						11
2015	4	21	31	4					60
2016		3	19	41	2				65
2018				1	4	14	6		25
2019					2	18	9	4	33
2020						2	6	9	17
TOTAL	**9**	**29**	**51**	**46**	**8**	**34**	**21**	**13**	**211**

Smolts: Scale ages

Collection Year	Age-1	Age-2	Age-3	Age-4	Total
2014	31	35	1	1	68
2015	23	10	1		34
2016	10	49	5		64
2017	61	25	1		87
2018	29	80	1		110
2019	29	10	2		41
TOTAL	**183**	**209**	**11**	**1**	**404**
TOTAL	**45.3%**	**51.7%**	**2.7%**	**0.2%**	

Smolts: Brood Year

	Brood Year									
Collection Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
2014	1	1	35	31						68
2015			2	9	23					34
2016				5	49	10				64
2017					1	25	61			87
2018						1	80	29		110
2019							2	10	29	41
TOTAL	**1**	**1**	**37**	**45**	**73**	**36**	**143**	**39**	**29**	**404**