Agenda Item E.1.a
SONCC Workgroup Report 1 (***Electronic Only***)
June 2021

Pacific Fishery Management Council
Southern Oregon/Northern California Coast Coho:

Fishery Harvest Control Rule Risk Assessment

May 2021

Pacific Fishery Management Council

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1. EXECUTIVE SUMMARY

The Southern Oregon/Northern California Coast (SONCC) coho Salmon Workgroup submitted a draft risk assessment report at the November 2020 Pacific Fishery Management Council (Council) meeting. Since that time, the Workgroup has held two meetings (January and May 2021) and provided the Council with a progress report at their April 2021 meeting.

Building upon the draft risk assessment from November 2020, this report provides an updated description of the SONCC coho Evolutionarily Significant Unit (ESU) and updated fisheries and escapement data.

A set of 12 alternative harvest control rules have been developed for Council consideration. The range of control rule forms include constant exploitation rate (ER) control rules, abundance-based ER control rules, and a placeholder for a matrix based control rule specifying limits on total ERs based on parental spawner abundance and an index of early life survival. The range of control rules includes those that specify limits on total ERs and those specifying limits only to ocean fishery ERs.

The set of control rules has been analyzed using a modeling approach that evaluates risks to SONCC coho populations and benefits to salmon fisheries. Population productivity and capacity were estimated for six population units: Rogue River, Scott River, Shasta River, Bogus Creek, Trinity River, and Freshwater Creek. These population units have relatively low levels of abundance and productivity relative to other coho populations such as those in the Oregon Coast Natural and Lower Columbia River Natural coho ESUs. Three of the six population units (Shasta River, Bogus Creek, and Trinity River) have high conservation risks regardless of the intensity of fishing owing to generally low abundance and/or productivity. Rogue River, Scott River, and Freshwater Creek are more abundant and productive and therefore the population risks are more sensitive to the level of fishing mortality. For these population units, risks increase with increasing ERs, while harvest increases until it plateaus or decreases at high levels of exploitation. Evaluation of abundance-based control rules suggest that there is potential for increased harvests at an equivalent level of risk when compared to constant ER control rules. Sensitivity of results to changes in model structure, abundance forecast error, and fishery implementation error have been conducted.

The feasibility of performing annual abundance forecasts has been updated since the previous draft report. The revised assessment suggests that there are few robust statistical associations between natural coho abundance and potential predictor variables. Additionally, there is concern about the dependability and timely availability of data needed for annual abundance forecasts in support of fisheries management, particularly for the natural population units in California.

All work described in this report is preliminary. Following the June 2021 Council meeting, the Workgroup will continue to refine analyses based on Workgroup discussions and guidance from the Council and its advisory bodies.

2. INTRODUCTION

This report describes work by the Pacific Fishery Management Council's (Council) ad-hoc Southern Oregon/Northern California Coast (SONCC) coho Salmon Workgroup (Workgroup) which was tasked with assessing a range of harvest control rules (HCR) for SONCC coho salmon for consideration by the Council. The report first provides background information, an overview of the Workgroup process, and the role of the Workgroup. It then describes the status and factors affecting the SONCC Coho Salmon Evolutionarily Significant Unit (ESU), followed by a description of the fisheries impacting SONCC coho and the current management framework, and prospects for abundance forecasting. The main body of the document is devoted to an evaluation of potential control rules with regard to conservation and fisheries, using a risk assessment approach.

Background

The SONCC coho salmon ESU is listed as threatened under the Endangered Species Act (ESA) (70 FR 37159). A variety of factors contribute to the status of the ESU including habitat loss due to dam building, degradation of freshwater habitats due to a variety of agricultural and forestry practices, water diversions, urbanization, hatchery practices, over-fishing, mining, climate change, poor ocean conditions, and severe flood events exacerbated by land use practices (Good et al. 2005, Williams et al. 2016). Fisheries impact SONCC coho in ocean and freshwater fisheries, although impacts across the fisheries are generally low. Council area salmon fisheries are managed consistent with provisions of the Pacific Coast Salmon Fishery Management Plan (FMP) for fisheries in Federal waters (3–200 nautical miles) off the coast of Washington, Oregon, and California. NMFS last consulted on the effects of Council fisheries on the SONCC coho salmon ESU under the ESA per Section 7(a)(2) in 1999 (NMFS 1999). In that opinion, NMFS concluded that Council fisheries would jeopardize the ESU and developed a three-part Reasonable and Prudent Alternative that (1) requires that management measures developed under the FMP achieve an ocean exploitation rate on Rogue/Klamath coho hatchery stocks of no more 13 percent, (2) prohibits coho-directed fisheries and coho retention in Chinook-directed fisheries off of California, and (3) requires that sampling and monitoring of Council fisheries is conducted.

In 2018, the Hoopa Valley Tribe filed a lawsuit alleging a failure by NMFS to reinitiate ESA consultation regarding the impacts of ocean salmon fisheries on SONCC coho salmon. In March 2020, the parties reached a stipulated agreement to stay the litigation, provided certain conditions are met. The stipulated agreement provides a timeline by which NMFS will confer with the Council on completion of a new SONCC coho HCR and a timeline for ESA consultation, as warranted, on the effects of the control rule. At the April 2020 Council meeting, NMFS proposed a process and timeline for Council consideration to develop a control rule. The Council established an ad-hoc technical Workgroup in response to the NMFS proposal and approved the Terms of Reference (Appendix A) for the Workgroup at its June 2020 meeting. The Workgroup has met six times since then to compile data, define potential control rules, consider the feasibility of abundance forecasting, and develop its risk assessment model. All meetings were open to the public. A detailed list of Workgroup meetings and presentations can be found online at the NMFS West Coast Region webpage.

Purpose and Need

The purpose the Council tasked the Workgroup with was to develop a proposed HCR for the SONCC Coho salmon ESU for Council consideration that would:

- allow fishing on abundant salmon stocks while not impeding the recovery of SONCC coho;
- establish HCRs in the form of fixed or tiered exploitation rates including consideration of control rules which reduce exploitation rates at low abundance levels, and which may include minimum or target spawner levels;
- assess a range of control rules including marine and freshwater fisheries combined, the marine and freshwater fisheries components, and marine fisheries only, affecting SONCC coho as appropriate, given potential data limitations, and what is feasible to accomplish within the specific timeline (See Appendix A for the timeline); and,
- evaluate the feasibility of considering the status of subcomponents of the ESU (e.g., Rogue River, Klamath and Trinity Rivers, Eel River), marine and freshwater environmental conditions, and other relevant factors as appropriate and as supported by the data available (similar to the Oregon Coast Natural coho salmon matrix).

The need is to ensure the harvest control rules considered and potentially adopted meet the requirements of the Magnuson-Stevens Act (MSA), ESA and other applicable laws.

The Council established the Workgroup with membership including technical representatives from the following entities:

- Pacific Fishery Management Council
- NMFS West Coast Region (WCR)
- NMFS Northwest Fisheries Science Center (NWFSC)
- NMFS Southwest Fisheries Science Center (SWFSC)
- U.S. Fish and Wildlife Service
- Yurok Tribe
- Hoopa Valley Tribe
- California Department of Fish and Wildlife
- Oregon Department of Fish and Wildlife
- Contractors as deemed necessary or suggested by Workgroup participating entities

The Workgroup was directed to:

- Collect and summarize relevant information regarding the status of SONCC coho, biological characteristics, magnitude and distribution of fishing mortality, and marine and freshwater environmental indicators.
- Develop a range of alternative HCRs.
- Analyze the biological risks and fishing related benefits of the alternative control rules.

- Assist the Council with developing a preferred harvest control rule alternative that can be recommended for adoption by the Council and submitted to NMFS for ESA review within 18 months from the Workgroup's initial meeting.
- Consult with the Council's Scientific and Statistical Committee (SSC) and Salmon Technical Team (STT) on the analytical methods used to evaluate draft alternatives. The Workgroup may consult with other Council advisory bodies and technical committees as necessary or as directed by the Council (Terms of Reference, Appendix A).

The risk assessment addresses three fundamental questions regarding the assessment of a control rule for SONCC coho salmon:

1. Can abundance of the SONCC coho ESU or its components be predicted with sufficient accuracy and precision?
2. What are the effects of different fishing rates for SONCC coho salmon on Council fisheries?
3. Can alternatives be implemented with negligible effects on escapement and viability of wild SONCC coho salmon populations?

The Workgroup is focused exclusively on exploring the impacts of salmon fisheries through the assessment of control rules that apply to the fisheries as described in the Workgroup's Terms of Reference. Considerations of other threats to SONCC coho salmon are outside the scope of the Workgroup task and have been described in detail in the Final Southern Oregon/Northern California Coast (SONCC) Coho Salmon Recovery Plan (NMFS 2014), the 2016 5-year status review (NMFS 2016) and various ESA biological opinions and other regulatory documents. NMFS considers other activities in the action area to be part of the environmental baseline. The NMFS West Coast Region and its partners are addressing the broader suite of threats separately through recovery actions and various provisions of the ESA and other laws.

3. STATUS OF THE SONCC COHO SALMON ESU

ESU & Population Structure

The SONCC coho salmon ESU was listed as threatened under the ESA on May 6, 1997 (62 FR 24588). The listing was most recently reaffirmed on June 28, 2005 (70 FR 37160). Critical habitat for SONCC coho salmon was designated on May 5, 1999 (64 FR 24049). In 2005, the Final 4(d) protective regulations were published (70 FR 37160, June 28, 2005). A recovery plan was finalized in 2014 (NMFS 2014). Subsequently, NMFS evaluated the available information on the status of the ESU in its 2016 status review and concluded that there was no change in extinction risk (Williams et al. 2016) and the ESU remains threatened. A new status review is underway and this document will be updated as appropriate as that information becomes available.

The SONCC coho salmon ESU includes all naturally spawned populations of coho salmon in coastal streams between Cape Blanco, Oregon and Punta Gorda, California, as well as coho salmon produced by three artificial propagation programs: Cole Rivers Hatchery, (Rogue River), Trinity River Hatchery, and Iron Gate Hatchery. (Klamath River). The ESU includes coastal watersheds from the Elk River (Oregon) in the north to the Mattole River (California) in the south (Figure 1). The ESU is characterized by three large basins and numerous smaller basins across a diverse landscape. The ESU is divided into seven diversity strata comprising 40 populations (Figure 1, Table 1) (NMFS 2014). The diversity strata are characterized by groups of populations that exhibit genotypic and phenotypic similarity due to exposure to similar environmental conditions or common evolutionary history (Williams et al. 2006). Each designated population in the ESU is classified based on its historical structure and functional role within the ESU (Table 1).

The four population classifications are:

- *Functionally independent populations*: populations with a high likelihood of persisting over 100-year time scales and that conform to the definition of independent "viable salmonid populations" offered by McElhany et al. (2000).
- *Potentially independent populations*: populations with a high likelihood of persisting over 100-year time scales, but that were too strongly influenced by immigration from other populations to be demographically independent.
- *Dependent populations*: populations believed to have had a low likelihood of sustaining themselves over a 100-year time period in isolation and that received sufficient immigration to alter their dynamics and extinction risk.
- *Ephemeral populations*: populations that were both small enough and isolated enough that they were only intermittently present.

The distribution of SONCC coho salmon within the ESU's range is reduced and fragmented, as evidenced by an increasing number of previously occupied streams from which SONCC coho salmon are now absent (Williams et al. 2011, Williams et al. 2016). Extant populations can still be found in all major river basins within the range of the ESU (70 FR 37159). However, extirpations, loss of brood years, and sharp declines in abundance of SONCC coho salmon in several streams throughout the range of the ESU indicate that the SONCC coho salmon spatial structure is more fragmented at the population-level than at the ESU scale. Though population-level estimates of abundance for most independent populations are lacking, NMFS concluded in its most recent status review (NMFS 2016) that none of the seven diversity strata currently supports a single viable population as defined by the Recovery Plan criteria, although all diversity strata are occupied.

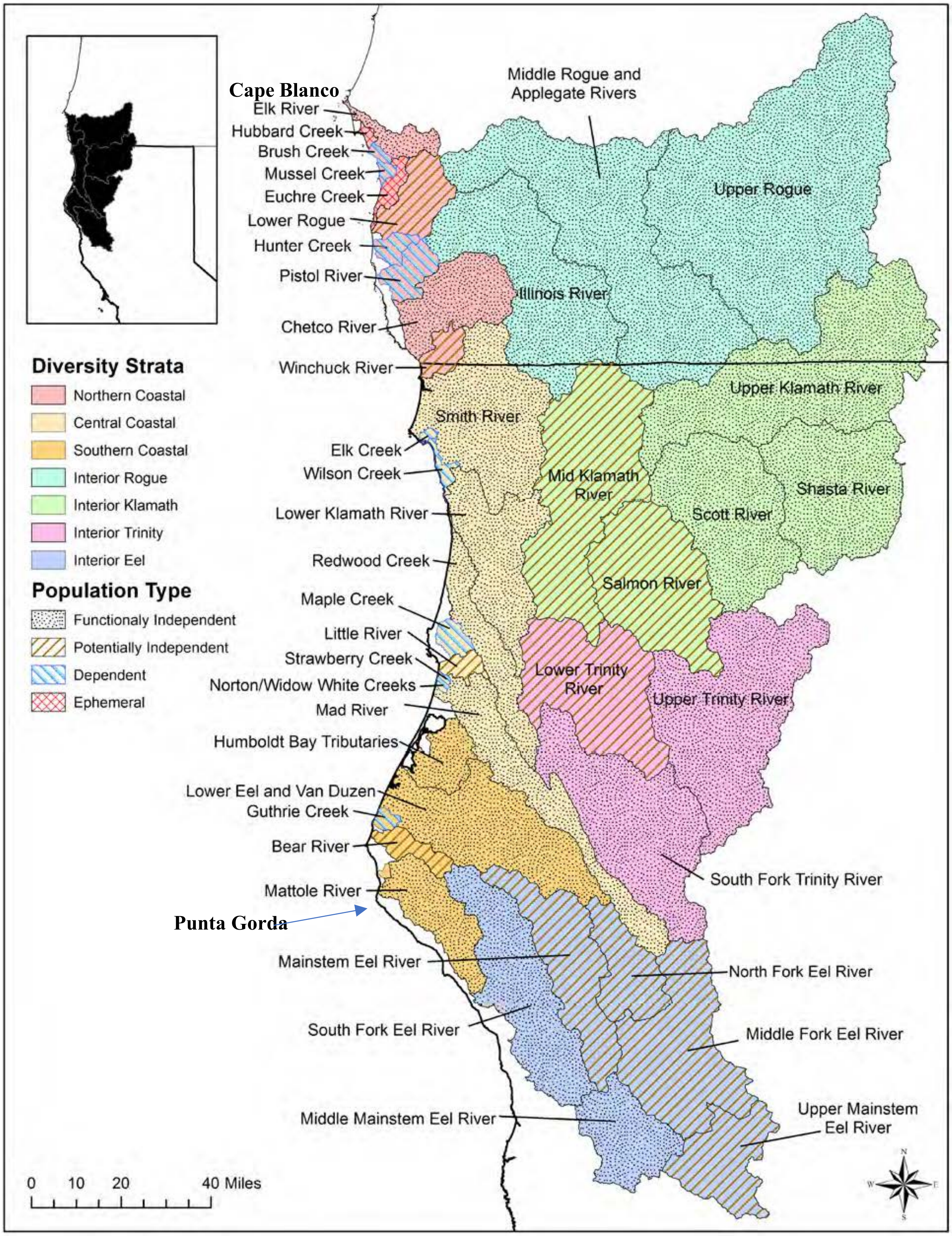

Figure 1. Population and diversity strata of the SONCC coho salmon ESU (NMFS 2014).

Table 1. Diversity strata, populations, current extinction risk, minimum target extinction risk and recovery criteria of SONCC coho salmon ESU (NMFS 2014). Core populations are noted in bold.

Stratum	Populations	Risk Status	Risk Goal	Recovery role	Recovery criteria	Depensation threshold[a]
Northern Coastal Basin	Elk R	High	Low	**Core**	2,400	63
	Brush Crk	High	Juveniles	Dependent	--	--
	Mussel Crk	High	Juveniles	Dependent	--	--
	Lower Rogue R	High	Moderate	Non-core 1	320	81
	Hunter Crk	High	Juveniles	Dependent	--	--
	Pistol Crk	High	Juveniles	Dependent	--	--
	Chetco R	High	Low	**Core**	4,500	135
	Winchuck R	High	Moderate	Non-core 1	230	57
Central Coastal Basin	Smith R	High	Low	**Core**	6,800	325
	Elk Crk	High	Juveniles	Dependent	--	--
	Wilson Crk	High	Juveniles	Dependent	--	--
	Lower Klamath R	High	Low	**Core**	5,900	205
	Redwood Crk	High	Low	**Core**	4,900	151
	Maple Crk/Big Lagoon	--	Juveniles	Dependent	--	--
	Little R	Moderate	Moderate	Non-core 1	140	34
	Strawberry Crk	--	Juveniles	Dependent	--	--
	Norton/Widow White Crk	--	Juveniles	Dependent	--	--
	Mad R	High	Moderate	Non-core 1	550	136
Southern Coastal Basin	Humboldt Bay tributaries	Moderate	Low	**Core**	5,700	191
	Lower Eel/Van Duzen R	High	Low	**Core**	7,900	394
	Guthrie Crk	--	Juveniles	Dependent	--	--
	Bear R	High	Juveniles	Non-core 2	--	--
	Mattole R	High	Moderate	Non-core 1	1,000	250
Interior Rogue R	Illinois R	High	Low	**Core**	11,800	590
	Middle Rogue/Applegate R	High	Moderate	Non-core 1	2,400	603
	Upper Rogue R	Moderate	Low	**Core**	13,800	689
Interior Klamath	Middle Klamath R	Moderate	Moderate	Non-core 1	450	113
	Upper Klamath R	High	Low	**Core**	8,500	425
	Shasta R	High	Low	**Core**	4,700	144
	Scott R	Moderate	Low	**Core**	6,500	250
	Salmon R	High	Moderate	Non-core 1	450	114
Interior Trinity	Lower Trinity R	High	Low	**Core**	3,600	112
	South Fork Trinity R	High	Moderate	Non-core 1	970	242
	Upper Trinity R	Moderate	Low	**Core**	5,800	365
Interior Eel	Mainstem Eel R	High	Low	**Core**	2,600	68
	Middle Mainstem Eel R	High	Low	**Core**	6,300	232
	Upper Mainstem Eel R	High	Juveniles	Non-core 2	--	--
	Middle Fork Eel R	High	Juveniles	Non-core 2	--	--
	South Fork Eel R	Moderate	Low	**Core**	9,300	464
	North Fork Eel R	High	Juveniles	Non-core 2	--	--

[a] *Based on spawner per kilometer of intrinsic potential.*

Natural Escapement

Quantitative population-level estimates of adult (age ≥ 3) spawner abundance that span a decade or more are scarce for independent or dependent populations in the SONCC coho ESU. Monitoring in California has improved considerably since 2010 due to the implementation of enhanced monitoring practices for some populations (e.g., video weirs, PIT-tag arrays). However, there is uncertainty about the level to which these efforts will continue in the future. For many populations, escapement information is limited to presence-absence data at best.

Spatial scale data for populations from the Oregon portion of the ESU are no longer collected and therefore no estimates of escapement are available at the population level for Oregon populations (Sounhein et al. 2014). The estimate of Rogue River coho salmon is a composite of several population units (Lower Rogue River, Illinois River, Middle Rogue/Applegate rivers, and Upper Rogue River) that continues to be collected and is extremely valuable.

The Workgroup assessed the available data for each population to determine if the data are sufficient for the purposes of the risk assessment. Table 2 summarizes the escapement data that were deemed sufficient by the Workgroup. The Workgroup has also discussed potential further aggregation for the purposes of control rule development. The group includes populations within five of the seven diversity strata in the ESU. The Illinois and Upper Rogue River populations in the Rogue River Basin, the Scott and Shasta Rivers in the Klamath Basin, and the Upper and Lower Trinity Rivers in the Trinity River Basin are core populations for ESU recovery. Freshwater Creek is one of the tributaries to Humboldt Bay which is also a core population for ESU recovery. Hatchery fish contribute significantly to escapement for stocks in the Klamath and Trinity Basins (Table 2 and Figure 2).

In California, the Workgroup concluded that sufficient data on escapement (10 or more years) were only available for the following components:

- two populations (Shasta and Scott rivers),
- a component of the Upper Klamath River population (Bogus Creek),
- a component of the Humboldt Bay Tributaries population (Freshwater Creek); and,
- two population aggregates (Rogue and Trinity; where aggregate is defined as a grouping of multiple populations).

Escapement estimation methods are described in Williams et al. (2016).

Adult returns of naturally produced coho to the Rogue, Trinity, Shasta, and Scott Rivers have been highly variable. For example, estimates derived from the beach seine surveys at Huntley Park on the Rogue River ranged from 414 to 24,509 naturally produced adults between 2000 and 2019 (Table 2). Similar variability has been observed in the Trinity, Shasta, and Scott River populations. Overall, the average annual escapement for these systems in the last decade (2010–2019; Table 2) is only 1,583 naturally produced fish. However, escapement data are sparse or lacking for the other major populations in the ESU (Eel, Smith, and Chetco rivers) and for the numerous smaller coastal populations. Therefore, escapement for the ESU is likely to be higher than the average estimate above.

In the 2016 status review, NMFS (2016) concluded that many independent populations in the ESU are well below low-risk abundance targets, and several, including the Shasta River, are below the high-risk depensation thresholds specified by the Recovery Plan (NMFS 2014) (Table 1). Escapement of adult coho for return years 2000 through 2019 are shown in Table 2. These data continue to support the conclusions of the 2016 status review. Though population-level estimates of abundance for most independent populations are lacking, it does not appear that any of the seven diversity strata currently supports a single viable population as defined by the TRT's viability criteria, although all diversity strata are occupied.

Table 2. Escapement of adult SONCC coho salmon to natural spawning areas for return years 2000 – 2019.

Return Year	Rogue River[1]		Freshwater Creek	Scott River		Shasta River		Bogus Creek[2]		Trinity River	
	Hatchery	Wild	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
2000	10,116	10,978	177							6,297	288
2001	14,013	12,015	701							15,770	2,945
2002	12,739	8,460	1,807							7,440	372
2003	7,296	6,805	731							10,991	3,264
2004	9,092	24,509	974					97	298	15,287	7,830
2005	5,339	9,957	789					41	46	9,974	1,728
2006	3,496	3,911	396					14	19	7,454	1,416
2007	2,275	5,136	262	0	1,529	5	244	71	126	1,612	940
2008	158	414	399	0	59	22	8	33	72	2,204	861
2009	518	2,566	89	0	76	2	7	2	3	1,718	438
2010	752	3,671	455	0	913	11	33	41	105	2,146	624
2011	1,157	4,545	624	0	344	42	17	80	27	2,403	991
2012	1,423	5,474	318	2	186	54	22	59	8	6,335	1,577
2013	1,999	11,210	155	0	2,631	61	99	353	85	8,935	3,948
2014	829	2,409	718	0	383	4	1	18	4	6,405	823
2015	1,620	4,072	449	0	188	0	43	4	9	166	459
2016	1,201	6,302	466	0	226	0	46	21	29	482	635
2017	886	4,526	535	4	364	0	38	8	29	107	34
2018	325	8,266	560	0	712	0	36	3	23	502	1
2019	195	2,156	303	0	338	0	50	5	47	358	63

[1]Escapement estimated at Huntley Park; inclusive of escapement to hatchery and natural areas.
[2]Bogus Creek is a tributary to the Upper Klamath and part of the Upper Klamath River population with a video weir to assess escapement.

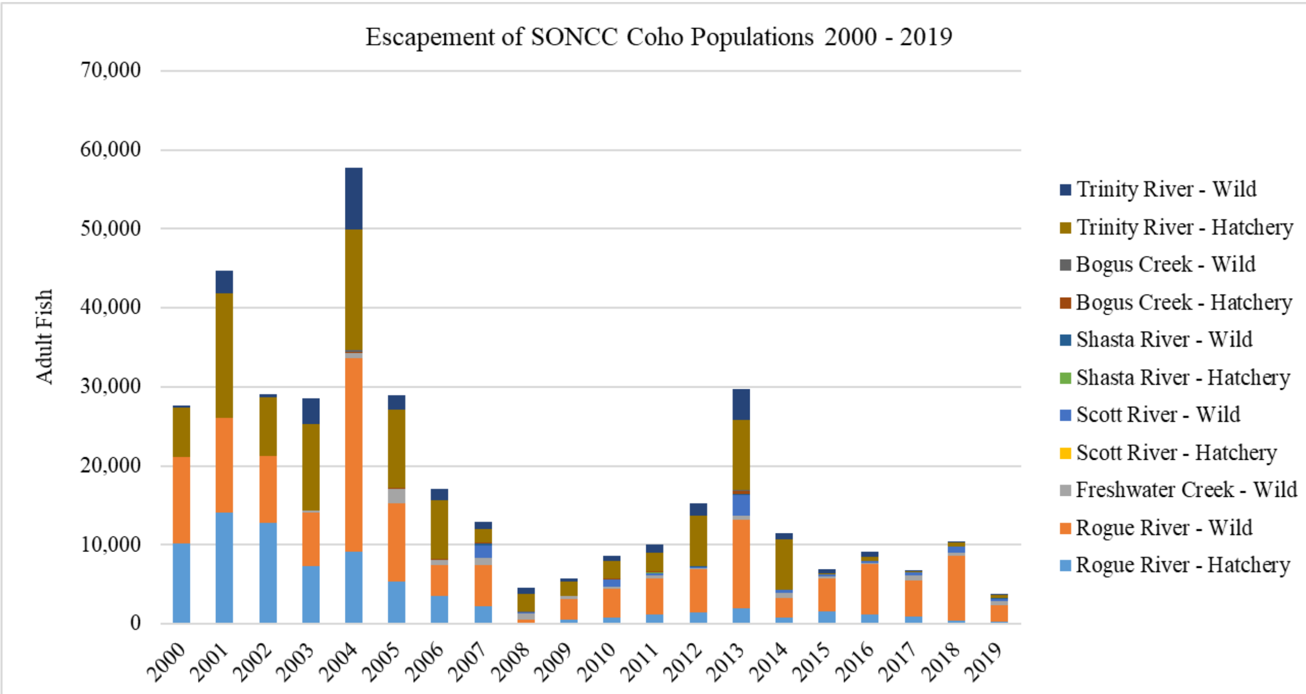

Figure 2. Trends in escapement for populations summarized in Table 2.

Hatcheries

Hatcheries provide benefits to the status of salmon by reducing demographic risks and preserving genetic traits for populations at low abundance in degraded habitats. In addition, hatcheries help to provide harvest opportunity. Hatchery-origin fish may also pose risk to listed species through genetic, ecological, or harvest effects. Details on how hatchery programs can affect ESA-listed salmon and steelhead can be found in Appendix 1 in NMFS (2020a), and are incorporated here by reference.

Coho produced from three artificial propagation programs are included as part of the SONCC coho salmon ESU: the Cole Rivers Hatchery (Rogue River); Trinity River Hatchery; and Iron Gate Hatchery (Klamath River) coho salmon programs (70 FR 37160, June 28, 2005). Current annual production goals at these hatcheries are 75,000, 300,000, and 75,000 coho smolts, respectively. These programs are described in more detail below. Steelhead and Chinook are also reared and released at these and other hatcheries within the area of the SONCC coho ESU. Annually, approximately 14.2 million salmonids are released into rivers within the SONCC coho ESU. Hatchery production in the area of the SONCC coho ESU is shown in Table 3

The following provides a description of each of the three major hatchery programs and Table 3 summarizes the current production at each of the facilities.

<u>Cole Rivers Hatchery (ODFW):</u>

Cole M. Rivers Hatchery (CRH) is located on the Rogue River (River Mile (RM) 157), Oregon downstream of Lost Creek Dam in the Upper Rogue River population of the SONCC coho ESU.

The hatchery was constructed by the US Army Corps of Engineers (USACE) in 1973 to mitigate for spawning and rearing areas blocked by the construction of Lost Creek, Applegate, and Elk Creek dams. The hatchery facility is used for adult collection, spawning, egg incubation and rearing of spring Chinook, coho, summer steelhead, and winter steelhead, and egg incubation and rearing of fall Chinook and rainbow trout (ODFW 2020).

The Cole Rivers Hatchery programs are operated to achieve conservation and harvest augmentation goals. The management goals for the coho program are to: 1) provide an artificial reserve to retain future management options in the recovery of Rogue Basin coho; 2) provide monitoring opportunities for Rogue River coho related to ocean distribution and marine survival and to provide information on incidental harvest mortality of wild coho; and 3) provide fish for commercial and recreational harvest while minimizing potential impacts to wild populations in the Rogue River Basin (ODFW 2020).

The current production goals are to produce 75,000 coho smolts at 10 fish/pound. The production goal was decreased from 200,000 smolts in brood year 2013. This reduction was primarily to lower stray rates, provide for increased production in the spring Chinook program and being consistent with coho mitigation goals. The smolts are released directly from the hatchery in late April. All coho are adipose fin-clipped and 25,000 are tagged with CWT prior to release. The return goal is 2,060 adult coho to mitigate for wild coho production lost from the construction of federal dams in the upper Rogue River Basin. Adults return to the hatchery from October to January. Broodstock are from adults that volitionally enter the hatchery trap. Spawning occurs from November through January.

Escapement goals for coho released from the Cole Rivers program are to achieve low rates of hatchery coho on spawning grounds (ODFW 2020). Adverse hatchery-related effects pose a medium risk to coho populations in the Rogue Basin. Available information suggests that the incidence of hatchery fish spawning in the wild is likely in the range of 5 to 15 percent (NMFS 2014).

Iron Gate Hatchery (CDFW)

Iron Gate Hatchery (IGH) is located on the Klamath River (RM 190), California at the base of Iron Gate Dam and is located within the Upper Klamath River population of the SONCC coho ESU. The hatchery was constructed by PacificCorp after completion of Iron Gate Dam in 1961. The hatchery program was required to mitigate for loss of spawning and rearing habitat resulting from the operations and maintenance of Iron Gate Dam. The IGH coho program is operated as an integrated recovery program to aid in the recovery and conservation of Upper Klamath coho by conserving genetic resources and reducing short-term extinction risks prior to future restoration of fish passage above Iron Gate Dam.

Coho production at IGH began in 1965 with eggs originating from Cascade hatchery in Oregon. Several other transfers occurred from around the region. Since 1976, IGH has used Klamath River coho as broodstock. Current production goals are to produce 75,000 coho smolts. Actual releases have averaged 89,749 from 2005 to 2011. On average, the releases have produced approximately 866 returning adults annually since 2000, however the annual average has dropped to 296 adult coho returns since 2010. Coho smolts are reared 15 fish/pound and are generally released directly from the hatchery in early April. All coho are marked externally with a left maxillary clip. Adipose fin-clips and CWTs are not used currently to mark and tag fish. Broodstock are collected from hatchery and wild adults returning to the IGH fish ladder and nearby Bogus Creek. Adult coho return to the hatchery from October to December. (CDFW 2014).

Adverse hatchery-related effects pose a medium risk for SONCC coho in the Middle Klamath and a very high stress in the Upper Klamath River. Bogus Creek coho represent the largest naturally spawning aggregation in the Upper Klamath population, however hatchery origin spawning in Bogus Creek averaged 28 percent of the escapement from 2004–2011 (CDFW 2014). Some of that contribution is due to an intentional strategy to release unused brood stock at IGH into the river to augment spawning for nearby populations in order to increase genetic diversity and reduce demographic risks associated with small population sizes. Hatchery coho salmon in the Shasta River averaged 30 percent of the escapement from 2007–2010 (CDFW 2011).

Trinity River Hatchery (CDFW)

Trinity River Hatchery (TRH) is located on the Trinity River (RM 110), California at the base of Lewiston Dam in the Upper Trinity River population of the SONCC coho ESU. The hatchery was constructed by the US Bureau of Reclamation after completion of the Lewiston Dam in 1963 to mitigate for the loss of salmonid habitat due to the construction of the Trinity and Lewiston dams and the operation of the Central Valley Project.

The TRH coho program is operated to provide fish for harvest in a manner consistent with the conservation of the Trinity coho population while meeting TRH mitigation requirements. The hatchery is operated as an integrated program to increase total adult abundance, productivity and fitness, while minimizing genetic divergence of hatchery broodstock from the naturally spawning population.

The current production goal is to release 300,000 coho smolts. This is a reduction from the previous production goal of 500,000 that was in place until 2014. The goal may be revised in the future based on a review of performance metrics and could range from 150,000 to 500,000 (NMFS 2020b). Coho smolts are reared from 10 to 12 fish/pound and are released directly from the hatchery in early March. All coho are marked externally with a right maxillary clip. Adipose fin-clips and CWTs are not used currently to tag and mark fish. Broodstock are collected from hatchery and wild origin adults returning to the TRH fish ladder.

Actual releases have averaged 479,921 (range 287,720 to 545,851) from 2001 to 2015 (CDFW 2017). Prior to final construction of TRH in 1964, coho broodstock originated from an in-river weir but were then augmented with out-of-basin sources to boost production. Out of basin sources include eggs imported from the Eel River and Cascade Hatchery, the Alsea River, and the Noyo River (CDFW 2017). Only endemic Trinity River broodstock has been used since 1971.

Objectives for the TRH program are to achieve a proportion of hatchery-origin spawners in natural areas (pHOS) of less than 30% in the Upper Trinity population and a pHOS of 5% for coho populations in the South Fork Trinity River and Lower Trinity River (NMFS 2020b). Adverse hatchery-related effects pose a very high risk in the Trinity River. Hatchery-origin coho salmon make up most of the spawning run to the Trinity River each year where pHOS has ranged from 36% to 100% across the Trinity River populations (NMFS 2014).

Table 3. Releases of hatchery salmonids within the SONCC Coho ESU (ODFW 2016; 2020; CDFW 2014; 2017; NMFS 2019; 2020a).

State	Hatchery	Species	Current Release Goal	Marking/Tagging	Release Location
Oregon	Cole Rivers	Coho	75,000	Adipose Clip + CWT	Rogue River
		Spring Chinook	1,700,000	Adipose Clip + CWT	Rogue River
		Winter Steelhead	132,000	Adipose Clip	Rogue River
		Summer Steelhead	220,000	Adipose Clip	Rogue/Applegate Rivers
	Elk River	Fall Chinook	325,000	Adipose Clip + CWT	Elk River
		Fall Chinook	200,000	Adipose Clip + CWT	Chetco River
California	Iron Gate	Coho	75,000	Left Maxillary Clip	Klamath River
		Fall Chinook	6,000,000	Adipose Clip + CWT	
	Trinity River	Coho	300,000	Right Maxillary Clip	Trinity River
		Spring Chinook	1,400,000	Mark?	
		Fall Chinook	2,900,000	Adipose Clip + CWT	
		Steelhead	448,000	Adipose Clip	
	Mad River	Steelhead	172,000	Adipose Clip	Mad River
	Rowdy Creek	Fall Chinook	150,000	Adipose Clip	Smith River
		Steelhead	80,000	Adipose Clip	Smith River

Factors affecting the ESU outside of fisheries

In addition to fisheries, factors contributing to the status of the ESU include: habitat loss due to dam building; degradation of freshwater habitats due to a variety of agricultural and forestry practices; water diversions; urbanization; hatchery practices; over-fishing; mining; climate change; ocean conditions; and severe flood events exacerbated by land use practices (Good et al. 2005, NMFS 2014, Williams et al. 2016). The lack of floodplain and channel structure is a key limiting factor in nearly all coastal populations and about half of interior populations (NMFS 2014). Sedimentation and loss of spawning gravels associated with poor forestry practices and road building are particularly chronic problems that can reduce the productivity of salmonid populations. Late 1980s and early 1990s droughts and unfavorable ocean conditions were identified as further likely causes of decreased SONCC coho salmon abundance (Good et al. 2005). From 2014 through 2016, the drought in California reduced stream flows and increased temperatures, further exacerbating stress, disease, and decreasing the quantity and quality of spawning and rearing habitat available to SONCC coho salmon. Ocean conditions have generally been unfavorable in recent years (2014 to present) due to El Niño conditions and the warm water "Blob" which impacted the U.S. west coast, and reduced ocean productivity and forage for SONCC coho salmon. The Scott and Shasta Rivers, both core populations from the Klamath River, are substantially impacted by water diversions annually.

Coho salmon are particularly vulnerable to climate change due to their need for year-round cool water temperatures, as they rear for one or more years in freshwater, unlike some other salmonid species (Moyle 2002). By increasing air and water temperatures, climate change is expected to decrease the amount and quality of coho salmon habitat, reducing the productivity of populations and exacerbating the decline of the species. Climate change effects on stream temperatures within Northern California are already apparent. For example, in the Klamath River, Bartholow (2005) observed an increase in water temperature of 0.5°C per decade since the early 1960s.

In coastal and estuarine ecosystems, the threats from climate change largely come in the form of sea level rise, loss of coastal wetlands, and changes in precipitation patterns. Sea levels will likely rise exponentially over the next 100 years, with possibly a 50–80 cm rise by the end of the 21st century (IPCC 2007). This rise in sea level will alter the habitat in estuaries and either provide increased opportunity for feeding and growth or, in some cases, will lead to the loss of estuarine habitat and a decreased potential for estuarine rearing. Marine ecosystems face an entirely unique set of stressors related to global climate change, all of which may have deleterious impacts on growth and survival while at sea. In general, the effects of changing climate on marine ecosystems are not well understood given the high degree of complexity and the overlapping climatic shifts that are already in place (e.g., El Niño, La Niña, Pacific Decadal Oscillation) and will interact with global climate changes in unknown and unpredictable ways. Overall, climate change is believed to represent a growing threat, and will challenge the resilience of salmonids in Northern California, including SONCC coho salmon.

4. FISHERY DESCRIPTION FOR SONCC COHO

Current fishery impact distribution and assessment

In the marine environment coho salmon from this ESU are primarily distributed off the coast of California and southern Oregon (NMFS 2016). Overfishing in non-tribal fisheries was identified as a significant factor in the decline of coho salmon (62 FR 24588, May 6, 1997). Significant overfishing occurred from the time marine survival significantly decreased for many stocks (ca. 1976) until the mid-1990s when harvest was substantially curtailed or prohibited. Tribal harvest was not considered to be a major factor in the decline of coho salmon in either the Klamath River Basin or Trinity River Basin (62 FR 24588, May 6, 1997).

Significant changes in fisheries harvest management have occurred in recent decades, resulting in substantial reductions in harvest of SONCC coho salmon. Because coho salmon-directed fisheries and coho salmon retention have been prohibited off the coast of California since 1996, the ocean exploitation rate of SONCC coho salmon is generally low and attributable to hooking and handling in Chinook-directed commercial and recreational fisheries off the coasts of California and Oregon. Low impacts are also associated with primarily mark selective and some limited non-mark selective coho salmon fisheries off the Oregon coast.

Management Framework

Ocean Fisheries

Ocean fisheries under the jurisdiction of the PFMC are managed according to the provisions of a biological opinion completed by NMFS in 1999 which established a maximum ocean exploitation rate on hatchery Rogue Klamath coho of 13 percent (NMFS 1999).

At that time of the 1999 consultation the Council proposed to manage SONCC coho under the provisions of Amendment 13 to the Pacific Coast Salmon FMP. Amendment 13 disaggregated management of Oregon Coast Natural (OCN) coho by establishing a matrix-based control rule based on marine survival and the parent spawner status for four OCN sub-stocks, the most southern of which was the Oregon component of the SONCC ESU[1] (Table 4). In that opinion, NMFS concluded that neither the FMP nor Amendment 13 provided specific protection for the California populations in the ESU, apart from the limitation on harvest rates determined by the status of the Oregon coho stocks and the acknowledgment that the Council manages all stocks listed under the ESA consistent with NMFS' ESA consultation standards. NMFS concluded that the absence of conservation goals for the California component of the ESU would jeopardize the SONCC coho salmon ESU. NMFS developed a three-part Reasonable and Prudent Alternative that requires that (1) management measures developed under the FMP achieve an ocean exploitation rate on Rogue/Klamath coho hatchery stocks of no more 13 percent, which includes all harvest-related mortality. This was the lowest exploitation rate specified under Amendment 13 for OCN coho sub-aggregates (Table 4); (2) prohibits coho-directed fisheries and coho retention in Chinook-directed fisheries off of California, and (3) requires sampling and monitoring of Council fisheries.

[1] Management for OCN coho was subsequently modified by Amendment 16 which removed the southern sub-stock from the management matrix. Management for SONCC coho remain under the provisions of the 1999 opinion.

NMFS' rationale in choosing the exploitation rate ceiling of 13 percent was that little information was available on natural coho spawning escapement levels in rivers of the California component of the SONCC ESU, such that the status of parent spawner recruitment was difficult to assess (NMFS 1999). An exploitation rate of 13 percent was the lowest exploitation rate proposed under Amendment 13 for OCN coho sub-aggregates (Table 4). Ocean exploitation rates on Rogue/Klamath coho at the time varied between 5 and 12 percent (NMFS 1999, also see Figure 3). The 13 percent ceiling on the ocean exploitation rate was conservative given the limited data on the ESU, and was meant to ensure that fishing mortality rates on California coho would not increase until an adequate assessment of parent spawner recruitment rates was possible. Ocean exploitation rates have generally been well below the ceiling, averaging 5.5 percent from 2010 to 2019.

Wild SONCC coho salmon are not tagged or monitored in ocean fisheries. Rogue and Klamath hatchery stocks have traditionally been used as a fishery surrogate stocks for estimating ocean exploitation rates on SONCC coho salmon. Natural-origin Rogue/Klamath basin coho salmon ocean exploitation rates were estimated using the Fishery Regulation and Assessment Model (FRAM), which relies on CWT recovery data from the late 1980s and early 1990s (Figure 3). The estimated ocean exploitation rate has been low and relatively stable since the early 1990s (average of 5.4% for years 1994–2019) which contrasts sharply with the much higher rates estimated for the 1980s and early 1990s (Williams et al. 2016).

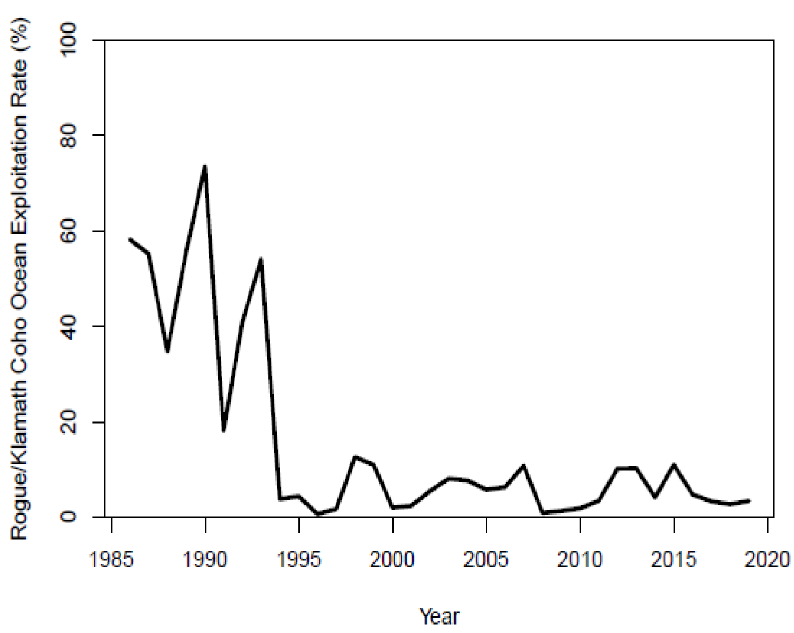

Figure 3. Trends in ocean exploitation rates on SONCC coho: 1985-2019 (Source: J Carey, NMFS).

Table 4. Exploitation rate ceilings associated with conditions of marine survival and parent escapement for Oregon coho as managed under Amendment 13 to the PFMC salmon FMP (NMFS 1999).

	Marine Survival		
	Low	Medium	High
High Parent Spawning Escapement	≤15%	≤30%	≤35%
Medium Parent Spawning Escapement	≤15%	≤20%	≤25%
Low Parent Spawning Escapement	≤15%	≤15%	≤15%
38% Below Low Parent Spawning Escapement	≤13%	≤13%	≤13%

Freshwater Recreational Fisheries

Impacts to SONCC coho from freshwater recreational fisheries are likely low and result from incidental mortalities in fisheries targeting Chinook and steelhead in California and Oregon, and hatchery coho in the Rogue River, Oregon (Williams et al 2016, NMFS 2014). Retention of coho is prohibited in California and the mark-selective fisheries in Oregon are relatively small scale. From creel surveys conducted in 1998 and 1999, ODFW estimated an incidental fishery related mortality of 5% on wild coho during mark-selective coho fisheries in the Rogue River (Matt Falcy, Personal communication). However, additional work is needed to estimate current levels of incidental fishing mortality.

Tribal Fisheries

Tribal fisheries in the Klamath and Trinity basins impact SONCC coho salmon through direct harvest and incidental mortalities in fisheries targeting other species.

Hoopa Valley Tribal Council manages fisheries for the benefit of its membership and conservation of the resource. The directed individual tribal member fishery (ITMF) includes harvest of both hatchery-origin and natural-origin coho salmon by gillnet and hook and line. A mark selective harvest of hatchery-origin coho is implemented annually through the deployment of a floating resistance board weir at the southern boundary of the Hoopa Valley Reservation. The weir is operated from early September through November, Monday through Friday between the hours of 1700–0900. All natural-origin coho are released upstream of the weir to continue migration. Total coho harvest from both the ITMF and weir fishery have been reported to co-managers for years 1991–2019.

The Yurok Tribe also manages fisheries for the benefit of its members and conservation of the resource. Out of concern for the status of coho salmon, the Yurok Tribal Council began implementing conservation measures to minimize harvest impacts to coho salmon in the early

1990s, several years before SONCC coho salmon were listed under the federal ESA. Such conservation measures have continued through to recent years, and have typically consisted of partial closures (e.g., two days per week) to minimize harvest impacts. The Yurok Tribal Council has also chosen to close its commercial fishery seasons near the beginning of coho run timing in the Klamath River estuary, to minimize harvest impacts. Another factor that minimizes harvest impacts to coho salmon in the Yurok fishery during some years is the fact the fishery had closed prior to the arrival of the coho run, due to attainment of the Yurok fall Chinook allocation.

Individual coho salmon populations returning to the Klamath Basin often intermingle and are caught together in fisheries that occur downstream of their final destination. This makes it difficult for fisheries managers to determine the contribution of different stocks to the catch that occurs in these mixed stock fisheries. Therefore, for the purposes of accounting in Klamath Basin fisheries in this report, it is assumed that fisheries are prosecuted continuously through the period of coho migration such that the natural-origin component of each coho population is harvested at the same rate for those populations moving through a specific area. Due to the locations of their respective fisheries, Yurok tribal fisheries encounter coho populations returning to both the Klamath and Trinity rivers, such as the Upper Klamath, Shasta, and Scott populations; whereas Hoopa Valley tribal fisheries encounter coho populations returning to the Trinity River: Upper Trinity River, Lower Trinity River and South Fork Trinity River (Figure 4).

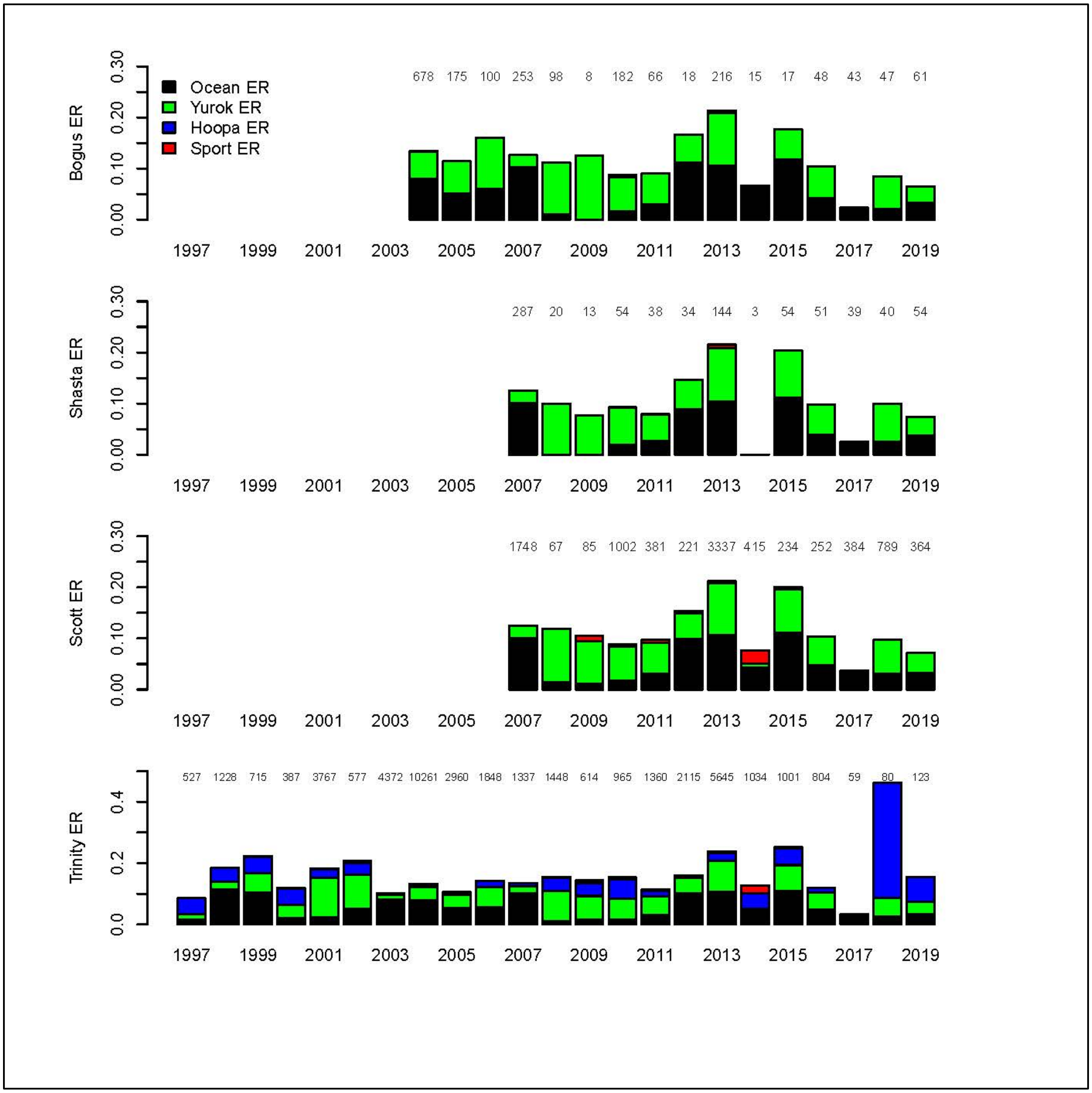

Figure 4. Exploitation rates for four SONCC coho population components (Bogus Creek, Shasta River, Scott River, and Trinity River aggregated). Numbers at the top of each bar represent the estimated pre-fishery ocean abundance for that stock and year.

Figure 4 and Table 5 through Table 9 display estimated exploitation rates for SONCC coho populations in California from all fisheries from 1997 to 2019. These exploitation rates include fish that were either kept or mortality that accrued in any specific year via release mortality, since non-tribal fisheries cannot legally retain coho in marine or freshwater areas in California.

Table 5. Exploitation rates estimated for coho originating from Bogus Creek (a component of the Upper Klamath River population, an interior Klamath River population) in ocean, tribal, and freshwater recreational fisheries.

Year	Ocean fisheries	Yurok Tribal fisheries	Klamath River recreational fisheries	Total ER
1997	NA	NA	NA	NA
1998	NA	NA	NA	NA
1999	NA	NA	NA	NA
2000	NA	NA	NA	NA
2001	NA	NA	NA	NA
2002	NA	NA	NA	NA
2003	NA	NA	NA	NA
2004	7.9%	5.3%	0.1%	13.3%
2005	5.3%	6.0%	0.1%	11.4%
2006	5.6%	9.8%	0.0%	15.4%
2007	10.1%	2.4%	0.0%	12.5%
2008	1.1%	9.8%	0.4%	11.3%
2009	1.5%	7.9%	1.0%	10.4%
2010	1.7%	6.7%	0.5%	8.9%
2011	3.1%	6.1%	0.6%	9.8%
2012	10.1%	5.1%	0.6%	15.8%
2013	10.6%	10.1%	0.4%	21.2%
2014	4.3%	0.8%	2.7%	7.8%
2015	11.0%	8.4%	0.3%	19.7%
2016	4.8%	5.4%	0.0%	10.2%
2017	3.3%	0.3%	0.0%	3.6%
2018	3.0%	6.7%	0.0%	9.7%
2019	3.3%	3.9%	0.0%	7.2%

Table 6. Exploitation rates estimated for the Shasta River coho population (an interior Klamath River population) in ocean, tribal, and freshwater recreational fisheries from.

Year	Ocean fisheries	Yurok Tribal fisheries	Klamath River recreational fisheries	Total ER
1997	NA	NA	NA	NA
1998	NA	NA	NA	NA
1999	NA	NA	NA	NA
2000	NA	NA	NA	NA
2001	NA	NA	NA	NA
2002	NA	NA	NA	NA
2003	NA	NA	NA	NA
2004	NA	NA	NA	NA
2005	NA	NA	NA	NA
2006	NA	NA	NA	NA
2007	10.1%	2.4%	0.0%	12.5%
2008	1.1%	9.8%	0.4%	11.3%
2009	1.5%	7.9%	1.0%	10.4%
2010	1.7%	6.7%	0.5%	8.9%
2011	3.1%	6.1%	0.6%	9.8%
2012	10.1%	5.1%	0.6%	15.8%
2013	10.6%	10.1%	0.4%	21.2%
2014	4.3%	0.8%	2.7%	7.8%
2015	11.0%	8.4%	0.3%	19.7%
2016	4.8%	5.4%	0.0%	10.2%
2017	3.3%	0.3%	0.0%	3.6%
2018	3.0%	6.7%	0.0%	9.7%
2019	3.3%	3.9%	0.0%	7.2%

Table 7. Exploitation rates estimated for the Scott River coho population (an interior Klamath River population) in ocean, tribal, and freshwater recreational fisheries from.

Year	Ocean fisheries	Yurok Tribal fisheries	Klamath River recreational fisheries	Total ER
1997	NA	NA	NA	NA
1998	NA	NA	NA	NA
1999	NA	NA	NA	NA
2000	NA	NA	NA	NA
2001	NA	NA	NA	NA
2002	NA	NA	NA	NA
2003	NA	NA	NA	NA
2004	NA	NA	NA	NA
2005	NA	NA	NA	NA
2006	NA	NA	NA	NA
2007	10.1%	2.4%	0.0%	12.5%
2008	1.1%	9.8%	0.4%	11.3%
2009	1.5%	7.9%	1.0%	10.4%
2010	1.7%	6.7%	0.5%	8.9%
2011	3.1%	6.1%	0.6%	9.8%
2012	10.1%	5.1%	0.6%	15.8%
2013	10.6%	10.1%	0.4%	21.2%
2014	4.3%	0.8%	2.7%	7.8%
2015	11.0%	8.4%	0.3%	19.7%
2016	4.8%	5.4%	0.0%	10.2%
2017	3.3%	0.3%	0.0%	3.6%
2018	3.0%	6.7%	0.0%	9.7%
2019	3.3%	3.9%	0.0%	7.2%

Table 8. Exploitation rates estimated for coho populations originating from the Interior Trinity River aggregate in ocean, tribal, and freshwater recreational fisheries from.

Year	Ocean fisheries	Yurok Tribal fisheries	Hoopa Valley Tribal fisheries	Klamath River recreational fisheries	Trinity River Recreational fisheries	Total ER
1997	1.6%	1.9%	5.2%	0.0%	0.0%	8.7%
1998	11.5%	2.5%	4.5%	0.0%	0.0%	18.5%
1999	10.3%	6.4%	5.5%	0.1%	0.0%	22.3%
2000	2.0%	4.4%	5.0%	0.2%	0.0%	11.7%
2001	2.4%	12.9%	2.8%	0.3%	0.0%	18.4%
2002	5.2%	11.0%	3.6%	0.9%	0.0%	20.7%
2003	8.1%	1.5%	0.4%	0.1%	0.0%	10.1%
2004	7.9%	4.4%	0.9%	0.1%	0.0%	13.3%
2005	5.3%	4.5%	0.7%	0.0%	0.0%	10.5%
2006	5.6%	6.7%	1.9%	0.0%	0.0%	14.2%
2007	10.1%	2.4%	1.0%	0.0%	0.0%	13.5%
2008	1.1%	9.8%	4.2%	0.4%	0.0%	15.6%
2009	1.5%	7.9%	4.1%	1.0%	0.0%	14.5%
2010	1.7%	6.7%	6.4%	0.5%	0.0%	15.3%
2011	3.1%	6.1%	1.6%	0.6%	0.0%	11.4%
2012	10.1%	5.1%	0.3%	0.6%	0.0%	16.1%
2013	10.6%	10.1%	2.6%	0.4%	0.0%	23.7%
2014	4.3%	0.8%	5.0%	2.7%	0.0%	12.8%
2015	11.0%	8.4%	5.5%	0.3%	0.0%	25.3%
2016	4.8%	5.4%	1.6%	0.0%	0.0%	11.9%
2017	3.3%	0.3%	0.0%	0.0%	0.0%	3.6%
2018	3.0%	6.7%	37.9%	0.0%	0.0%	47.7%
2019	3.3%	3.9%	8.0%	0.0%	0.0%	15.2%

Table 9. Exploitation rates estimated for coho populations originating from Freshwater Creek (a component of the Humboldt Bay Tributaries population in the Southern Coastal Basin strata) in ocean, tribal, and freshwater recreational fisheries from.

Year	Ocean fisheries
2000	2.0%
2001	2.4%
2002	5.2%
2003	8.1%
2004	7.9%
2005	5.3%
2006	5.6%
2007	10.1%
2008	1.1%
2009	1.5%
2010	1.7%
2011	3.1%
2012	10.1%
2013	10.6%
2014	4.3%
2015	11.0%
2016	4.8%
2017	3.3%
2018	3.0%
2019	3.3%

Examples of other PFMC salmon management frameworks

A variety of fishery management strategies are currently employed in salmon fisheries for other stocks managed under the FMP. These strategies are primarily abundance based and employ a variety of estimators or indicators related to natural fish abundance including forecasts of abundance, estimates of spawners, and estimates of marine survival using indicators of ocean conditions. Indicators are based on wild or hatchery fish at an aggregate or indicator population level.

Fishery management strategies have also involved different combinations of exploitation rates and abundance or marine survival thresholds at which different rates are applied. For example, single year alternatives are based on annual run size expectations while multi-year alternatives may include extra conditions for adopting a higher or lower rate (e.g., limits on exploitation rates following successive low run years). In addition, the balance of conservation risks and fishery objectives can be evaluated when considering an exploitation rate or abundance threshold.

The following subsections are examples of strategies employed in other fisheries and for other salmon stocks throughout the region. These may be useful when considering a suite of approaches for SONCC coho salmon.

Puget Sound Coho

Puget Sound coho stocks are managed under the 2019–2028 Pacific Salmon Treaty Agreement using a stepped harvest rate control rule (Figure 5) (Southern Coho Management Plan Chapter 5, Annex IV, Article XV, PST 2019). Under this control rule, exploitation rate ceilings are determined on the basis of age-3 abundance, where abundance is divided into three zones defined by two breakpoints defined as:

$$A = \frac{MSST}{1-F_{low}}, \quad \text{breakpoint between critical and low abundance,}$$

$$B = \frac{S_{MSY}}{1-MFMT}, \quad \text{breakpoint between low and normal abundance.}$$

MSST = minimum stock size threshold
MFMT = maximum fishing mortality threshold
S_{MSY} = spawners at maximum sustainable yield

The exploitation rate ceiling has a maximum value of maximum fishing mortality threshold (MFMT; S_{MSY}) when $N > B$, is reduced to a low exploitation rate (F_{low}) when $A < N < B$, and further reduced to a critical exploitation rate ($F_{critical}$) not to exceed 0.20 when $N < A$. For all Puget Sound coho stocks, the critical/low spawning escapement breakpoint and low exploitation rate are used to define the minimum stock size threshold (MSST).

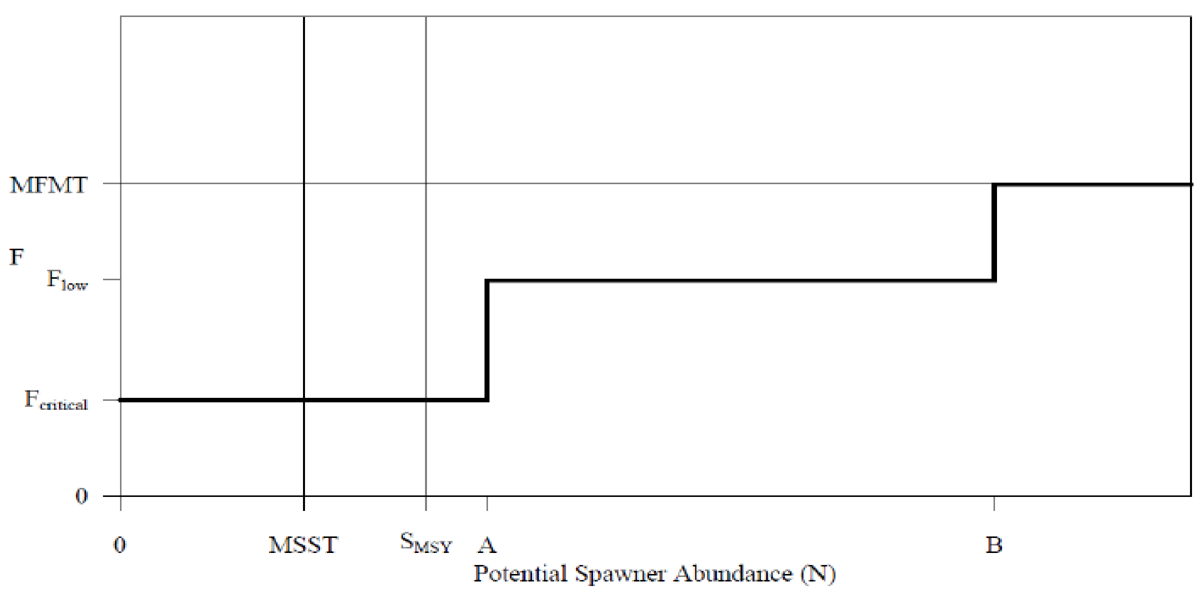

Figure 5. Control rule for Puget Sound coho. Abundance is pre-fishery ocean age-3 abundance in spawner equivalent units, and F is the exploitation rate.

Oregon Coast Natural and Lower Columbia River coho

Abundance-based exploitation strategies were adopted by the Council in 1997 for management of fisheries for OCN coho and in 2005 for Lower Columbia River natural (LCN) coho. The annual maximum allowable total exploitation rates (marine and freshwater fisheries combined) vary in response to changes in observed brood year-specific parental spawner abundance relative to full seeding of the habitat and marine survival conditions (Table 10 and Table 11).

Table 10. Harvest management matrix for LCR coho showing allowable fishery exploitation rates based on parental escapement and marine survival index.

Parental Escapement (rate of full seeding)		Marine Survival Index (based on return of jacks per hatchery smolt)					
		Very Low (≤ 0.06%)	**Low (≤ 0.08%)**	**Medium (≤ 0.17%)**	**High (≤ 0.40%)**	**Very High (> 0.40%)**	
Normal	≥ 0.30	10%	15%	18%	23%	30%	**Total Allowable exploitation rate**
Very Low	< 0.30	≤ 10%	≤ 15%	≤ 18%	≤ 23%	≤ 30%	

Table 11. Harvest management matrix identifying allowable fishery impacts and ranges of resulting recruitment based on parental spawner abundance and marine survival (OCN work group revisions to original Council matrix).

Parent Spawner Status[a/]	Marine Survival Index (Wild adult coho salmon survival as predicted by the two-variable GAM ensemble forecast)			
	Extremely Low <2%	**Low** 2%-4.5%	**Medium** >4.5%-8%	**High** >8%
High Parent Spawners > 75% of full seeding	E ≤ 8%	J ≤ 15%	O ≤ 30%	T ≤ 45%
Medium Parent Spawners > 50% & ≤ 75% of full seeding	D ≤ 8%	I ≤ 15%	N ≤ 20%	S ≤ 38%
Low Parent Spawners > 19% & ≤ 50% of full seeding	C ≤ 8%	H ≤ 15%	M ≤ 15%	R ≤ 25%
Very Low Parent Spawners > 4 fish per mile & ≤ 19% of full seeding	B ≤ 8%	G ≤ 11%	L ≤ 11%	Q ≤ 11%
Critical Parent Spawners ≤4 fish per mile	A 0 – 8%	F 0 – 8%	K 0 – 8%	P 0 – 8%

Sub-aggregate and Basin Specific Spawner Criteria Data

Sub-aggregate	Miles of Available Spawning Habitat	100% of Full Seeding	"Critical"		Very Low, Low, Medium & High		
			4 Fish per Mile	12% of Full Seeding	19% of Full Seeding	50% of Full Seeding	75% of Full Seeding
Northern	899	21,700	3,596	NA	4,123	10,850	16,275
North-Central	1,163	55,000	4,652	NA	10,450	27,500	41,250
South-Central	1,685	50,000	6,740	NA	9,500	25,000	37,500
Southern *(Removed per adoption of Amendment 16)*							
Coastwide Total	*3,747*	*126,700*	*14,988*		*24,073*	*63,350*	*95,025*

a/ Parental spawner abundance status for the OCN aggregate assumes the status of the weakest sub-aggregate.

Columbia River Upriver Bright Fall Chinook

The parties to *U.S. v. Oregon* are currently operating under the 2018–2027 Management Agreement. This agreement provides specific fishery management constraints for upriver spring, summer, and fall Chinook, coho, sockeye and steelhead. Fall season fisheries in the Columbia River Basin below the confluence of the Snake River are managed according to the abundance-based harvest rate schedule shown in Table 12. In this table, Upriver Bright (URB) stock Chinook harvest rates are used as a surrogate for Snake River wild fall Chinook harvest rates. URB fall Chinook escapement goals include 60,000 adult fall Chinook (natural and hatchery) management goal above McNary Dam. Total harvest rates in combined Treaty Indian and non-Indian Columbia River fisheries increase with increased run size based on forecasted returns to the Columbia River.

Table 12. Columbia River Fall Management Period Chinook Harvest Rate Schedule for URB fall Chinook including the listed Snake River wild component.[1]

Expected URB River Mouth Run Size	Expected River Mouth Snake River Natural Origin Run Size	Treaty Total Harvest Rate	Non-Treaty Harvest Rate	Total Harvest Rate	Expected Escapement of Snake R. Natural Origin Past Fisheries
<60,000	<1,000	20%	1.50%	21.50%	784
60,000	1,000	23%	4%	27.00%	730
120,000	2,000	23%	8.25%	21.25%	1,375
>200,000	5,000	25%	8.25%	33.25%	3,338
	6,000	27%	11%	38.00%	3,720
	8,000	30%	15%	45.00%	4,400

[1] *If the Snake River natural fall Chinook forecast is less than level corresponding to an aggregate URB run size, the allowable mortality rate will be based on the Snake River natural fall Chinook run size.*

Sacramento River Winter Chinook

In 2017, the Council adopted a new control rule that specifies the maximum forecast age-3 impact rate for the area south of Point Arena, California (Figure 6). The fishing regime for Sacramento River Winter Chinook maintains the fishery season and size restrictions that were part of the Reasonable and Prudent Alternative in the previous biological opinion. When the age-3 escapement absent fishing is forecasted to be 3,000 or more, the maximum forecast age-3 impact rate on Sacramento winter-run Chinook is 0.20. Between age-3 escapement absent fishing levels of 3,000 and 500, the maximum forecast age-3 impact rate decreases linearly from 0.20 to 0.10. At age-3 escapement absent fishing levels less than 500, the maximum forecast age-3 impact rate decreases linearly from 0.10 to zero.

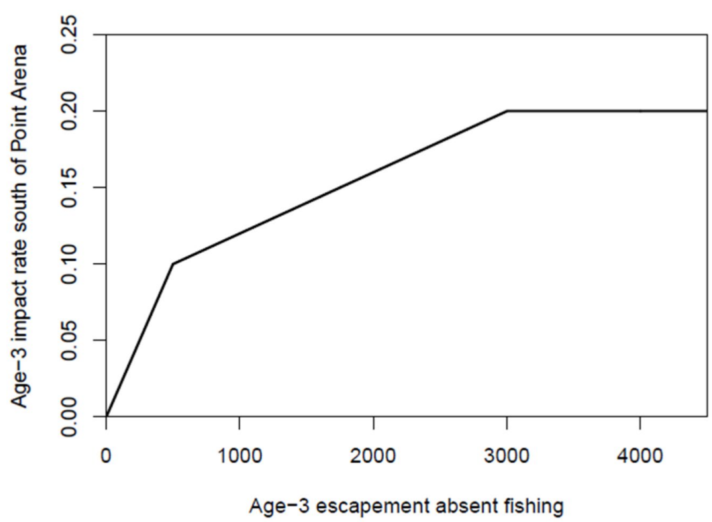

Figure 6. Sacramento River winter Chinook impact rate control rule, which specifies the maximum forecast age-3 impact rate for the area south of Point Arena, California, as a function of forecasted age-3 escapement absent fishing.

5. ABUNDANCE FORECASTING

The Council tasked the Workgroup with evaluating HCR in the form of fixed or tiered exploitation rates including consideration of control rules which reduce exploitation rates at low abundance levels, and which may include minimum or target spawner levels. The feasibility and effectiveness of several of the types of control rules under evaluation by the Workgroup will depend in part on whether abundance can be predicted with reasonable accuracy and precision.

This section reviews: 1) the current approach used to forecast SONCC coho salmon as part of the Oregon Production Index public hatchery aggregate; 2) the general set of methods available for generating forecasts, and their associated data needs and considerations; 3) a preliminary statistical assessment of forecast potential for SONCC components using the run size data assembled by the Workgroup (see chapters 3 and 4); and 4) other considerations affecting the practical feasibility of generating forecasts for use in annual management for each component.

Background

Implementing an abundance-based HCR requires that the ocean abundance of the SONCC coho salmon ESU, or representative components thereof, be forecast prior to the fishing season. Under the existing management framework, the ocean abundance of hatchery-origin SONCC coho salmon is forecasted annually as part of a larger Oregon Production Index public hatchery (OPIH) forecast process. More specifically, the Oregon Production Index Technical Team (OPITT) generates a forecast of aggregate hatchery-origin coho salmon abundance from across the OPI range (from the Columbia River to Northern California) using a sibling regression model. A subset of this aggregate forecast is then apportioned to Rogue-Klamath based on the total number of smolts release from three facilities (Trinity River Hatchery [TRH], Iron Gate Hatchery [IGH], and Cole Rivers Hatchery [CRH]) for the brood in question.

In contrast to hatchery-origin fish, the abundance of natural-origin SONCC coho salmon is not forecast at the present time. Here we consider the possibilities for doing so in general terms, focusing on questions of:

> (Q1) *Data considerations*—what populations have run reconstruction data (inclusive of ocean and freshwater abundance and pertinent predictors such as marine survival), with a record of sufficient length?
>
> (Q2) *Statistical considerations*—what forecasting approach(es) might be appropriate for SONCC coho salmon? Do meaningful relationships between potential forecast predictors and ocean abundance exist?
>
> (Q3) *Practical considerations* — Among populations with sufficient data and statistical relationships, which are likely to be monitored consistently going forward and that support timely reporting of estimates (i.e., practical requirements for future implementation)? What additional collaborative/co-management data compilation, review and agreement process would be necessary to make such information useful to Council management each year?

Forecast Considerations and SONCC Coho Salmon

Salmon abundance forecasts are made at varying levels of spatial scale or biological resolution (e.g., population, metapopulation, basin, stock aggregate, etc.), for hatchery- and/or natural-origin fish separately, and even for indices of abundance/production (e.g., Sacramento Index) rather than 'true' population abundance itself, with the choice being governed largely by data availability and management needs. For SONCC coho salmon in particular, the forecasts are informed by three hatchery components (IGH, TRH, and CRH). The following discussion explores the data availability and potential for forecasting other populations within the ESU.

Forecasts of salmon abundance are generated using models, ranging from simple moving averages of abundance in prior years to complex population or life cycle models. Yet all typically fall into one of three broad categories (nomenclature after Velez-Espino et al. 2019): sibling regression models, mechanistic models, and time series models. Each of these may also include environmental covariates that correlate with survival during outmigration or early marine stages, or otherwise account for a component of abundance variation.

Sibling regression models predict the abundance of older age classes during year *t* based on the prior year's abundance for younger (sibling) age classes from the same brood in year *t* - 1 (for coho salmon, jacks). Mechanistic models are varied in form and complexity (Table 13), but typically predict abundance in year *t* by modeling the survival process for a cohort/cohorts, seeded with some empirical information in prior years (e.g., outmigrant abundance, parent-generation spawner abundance, etc.). Examples here include 'return rate' forecasts that apply recent estimates of survival or predictions of survival, often with underlying environmental covariate relationships, to observations of outmigrant abundance for the brood of interest (e.g., Washington's LCN coho populations) or they may simply be regressions of outmigrant or parent-generation spawner abundance vs. a brood year's subsequent ocean abundance. Lastly, time series models can be used to predict abundance from observations of abundance in prior years alone. Again, while this approach can be relatively simple and straightforward (e.g., moving-average predictions, OCN Lakes coho salmon), time series models can also be complex and varied, including covariates and/or autoregressive terms, among other possibilities.

For SONCC coho salmon applications, the best choice of forecasting method(s) from those described above and/or the ESU components is in part a function of data availability (Table 13). At the most basic level (e.g., 3-year moving average), a forecast could conceivably be made for any population for which a few years of escapement data exist, given that appropriate adjustments for incidental marine and freshwater fishery-related and natural mortality can also be made for each run year. However, if the data set were that small it would be difficult to assess forecast performance with confidence. For populations having a decade or more of demographic (e.g., smolt-to-adult survival) or abundance (smolt abundance, jack abundance, parent-generation spawners, etc.) data, the possibilities include sibling regressions, mechanistic models, more complex time-series models, hybrids of these methods, or even other statistical approaches (e.g., Rupp et al. 2012, OCN Rivers).

While data volume is a precursor to a meaningful assessment of forecast feasibility, other data-related factors may influence success in the SONCC coho salmon context. First, reasonably strong statistical relationships between predictor variables (e.g., jack abundance, environmental variables, etc.) and the ocean abundance of coho salmon at the start of the fishing season are necessary. Though perhaps obvious, observation error may be exceptionally high for some populations in the ESU due to their late spawn timing and the flashy fall-winter hydrology of many streams in the region, making it difficult to detect and apply underlying predictive relationships. Late spawn timing may also determine when the age-specific estimates of escapement (i.e., jacks) needed to forecast abundance using sibling regression methods typically become available, possibly influencing feasibility in practical terms.

Assessment of Forecast Potential

Given the considerations outlined above and in population data compiled by the Workgroup (Chapter 3), there six segments of the SONCC ESU for which the statistical aspects of forecasting could be assessed: (1) the Rogue River; (2) Bogus Creek; (3) Scott River; (4) Shasta River; (5) the Trinity River aggregate; and, (6) Freshwater Creek. While these populations/aggregates reflect a fraction of the ESU, they span much of the ESU's geographic range and integrate a moderate level of population and physiographic diversity (see Chapter 3). The datasets available for these populations span one to two decades for ocean abundance and escapement. Data sets for monitoring smolt abundance generally span fewer years or are lacking.

Using these data, forecast potential was evaluated for each population/population aggregate using up to four different approaches: (1) a sibling model, if jack data were available; (2) an outmigrant model, if the segment was associated with outmigrant/smolt monitoring of sufficient duration; (3) a parent-generation spawners model; and, (4) a three-year moving average model (note, 3 and 4 could be tested for all populations). Additionally, an intercept-only model was also fit to each dataset to provide a null-model context (i.e., do 1–4 do better than the series mean?). Two aspects of performance were considered, model-fit statistics (i.e., do significant and/or strong relationships exist?) and predictive error (mean error [ME], root mean squared error [RMSE]) using leave-one-out cross validation (after Winship et al. 2015). Because the Workgroup did not set an a priori threshold for 'acceptable performance', results were largely evaluated on a relative (best vs. worst) basis and for each population/population aggregate separately. The Workgroup also considered whether marine indicators (i.e., Pacific Decadal Oscillation, Sea Surface Temperature, El Nino-Southern Oscillation Index) might prove useful to forecasting. Owing to a combination of short datasets (i.e., not ideal for fitting complex multivariate models) and weak relationships observed during initial variable screening, this was not pursued any further.

Of the 26 different models fit for the six populations, two exhibited moderate-to-strong statistical relationships with potential predictive value (Table 14): the outmigrant model for the Scott River population and the sibling model for the Rogue River population[2]. Summary statistics for remaining covariate-based models suggest weak associations exist between ocean abundance and the outmigrant, jack, and/or parent-generation spawner predictors, and in several cases these models offer no improvement over simply using the time-series mean as a 'forecast' (e.g., Scott

[2] Note, because there is not a time series for natural-origin jacks for the Rogue River available at this time, this relationship was assessed using Cole River Hatchery jacks as a proxy.

River sibling and Shasta River outmigrant models). Lastly, the three-year moving average forecast method performed reasonably well for Freshwater Creek, but not for any of the other populations.

Practical Considerations

Beyond assessing statistical potential, the Workgroup considered the feasibility of making forecasts annually going forward in a manner that would be supportive of Council-area fishery planning and assessment. While Workgroup members highlighted agency commitments to future monitoring, timely reporting of data and manager collaboration, it acknowledged several challenges and uncertainties to the feasibility of forecasting population abundance in the SONCC coho ESU:

- Stability and purpose of current monitoring programs: While many programs have been relatively stable over time, the funding sources and periodicity in which funding is renewed varies among the programs. In other cases, shifting priorities can affect the continuity of programs. Some coho monitoring programs assess only presence/absence or data collection is secondary to collection and monitoring of Chinook in those systems.
- Data timing for annual use: In some areas, data are available in time to use for annual forecasting. However, in many California systems, coho surveys extend well into January or early February such that some of the monitoring data necessary that would be necessary for annual forecasts may not become available until early March each year, generally too late to inform Council management. This would not be a concern for control rules that rely on lagged data, e.g., parent spawners.
- Status of integration into current comanager process and discussion. In most case, forecasts are generated by multiple entities. The process for data sharing, technical evaluation, manager consensus, documentation and when information is available varies across states and watersheds. Forecasts for Columbia River and Oregon coho are developed by the states and tribes in several collaborative forums and available in time for the annual planning cycle. The Klamath Technical Team convenes a multi-day meeting that allows for information sharing, data review and consensus agreement on forecasts for fall Chinook salmon in the Klamath and Trinity basins. However, that process does not currently involve coho salmon data review.

Table 15 summarizes forecast model performance and the associated data needs and timing for each of the population/population aggregates as discussed above.

Table 13. Methods for forecasting of the ocean abundance of coho salmon in year *t*. For the fields under 'Historical and annual data needs', X = required. Note also that estimates for environmental covariates are also needed on a timely basis if they are part of the forecast model (applicable to all).

Forecast type	Conceptual structure	Model complexity	Data burden	Historical and annual data needs			Comments
				Adult N (Ad_t)	Jack N (Ja_t)	Outmigrant or juvenile N (Sm_t)[1]	
Sibling regression	$Ad_t \sim Ja_{t-1}$	Moderate-High	Moderate	X	X		Timely estimates of jack abundance in prior year needed (lags on ageing?).
Mechanistic model	e.g., $Ad_t \sim S. \times Sm_{t-1}$	Moderate-High	Moderate-High	X	~	X	Data needs depend on type of model (e.g., survival estimates [*S.*] are needed for return rate models).
Time series model	$Ad_t \sim f(Ad_{t-1}, Ad_{t-2} \ldots Ad_{t-n})$	Low-High	Low	X	~		Complexity can vary widely.

[1] *Parent-generation spawner abundance may be a suitable alternative here (i.e.,* $Ad_t \sim Ad_{t-3}$*)*

Table 14. Summary statistics for potential relationships/models assessed for forecasting the pre-fishing ocean abundance for select populations of SONCC coho salmon. Root mean square error (RMSE) and mean error (ME) are based on leave-one-out cross validation. NA denotes cases where a particular statistic was not relevant, or a particular model could not be fit due to a lack of information for a predictor. Note, all models were fit using log-transformed predictor and response variables.

	Intercept (null) model					**Sibling model**					**Outmigrant model**					**Parent-generation spawners model**					**3-year moving average model**				
Population	***N***	**R^2**	***P***	**RMSE**	**ME**	***N***	**R^2**	***P***	**RMSE**	**ME**	***N***	**R^2**	***P***	**RMSE**	**ME**	***N***	**R^2**	***P***	**RMSE**	**ME**	***N***	**R^2**	***P***	**RMSE**	**ME**
Bogus Creek	16	*NA*	*NA*	1.237	0.000	15	0.03	0.560	1.175	0.025	*NA*	*NA*	*NA*	*NA*	*NA*	13	0.30	0.052	1.001	0.019	13	*NA*	*NA*	1.197	-0.176
Scott River	13	*NA*	*NA*	1.142	0.000	12	0.04	0.517	1.151	-0.048	12	0.61	0.003	0.870	0.062	10	0.14	0.282	0.995	-0.049	10	*NA*	*NA*	1.068	0.259
Shasta River	13	*NA*	*NA*	1.137	0.000	12	0.17	0.190	0.973	0.042	13	0.15	0.192	1.130	0.066	10	0.00	0.881	1.048	0.021	10	*NA*	*NA*	1.201	-0.216
Trinity River	23	*NA*	*NA*	1.301	0.000	22	0.24	0.019	1.217	-0.030	*NA*	*NA*	*NA*	*NA*	*NA*	20	0.25	0.026	1.270	-0.029	20	*NA*	*NA*	1.322	0.122
Freshwater Creek	20	*NA*	*NA*	0.703	0.000	*NA*	*NA*	*NA*	*NA*	*NA*	12	0.05	0.493	0.689	-0.009	17	0.02	0.617	0.639	0.014	17	*NA*	*NA*	0.415	-0.093
Rogue River	20	*NA*	*NA*	0.910	0.000	19	0.55	0.000	0.662	-0.021	*NA*	*NA*	*NA*	*NA*	*NA*	20	0.00	0.947	0.940	0.003	17	*NA*	*NA*	0.846	-0.024

Table 15. Summary of considerations about the feasibility of annual forecasting and HCR implementation for natural-origin SONCC coho salmon.

Population	Statistical Evaluation of Ocean Abundance Forecast Potential [1/]	Future Dependability of Essential Data Streams [2/]	Postseason & Preseason Assessment Needs & Roles [3/]	Annual Timing of Data Availability [4/]	Comments
Bogus Creek	Weak relationship with parent-gen. spawners (R^2 = 0.30, P = 0.052)	Moderate (may be affected by changes in funding or survey priorities after dam removal)	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of ocean abundance and impacts in fisheries; *Parties involved* [5/]: CDFW, ODFW, HVT, YT, NMFS, USFS, USFWS, STT, …	Early-to-mid March	Timing and dependability limitations may be partly addressed through increased funding; pre- and postseason assessment work may require increased capacity across organizations.
Scott River	Moderate to strong relationship with outmigrant abundance (R^2 = 0.61, P = 0.003)	Moderate (may be affected by changes in funding or survey priorities after dam removal; gap in smolt monitoring as recent as 2017)	*Data needs*: river & ocean fishery impacts; escapement by age, origin; outmigrant abundance; forecasts of ocean abundance and impacts in fisheries; *Parties involved*: …	Early-to-mid March	As above.
Shasta River	Weak relationship with jack abundance (R^2 = 0.17, P = 0.190)	Moderate (may be affected by changes in funding & survey priorities when dams are removed)	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; *Parties involved*: …	Early-to-mid March	As above.
Trinity River	Weak and similar relationships with jack abundance (R^2 = 0.24, P = 0.019) and parent-gen. spawners (R^2 = 0.25, P = 0.026); [hatchery jacks hold promise]	Moderate-to-high (funded through federal agreements that are subject to renewal)	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; *Parties involved*: …	Early-to-mid March	As above.
Freshwater Creek	No significant relationships w/ smolt or parent-gen abundance; 3-	Moderate (Potential funding gap identified for coming year, future funding uncertain)	*Data needs*: ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries;	Early-to-mid March	As above. Also, note that monitoring is collaborative, multi-organization

Population	Statistical Evaluation of Ocean Abundance Forecast Potential [1/]	Future Dependability of Essential Data Streams [2/]	Postseason & Preseason Assessment Needs & Roles [3/]	Annual Timing of Data Availability [4/]	Comments
	year moving average yields best RMSE		*Possible entities*: …		effort with little representation in workgroup.
Rogue River	Moderate to strong relationship with CRH jacks (no series for natural-origin jacks available for Rogue at this time)	Moderate-to-high (likely secure, no issues/concerns on horizon)	Data needs: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; Possible entities: …	Early-to-mid February (Huntley Park seining and returns to hatchery)	
Iron Gate Hatchery	N/A – forecast relationships have not been assessed for hatchery populations.	N/A -- The program is slated for termination during dam removal.	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; *Possible entities*: …	*Hatchery*: mid-February *All returns*: Early-to-mid March	Given program's forthcoming termination, holds limited value as a surrogate.
Fall Creek Hatchery	N/A – forecast relationships have not been assessed for hatchery populations.	Moderate. Program implementation is currently uncertain immediately following dam removal and planned for termination after 8 years.	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; *Possible entities*: …	*Hatchery*: mid-February *All returns*: Early-to-mid March	Given program's possible termination, of limited value as surrogate.
Trinity River Hatchery	N/A – forecast relationships have not been assessed for hatchery populations.	High (funded through federal agreements that are subject to renewal)	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; *Possible entities*: …	*Hatchery*: mid-February *All returns*: Early-to-mid March	Note: significant changes in overall hatchery production could affect utility of Trinity River Hatchery jack vs. natural origin abundance relationships (if used for forecasting). Change from 500,000 to 300,000 production goal in 2014, to be re assessed in 2021.

Population	Statistical Evaluation of Ocean Abundance Forecast Potential 1/	Future Dependability of Essential Data Streams 2/	Postseason & Preseason Assessment Needs & Roles 3/	Annual Timing of Data Availability 4/	Comments
Cole Rivers Hatchery	N/A – forecast relationships have not been assessed for hatchery populations.	Moderate-to-high (likely secure, no issues/concerns on horizon)	*Data needs*: river & ocean fishery impacts; escapement by age, origin; forecasts of abundance and impacts in fisheries; *Possible entities*: …	Early-to-mid February	Experienced production change for 2013 BY+ (200k to 75k smolts) Included in OPI forecast

1/ Statistical assessment involved fitting bivariate regressions or computing moving average-based predictions and comparing RMSE and ME from leave-one-out cross validation, as well as model fit and significance statistics (R^2, P), between models for each population (see Table 14). An intercept-only model was also fit for each population to provide a null model context (i.e., do forecasts based on predictors do any better than assuming the mean of the historical distribution for next year's forecast?); and how 'good' or 'bad' models performed was qualitatively assessed by considering RMSE relative to average abundance in the time series.
2/ How likely is it that current monitoring and evaluation projects/programs will persist into the future (i.e., high = will continue in perpetuity, moderate = of primary interest, but may experience gaps due to reduced funding, etc., low = has recently experienced or may soon experience a data gap due to a loss of funding or other causes). This includes escapement monitoring capable of yielding annual estimates of age- and/or origin-specific escapement, as well as river and ocean fishery impacts. The same question applies for smolt monitoring data (e.g., for stocks with forecast potential reliant on outmigrant abundance). Also, have data streams of interest experienced any gaps or blackout years in the recent record? Are future gaps or termination of surveys expected?
3/ Both pre- and postseason assessment work supportive of forecasting will necessarily involve data and estimates for key fishery and population parameters; technical staff from multiple organizations (state, tribal, federal); work includes compiling and analyzing data from the prior year's return, including estimates of escapement and catch (or incidental mortality) by fishery (river, ocean) and outmigrant abundance (as necessary), as well as generating preseason forecasts of ocean abundance and fishery impacts.
4/ 'Availability' assumes that data have been subject to sufficient QA/QC, are accompanied by appropriate documentation (e.g., companion report/memos), and have been shared with co-managers for review, as appropriate (i.e., preliminary data are not sufficient). Note that the best predictors for some populations may be available sooner (e.g., parent-generation spawners).
5/ This is the potential list of organizations holding SONCC coho salmon management/assessment interests; the actual subset engaging for each population may not include all.

6. HARVEST CONTROL RULES CONSIDERED

The Workgroup has developed an initial suite of HCRs for analysis using the risk assessment model. The range of this initial set of HCRs is consistent with the Terms of Reference and the Purpose and Need portion of Chapter 2 in this report. In particular, the Workgroup has developed fixed control rules (HCR 1–7, Figure 7), control rules with tiers that reduce ERs at low abundance levels (HCR 8-11, Figure 8), and a potential matrix-based control rule (Figure 11). Furthermore, the initial suite of control rules includes those that apply to marine fisheries only and to marine and freshwater fisheries combined.

Figure 7 displays an initial set of constant exploitation rate control rules. Control rule 1 is specified as a total (marine and freshwater) exploitation rate of zero, and is included only to provide a reference for population outcomes in the absence of fisheries. Control rules 2–4 specify constant total ERs of 7, 13, and 26 percent, respectively. Control rules 5–7 specify constant ocean ERs of 7, 13, and 26 percent, respectively. For comparison, the present HCR is a static 13% marine ER, and 7% and 26% reflect approximately half and twice this rate. Control rule 6 represents the status quo control rule for Rogue-Klamath coho.

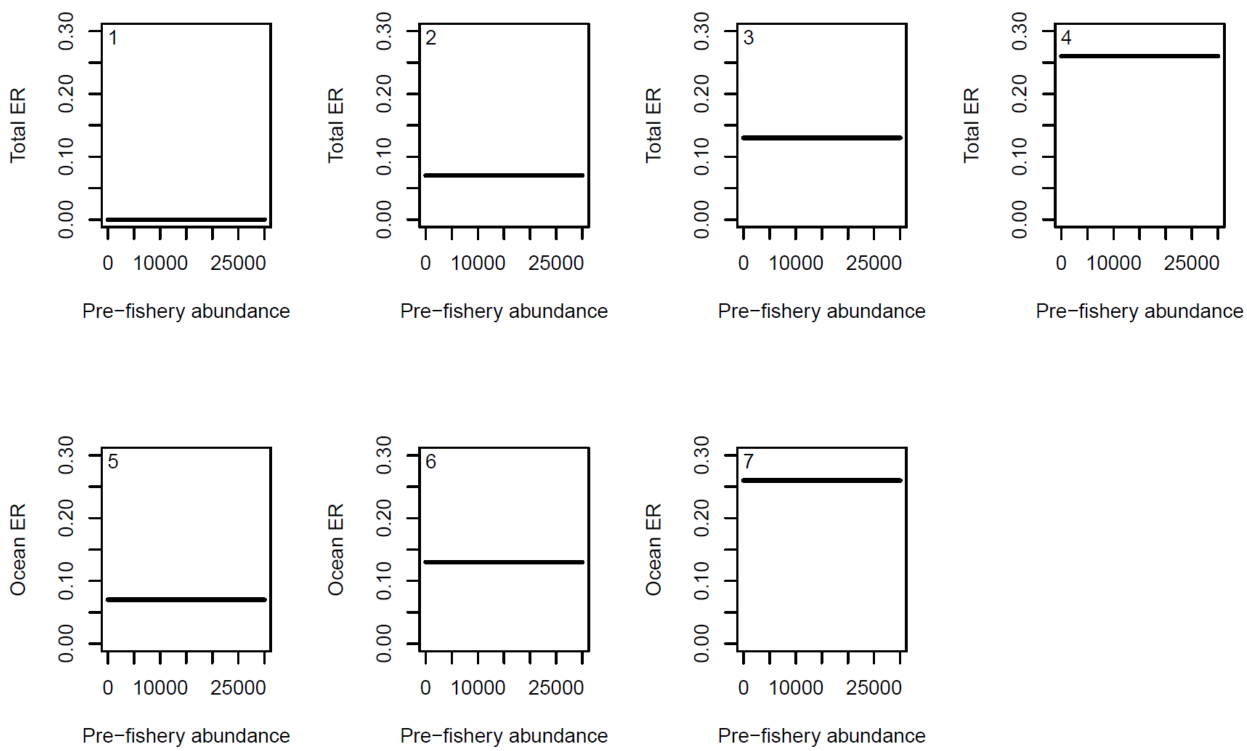

Figure 7. Graphical depiction of control rules 1–7. Control rules 1–4 specify constant total exploitation rates and control rules 5–7 specify constant exploitation rates that apply only to ocean fisheries. These control rule would apply to the Klamath/Trinity/Rogue aggregate natural-origin abundance.

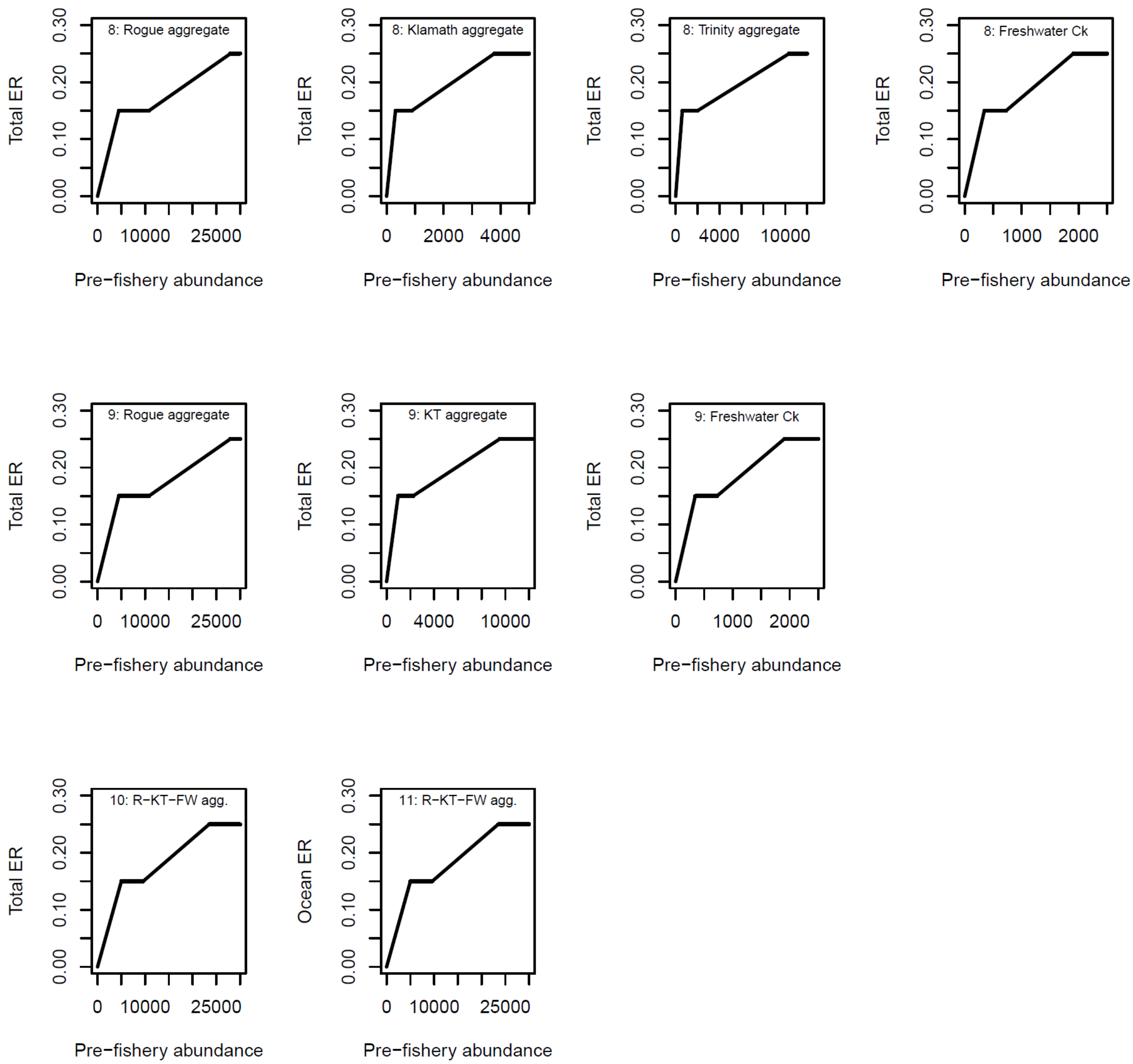

Figure 8. Graphical depiction of control rules 8–11. Control rules 8 and 9 consist of systems of harvest controls for various SONCC coho population aggregates and are specified as abundance-based limits to total ERs. Control rules 10 and 11 apply to total SONCC coho abundance (for components with sufficient data), which includes Rogue aggregate abundance (R), Klamath-Trinity aggregate abundance (KT), and Freshwater Creek (FW). Control rule 10 specifies limits to the total ERs while control rule 11 applies only to ocean fisheries. See Table 11 for an example of a matrix-based HCR for SONCC coho.

Figure 8 displays an initial set of abundance-based control rules, which would require forecasts of abundance. Each of the control rules in Figure 8 have the same basic form, which is depicted in Figure 9. These abundance based control rules specify a cap on the exploitation rate (Y3 in Figure 9) at "high" abundance (> X4). As abundance decreases below abundance level X4, the allowable exploitation rate decreases linearly until abundance level X3. Between “moderate” abundance levels X3 and X2, the control rules specify a constant “moderate” level of the exploitation rate, Y2. When abundance is predicted to be low (below X2), the exploitation rate decreases linearly from Y2 to X1 (an exploitation rate of zero). For each of the control rules in Figure 7, the “moderate” level of abundance (between X2 and X3) is defined as the middle 50 percent of the distribution of past abundances. The 25th percentile of the abundance distribution lies below X2, while the 75th percentile of the abundance distribution lies between X3 and X4, with X4 defined as the highest observed past abundance level. The constant ERs specified at moderate and high abundances are 15 and 25 percent, respectively, for each control rule.

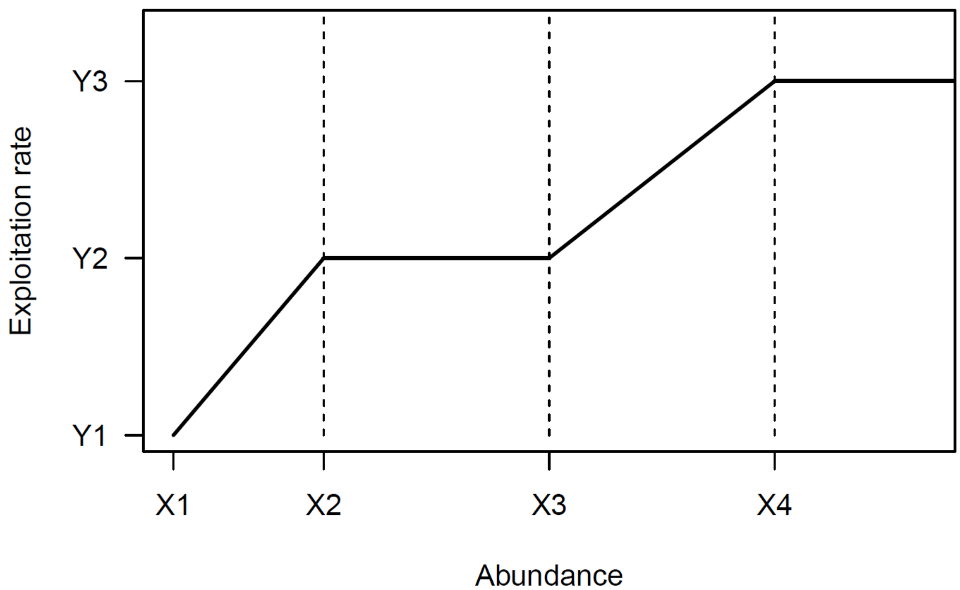

Figure 9. General form of control rules 8–11. Reference abundance and exploitation rate levels are defined in the text.

Control rule 8 represents a system of harvest controls applied independently to four components of the SONCC coho ESU (Figure 8). The Rogue aggregate applies to a multi-population aggregate of coho abundance as estimated at Huntley Park in the lower Rogue River. The Klamath aggregate applies to a multi-population aggregate of coho abundance, including Bogus Creek, Shasta River, and Scott River, all of which are tributaries to the Klamath River. The Trinity aggregate applies to a multi-population aggregate of coho abundance which applies to coho spawning in natural areas in the upper, lower and South Fork Trinity rivers. Finally, Freshwater Creek is a component of the Humboldt Bay tributaries population. Application of control rule 8 would require that each of the four components be at or below the maximum total exploitation rates specified for that component, i.e., fisheries would be managed for the weakest commingled stock.

Control rule 9 is equivalent to control rule 8, but the Klamath and Trinity aggregates were combined into a single KT aggregate. Control rules 10 and 11 both apply to the total Rogue, Klamath, Trinity, and Freshwater Creek abundance. Control rule 10 specifies maximum allowable total exploitation rates while control rule 11 specifies maximum allowable ocean exploitation rates.

The work group is also exploring the feasibility of using a matrix approach based on natural seeding levels of SONCC coho and a marine survival index based on hatchery jacks (Table 16). This approach is a potential alternative for abundance-based management if forecasts of natural origin SONCC coho abundance is not feasible.

Table 16. Example matrix harvest control rule.

		Marine Survival Index[1]		
		≤33 percentile	**33-67 percentile**	**>67 percentile**
Natural Seeding level[2]	**> capacity**	**15%**	**20%**	**25%**
	CRT - Capacity	**10%**	**15%**	**20%**
	≤ Critical Risk Threshold	**5%**	**10%**	**15%**

[1]Marine survival Index based on brood year jacks-per-smolt for Cole Rivers and Trinity Hatcheries. (Iron Gate not included)

[2]Natural seeding level based on brood year average for index populations.

A summary of control rule attributes can be found in Table 17.

Table 17. Attributes of candidate control rules (excluding matrix-based control rule). The number of separate components column refers to the number of discrete harvest controls within a particular control rule.

Control Rule	Form	Number of separate components	ER type	Minimum ER	Maximum ER	ER at median abundance
1	constant ER	1	Ocean and FW	0.00	0.00	0.00
2	constant ER	1	Ocean and FW	0.07	0.07	0.07
3	constant ER	1	Ocean and FW	0.13	0.13	0.13
4	constant ER	1	Ocean and FW	0.26	0.26	0.26
5	constant ER	1	Ocean	0.07	0.07	0.07
6	constant ER	1	Ocean	0.13	0.13	0.13
7	constant ER	1	Ocean	0.26	0.26	0.26
8	N-based ER	4	Ocean and FW	0	0.25	0.15
9	N-based ER	3	Ocean and FW	0	0.25	0.15
10	N-based ER	1	Ocean and FW	0	0.25	0.15
11	N-based ER	1	Ocean	0	0.25	0.15

While the basic configuration of the abundance-based control rules allows for reduced exploitation rates at low abundances, the specific abundance breakpoints and levels of exploitation rate are not based on biological attributes of the population components or aggregates. Rather, these control rules were parameterized by the distributions of past abundance and an examination of past exploitation rates. It is possible that the form and parameterization of these control rules could be modified in the future. Furthermore, the form and number of potential control rules may change based on further analysis and Council guidance to the Workgroup.

7. WILD POPULATION RISK ASSESSMENT

For depleted or ESA-listed salmon stocks, quantitative risk assessments provide a more-directed approach for considering conservation risks than the conventional yield-based stock-recruitment analyses traditionally applied to salmon. Risk assessments consider the combined effects of fishing, fishery uncertainty, and variable production and survival on escapement levels that may affect the long-term persistence or viability of a population or group of populations. Quantitative risk assessments for listed salmon species have widely taken the form of a Population Viability Analysis (PVA). PVAs use quantitative methods to predict the likely future status of a population or collection of populations of conservation concern (Morris and Doak 2002; Beissinger and McCullough 2002).

PVA models are particularly well-suited for fishery risk assessments because effects of exploitation rates on demographic risk and metrics of fishery performance can be directly quantified. Salmon PVAs typically utilize stochastic stock-recruitment models to estimate species survival and recovery likelihoods from population abundance, productivity and spatial structure, and population variability. This approach can also effectively evaluate fishing effects on populations of different productivity including weak populations that are most at risk of falling to critical low levels where they are no longer capable of sustaining themselves.

This assessment adapted and applied a PVA framework to evaluate risks associated with HCR alternatives for SONCC coho salmon. Similar modeling approaches have previously been utilized by the Council in conservation risk analyses for other stocks including Klamath Fall Chinook, Lower Columbia River Fall Chinook, LCN Coho, and Sacramento Winter Chinook salmon.

Performance measures

HCRs were evaluated based on performance measures for conservation and fishery performance:

Conservation metrics

Spawning escapement is simply the numbers of natural-origin adults in a population that reach the spawning grounds. ESA status is often measured based on the geometric mean of recent escapements compared with a threshold of risk or viability. The geometric mean is the nth root of the product of n years (12 years for SONCC coho: NMFS 2014). Geometric means differ from arithmetic averages as a truer measure of status which avoid disproportionate effects of periodic large or very low escapements that can skew the average. Both means and variability in escapement are important. It does little good to avoid extinction on average when extinction actually occurs during periods of low escapement. Run size available to ocean or freshwater fisheries may also be an important metric in some situations.

Extinction risk is generally defined in our PVA framework as the probability that an ESA-listed unit (e.g., population) or stock will be below some minimum size over a prescribed period of time. Salmon are believed to go extinct when population abundance and productivity are reduced to low levels where numbers "bottom out" under periods of low survival associated with variable environmental conditions.

Fishery performance metrics

Exploitation rate is the percentage of fish that are harvested or incidentally killed by the fisheries. Exploitation rate affects how many fish of the subject stock or populations are harvested but, for non-target stocks, often drives access to and harvest of more abundant natural or hatchery salmon stocks of coho or Chinook in this case) salmon in mixed stock fisheries. Risk analyses consider the net effect of fishing on spawning escapement and extinction risks. Our simulations currently consider total exploitation rates. The risk analysis does not allocate component rates among fisheries.

Harvest is the number of individuals from the subject stock taken by the fisheries. Harvest of other associated stocks affected by subject stock limits is also an important number in mixed stock fisheries.

Frequency of occurrence of various exploitation rates or rate strata may also be an important consideration in mixed stock fisheries.

Populations considered

SONCC Coho

Risk assessments based on population viability are typically based on populations representative of the ESA-listing and fishery management units. Populations and population strata have previously been defined by the ESA Recovery Plan for SONCC coho (Table 18).

In the case of SONCC coho, stock assessment data is available for six geographic areas representing populations, portions of populations or population aggregates:

1. Rogue River is an aggregate of three interior populations based on long-term seine sampling data at Huntley Park on the lower Rogue in the Interior Rogue stratum. The aggregate stock is relatively productive (6.84 recruits per spawner at low abundance) and relatively abundant (5,636 spawners at equilibrium) but risk levels were intermediate due to a high critical risk threshold (1,882) identified as a depensation threshold for this aggregate stock by the recovery plan.
2. Bogus Creek represents a portion of the upper Klamath River population in the Interior Klamath stratum. Hatchery influence is historically very high (NMFS 2014). Bogus Creek is a very small (Neq = 80), unproductive (2.21 recruits per spawner at low abundance) and heavily hatchery-influenced (pHOS= 0.423) portion of a population. Risks are uniformly very high regardless of fishing rate. The population may only continue to persist due to continuing hatchery subsidy.
3. Shasta River is a population in the Interior Klamath stratum of the ESU. Hatchery influence is historically high (NMFS 2014). Another very small (Neq = 57) and heavily hatchery-influenced (pHOS= 0.422) population. Risks are uniformly very high regardless of fishing rate. The population may only continue to persist due to continuing hatchery subsidy.
4. Scott River is a population in the Interior Klamath stratum of the ESU. This population is intermediate to other SONCC populations in productivity (3.08), abundance (713) and sensitivity to fishing.

5. Trinity River is an aggregate of all three Trinity populations of the Interior Trinity stratum based on weir sampling. Abundance is very low in the Lower and South Fork Trinity populations, hence, 90% of the coho are believed to be from the Upper Trinity. This population is apparently subject to very high hatchery contribution (pHOS= 0.827) from the Trinity Hatchery in the upper basin which likely complicates stock assessments and corresponding estimates of natural population parameters Hatchery influence is historically very high (NMFS 2014). Population capacity appears to be relatively large (3,334) but the productivity at low escapements was estimated to be below replacement. Risks are uniformly very high regardless of fishing rate.
6. Freshwater Creek is a Humboldt Bay tributary in the Southern Coastal Basins stratum. This creek is one of four streams comprising this population including Jacoby Creek, Elk River and Salmon Creek. No hatcheries operate near this system. This population is comprised entirely of natural-origin fish. This population is moderately productive (5.05 recruits per spawner) and abundant (441 spawners at capacity). This population is at the lowest risk and least sensitivity to low rates of fishing.

Spawner-Recruit Analysis

Spawner and recruit estimates (Table 19) were based on run reconstructions for the subject populations. Run reconstructions identify total numbers of spawners and natural-origin adults returning from progeny from each brood year of spawners. Recruitment estimates are ocean recruits (prior to ocean fisheries). They are river mouth returns (accounting for escapement and any river harvest) expanded by the ocean impact rate. See Appendix B for methods used to estimate recruits.

Data used in the spawner-recruit analysis was as follows:

Brood Year - The year in which the majority of the adults returned to the river and began spawning.

Escapement (S_y) - The observed total age 3 escapement to the spawning grounds. This includes natural and hatchery origin fish, but does not include the brood stock taken into the hatchery. This can also be called total spawners.

pHOS - The proportion of Escapement that is hatchery origin (that is, were reared in the hatchery as juveniles).

Brood stock - The number of natural origin fish taken into the hatchery.

CY ER (H_y) - Calendar year exploitation rate. The proportion of natural-origin fish that would have returned this year that were harvested. This includes ocean and terminal fishery effects.

The Escapement, S_y, in year y, is the number of natural origin recruits, R_{y-3}, from brood year $y-3$ after the harvest, H_y, and removal of the natural origin brood stock, $broodstock_y$, inflated to account for the proportion of hatchery origin fish, $pHOS_y$ is.

$$S_y = \frac{R_{y-3}(1 - H_y) - broodstock_y}{1 - pHOS_y}$$

And thus, estimates of natural origin recruits returning in year, y, from brood year y−3 is:

$$R_{y-3} = \frac{S_y(1 - pHOS_y) + broodstock_y}{1 - H_y}$$

Stock-recruit relationships were described with Beverton-Holt and Hockey stick functions (Table 19). Functions were fit to population data fit using simple least squares model for each population independently and using a simple Bayesian hierarchical model with a shared temporal pattern (M. Liermann, NOAA, personal communication).

The basic parameters for a stock-recruitment function include:

Productivity - maximum recruits per spawner as spawners approach zero
Capacity - asymptotic number of recruits at large numbers of spawners
Neq - Equilibrium abundance defined by the replacement point where spawners equal recruits.
SD - Error term in the stock-recruitment fit to the data.
Smax - Maximum number of spawners observed in the data
Rmax - maximum number of recruits observed in the data

Autocorrelation of errors among years was also examined based on an independent calculation from residuals of the model fit. The autocorrelation parameter is labeled "Acor".

Correlations in annual spawning escapement and recruitment were examined by pairwise comparisons (Figure 10).

Table 18. Populations, strata, current extinction risk, minimum target extinction risk, recovery criteria, and intrinsic potential of SONCC coho salmon ESU (NMFS 2014).

Stratum	Populations	Risk status	Risk goal	Recovery role	Recovery criteria	Intrinsic potential (km)[a]	Analysis populations
Northern Coastal Basin	Elk R	High	Low	Core	2,400	62.6	--
	Brush Crk	High	Juveniles	Dependent	--	--	--
	Mussel Crk	High	Juveniles	Dependent	--	--	--
	Lower Rogue R	High	Moderate	Non-core 1	320	80.9	--
	Hunter Crk	High	Juveniles	Dependent	--	14.6	--
	Pistol Crk	High	Juveniles	Dependent	--	30.2	--
	Chetco R	High	Low	Core	4,500	135.2	--
	Winchuck R	High	Moderate	Non-core 1	230	56.5	--
Interior Rogue R	Illinois R	High	Low	Core	11,800	324.8	Rogue
	Middle Rogue/Applegate R	High	Moderate	Non-core 1	2,400	17.4	
	Upper Rogue R	Moderate	Low	Core	13,800	18.8	
Central Coastal Basin	Smith R	High	Low	Core	6,800	204.7	--
	Elk Crk	High	Juveniles	Dependent	--	151.0	--
	Wilson Crk	High	Juveniles	Dependent	--	18.8	--
	Lower Klamath R	High	Low	Core	5,900	34.2	--
	Redwood Crk	High	Low	Core	4,900	7.0	--
	Maple Crk/Big Lagoon	--	Juveniles	Dependent	--	9.9	--
	Little R	Moderate	Moderate	Non-core 1	140	136.5	--
	Strawberry Crk	--	Juveniles	Dependent	--	190.9	--
	Norton/Widow White Crk	--	Juveniles	Dependent	--	393.5	--
	Mad R	High	Moderate	Non-core 1	550	13.8	--
Interior Klamath	Middle Klamath R	Moderate	Moderate	Non-core 1	450	47.8	--
	Upper Klamath R	High	Low	Core	8,500	249.8	Bogus Crk
	Shasta R	High	Low	Core	4,700	589.7	Shasta R
	Scott R	Moderate	Low	Core	6,500	683.2	Scott R
	Salmon R	High	Moderate	Non-core 1	450	900.9	--
Interior Trinity	Lower Trinity R	High	Low	Core	3,600	113.5	Trinity R
	South Fork Trinity R	High	Moderate	Non-core 1	970	424.7	
	Upper Trinity R	Moderate	Low	Core	5,800	206.3	
Southern Coastal Basin	Humboldt Bay tributaries	Moderate	Low	Core	5,700	250.5	Freshwater Crk.
	Lower Eel/Van Duzen R	High	Low	Core	7,900	113.5	--
	Guthrie Crk	--	Juveniles	Dependent	--	102.1	--
	Bear R	High	Juveniles	Non-core 2	--	241.8	--
	Mattole R	High	Moderate	Non-core 1	1,000	365.0	--
Interior Eel	Mainstem Eel R	High	Low	Core	2,600	68.4	--
	Middle Mainstem Eel R	High	Low	Core	6,300	231.5	--
	Upper Mainstem Eel R	High	Juveniles	Non-core 2	--	--	--
	Middle Fork Eel R	High	Juveniles	Non-core 2	--	--	--
	South Fork Eel R	Moderate	Low	Core	9,300	463.7	--
	North Fork Eel R	High	Juveniles	Non-core 2	--	--	--

[a] *Equal to depensation threshold for population.*

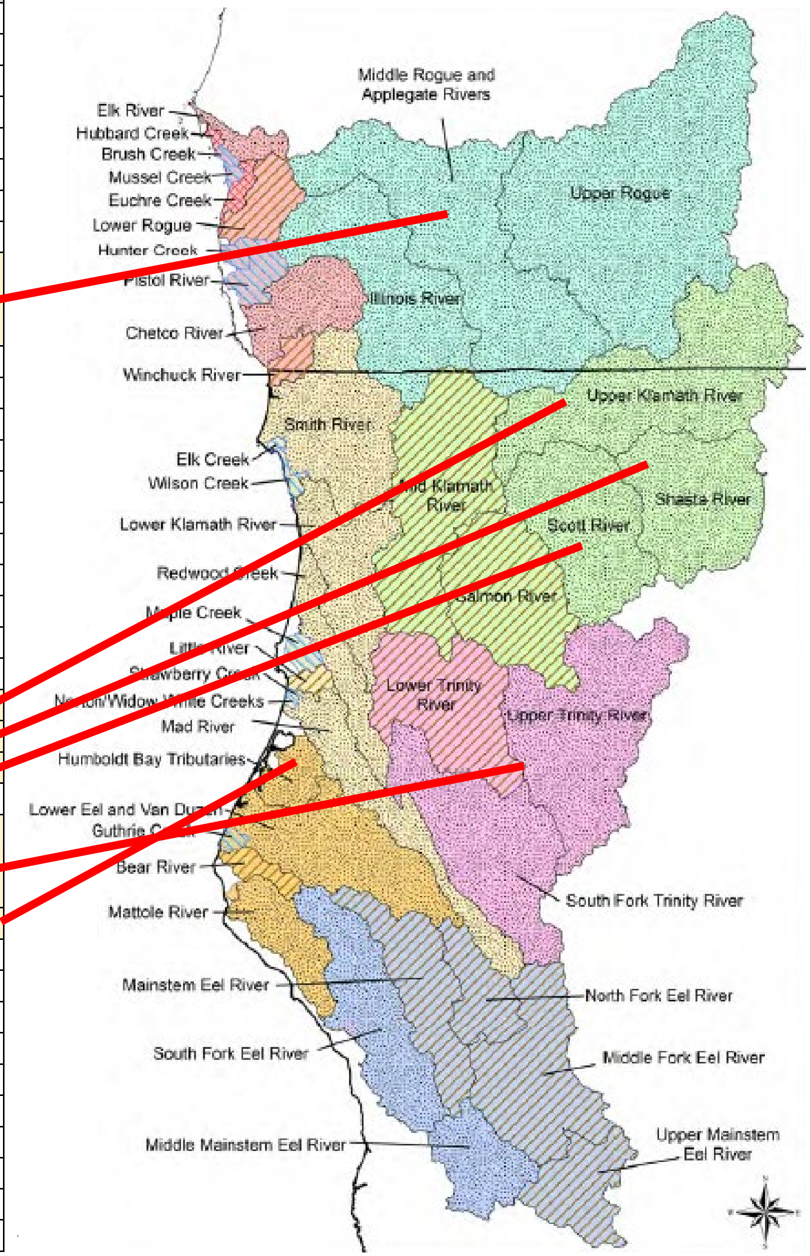

Table 19. Spawner (NOR+HOR) and recruit data for populations of SONCC coho.

Year	Rogue R.			Bogus Crk.			Freshwater Crk.			Scott R			Shasta R.			Trinity R.		
	Spnrs	pHOS	Recr	Spnrs	pHOS	Recr	Spnrs	pHOS	Recr	Spnrs	pHOS	Recr	Spnrs	pHOS	Recr	Spnrs	pHOS	Recr
1996	6,076	0.06	1,637	--		--	--		--	--		--	--		--			
1997	8,253	0.05	11,995	--		--	--		--	--		--	--		--	2,892	0.84	389
1998	2,484	0.06	13,528	--		--	--		--	--		--	--		--	5,995	0.85	3,850
1999	1,638	0.13	10,749	--		--	--		--	--		--	--		--	1,692	0.73	589
2000	11,895	0.04	8,608	--		--	177	0	795	--		--	--		--	6,585	0.96	4,384
2001	13,514	0.04	27,972	--		--	701	0	1,058	--		--	--		--	18,715	0.84	10,342
2002	10,618	0.05	11,035	--		--	1,807	0	833	--		--	--		--	7,812	0.95	2,983
2003	7,907	0.04	4,512	--		--	731	0	419	--		--	--		--	14,255	0.77	1,869
2004	25,823	0.01	5,933	395	0.25	254	974	0	291	--		--	--		--	23,117	0.66	1,343
2005	10,410	0.02	470	87	0.47	100	789	0	403	--		--	--		--	11,702	0.85	1,471
2006	4,243	0.03	2,842	33	0.42	9	396	0	90	--		--	--		--	8,870	0.84	622
2007	5,394	0.02	4,356	197	0.36	184	262	0	463	1,529	0	1,016	249	0.02	55	2,552	0.63	973
2008	448	0.01	5,194	105	0.31	66	399	0	644	59	0	386	30	0.73	38	3,065	0.72	1,375
2009	2,800	0.01	6,440	5	0.4	18	89	0	354	76	0	224	9	0.22	34	2,156	0.8	2,139
2010	4,187	0	13,813	146	0.28	221	455	0	173	913	0	3,410	44	0.25	147	2,770	0.77	5,753
2011	4,920	0.01	2,782	107	0.75	15	624	0	750	344	0	419	59	0.71	3	3,394	0.71	1,039
2012	5,784	0.01	5,042	67	0.88	18	318	0	504	188	0.01	239	76	0.71	55	7,912	0.8	1,014
2013	12,374	0.01	7,950	438	0.81	48	155	0	489	2,631	0	254	160	0.38	52	12,883	0.69	811
2014	2,632	0.01	4,936	22	0.82	43	718	0	553	383	0	384	5	0.8	39	7,228	0.89	59
2015	4,530	0.01	9,525	13	0.31	47	449	0	577	188	0	799	43	0	40	625	0.27	79
2016				51	0.41	62	466	0	313	226	0	367	46	0	54	2,901	0.78	123
2017				37	0.22		535	0		368	0.01		38	0		141	0.76	
2018				26	0.12		560	0		712	0		36	0		503	1	
2019				52	0.1		303	0		338	0		50	0		421	0.85	

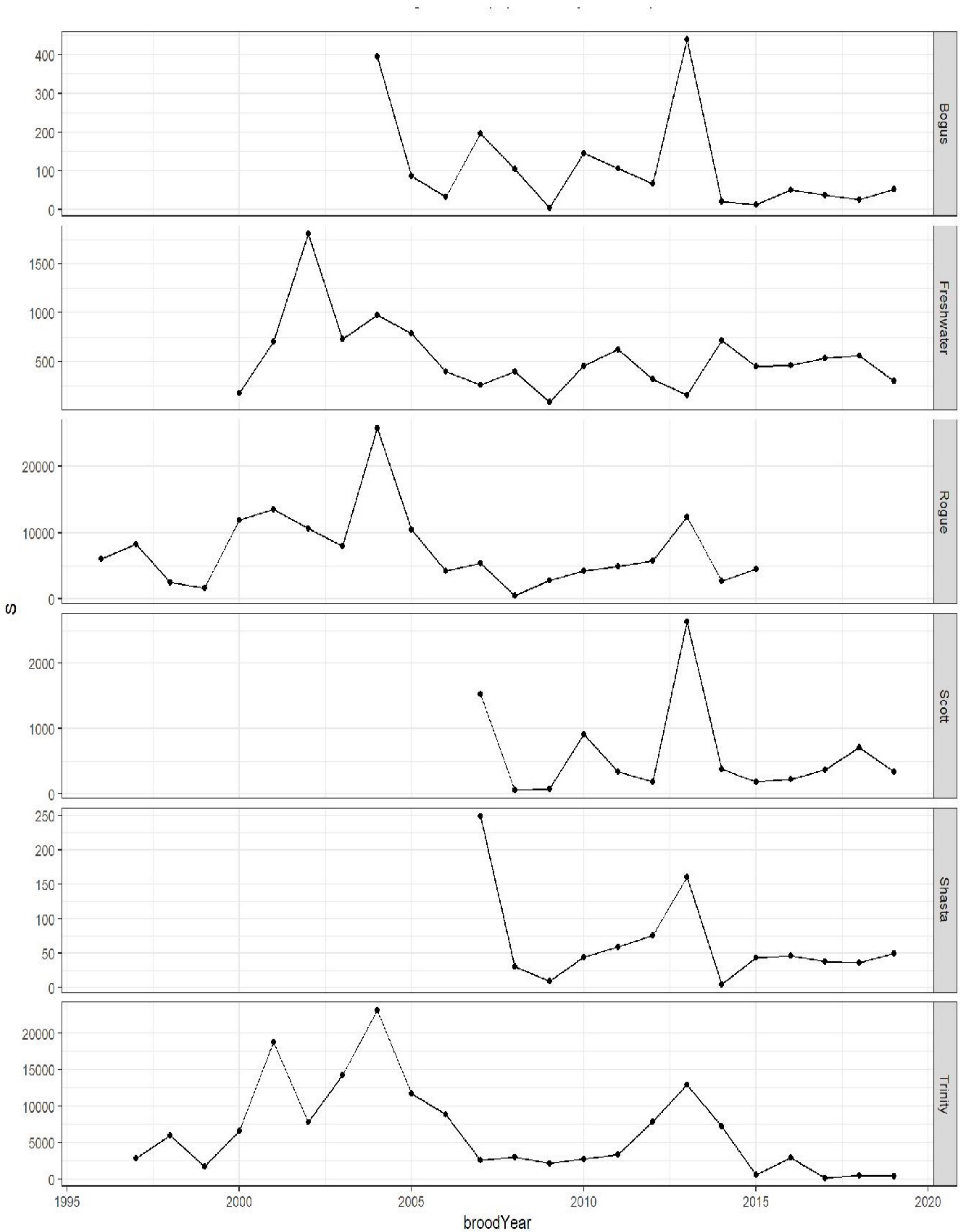

Figure 10. Observed escapement (total spawners) by year.

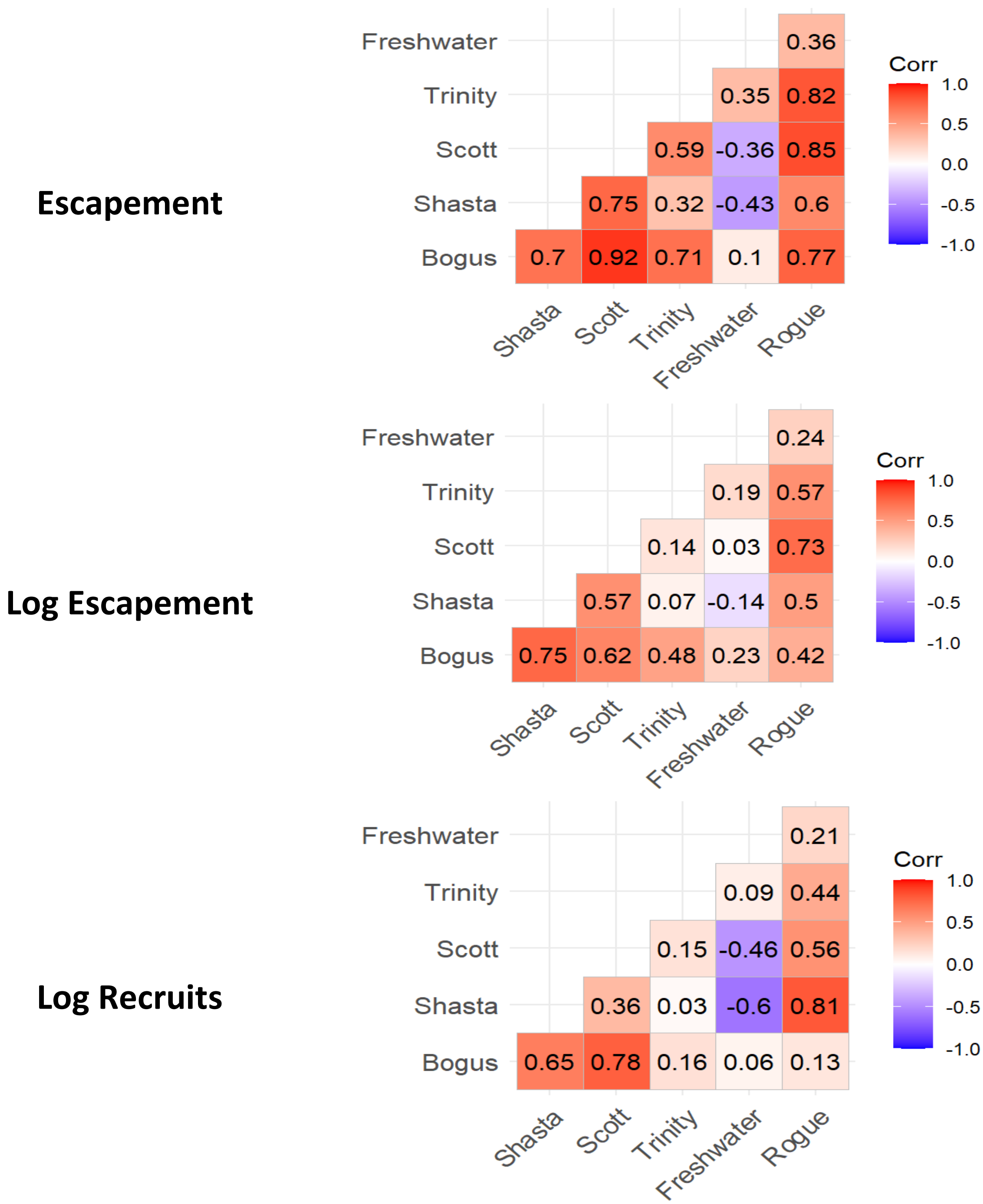

Figure 11. Pairwise Pearson correlation coefficients for escapement and recruits among SONCC populations.

Beverton-Holt Functions

The Bayesian model formulation was:

$$R_{p,y} = \frac{S_{p,y}}{\frac{1}{prod_p} + \frac{S_{p,y}}{cap_p}} e^{w_{p,y}+z_y}$$

Recruits, $R_{p,y}$, for each year, y, and population, p, is modeled using a spawner-recruit function while assuming log-normal error with a common temporal component shared among populations. Here, $S_{p,y}$ is spawners, $prod_p$ is the population specific productivity parameter, cap_p is the population specific capacity parameter, and $w_{p,y}$ and z_y are the population specific and common residuals respectively. The residuals are modeled as, $w_{p,y}$~normal (0,σp) and z_y~normal (0,σtot), where common temporal pattern is constrained to sum to 0, $\sum z_y=0$. The productivity and capacity parameters are modeled using a hierarchical structure, where they each come from common log normal distributions.

$$\log(prod_p) \sim normal(\mu prod, \sigma prod)$$

$$\log(cap_p) \sim normal(\mu cap, \sigma cap)$$

Vague normal, normal (0,100), and gamma, gamma (0.001,0.001), priors are applied to the mean, μ, and precision (1/σ2) hyper prior parameters respectively.

Results of stock-recruit analyses are detailed in Table 20 and Figure 19 through Figure 24. Least squares and Bayesian methods produced slightly different estimates of stock recruitment parameters but corresponding curves were very similar (Figure 19 - Figure 24). Fits of the stock-recruitment function to the data were generally poor with wide credible intervals identified to parameters for all populations. The Bayesian model reduced some of the extreme parameter estimates and produced wide credible intervals for many of the parameters (Figure 13). Least square parameters are within the 80% credible interval for the posterior estimates for the Bayesian fits (Figure 13).

The SONCC stocks share some annual variability (Figure 11) with Freshwater Creek as an outlier. When modeled together the Bayesian analysis did not predict a strong common temporal trend likely due to the short time series and Freshwater Creek.

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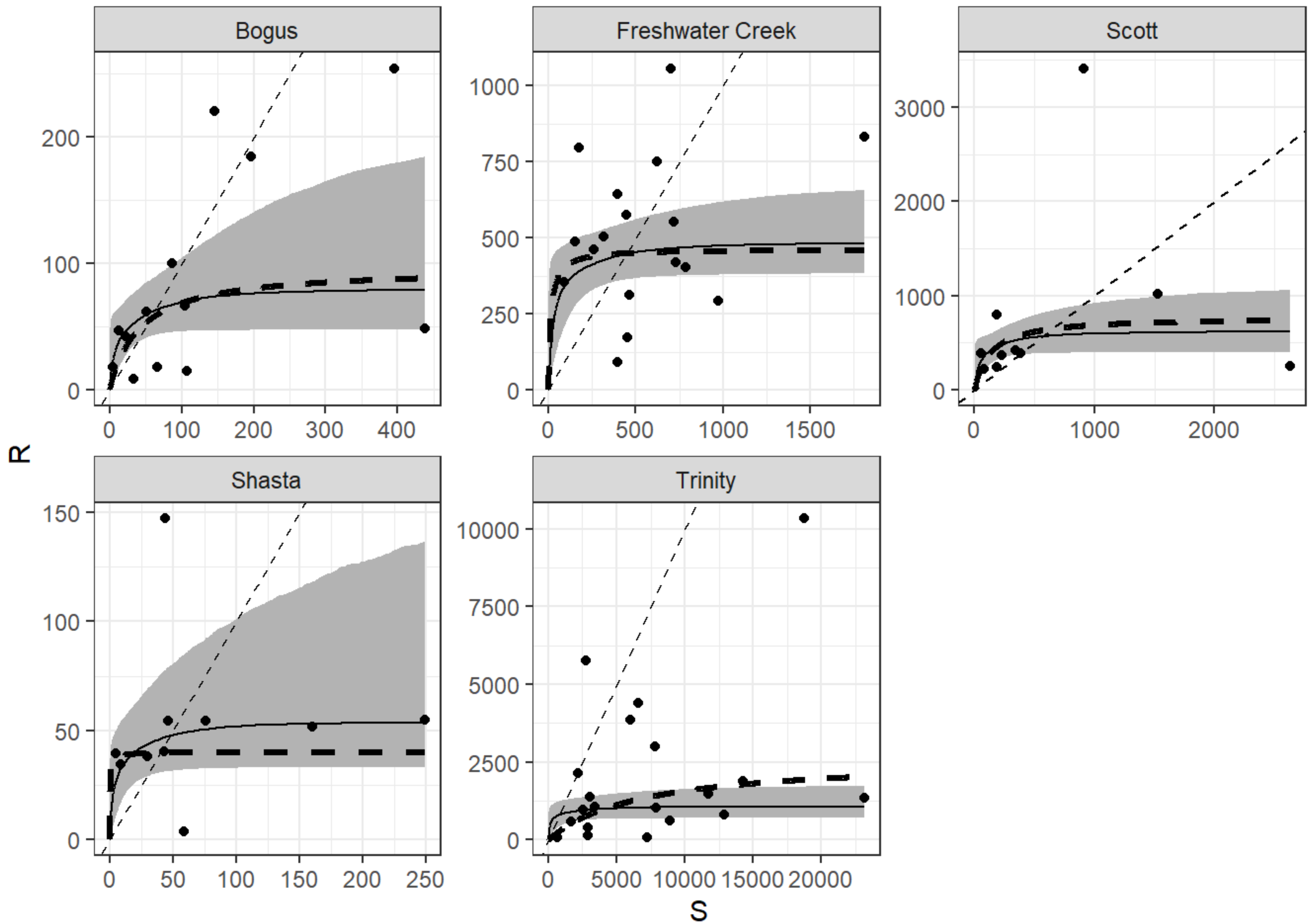

Figure 12. Plot of Beverton-Holt stock-recruitment functions for SONCC populations. Bold dashed lines are the individual least squares fits. The solid line and gray band represent the 10%, 50% and 90% quantiles for the Bayesian model posterior (i.e., 80% pointwise credible intervals. Not prediction intervals).

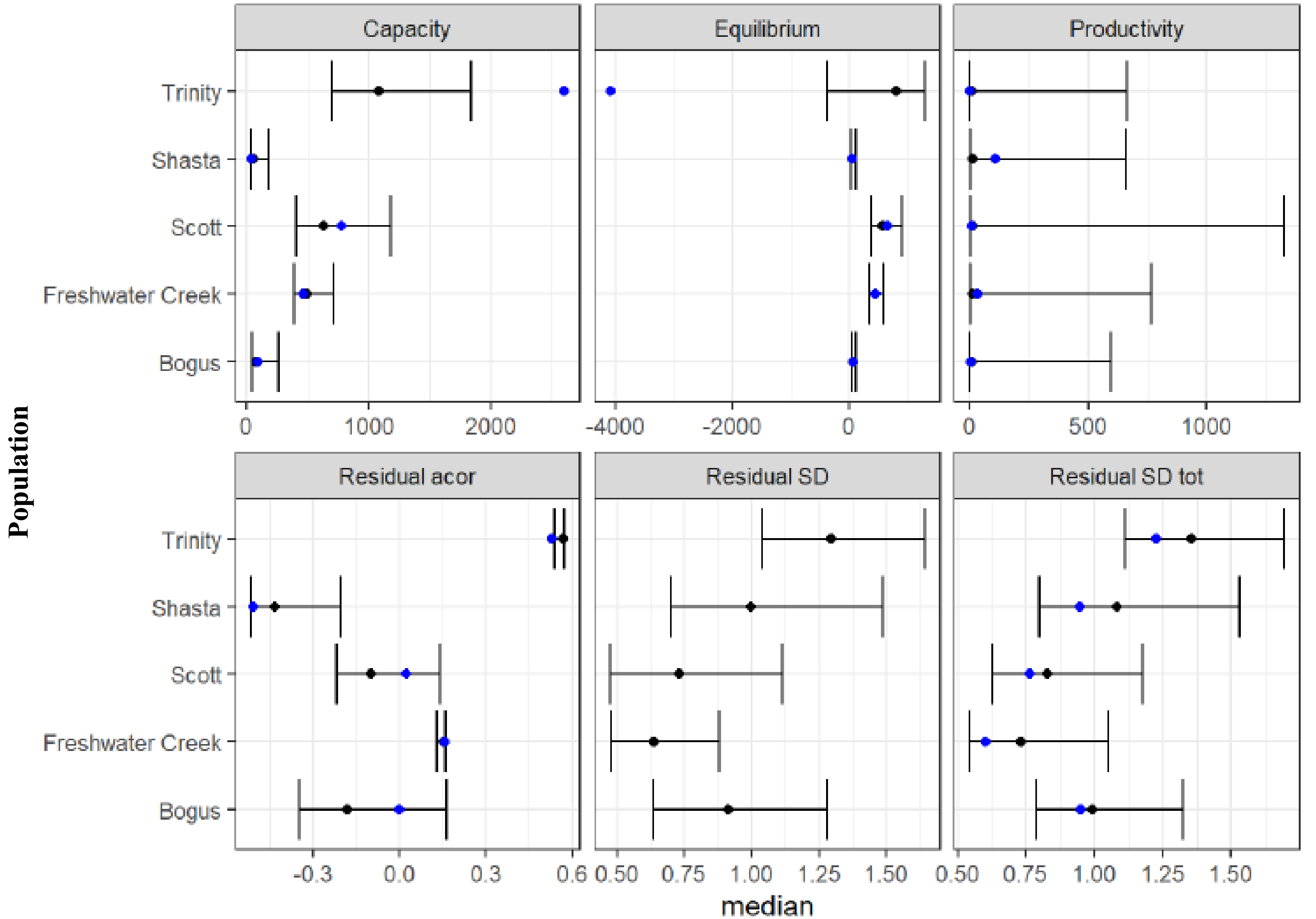

Figure 13. Plot of the population specific parameters with the blue points representing the least squares fit and the black points and bars representing the median and 80% credible interval for the posterior estimates for the Bayesian fits.

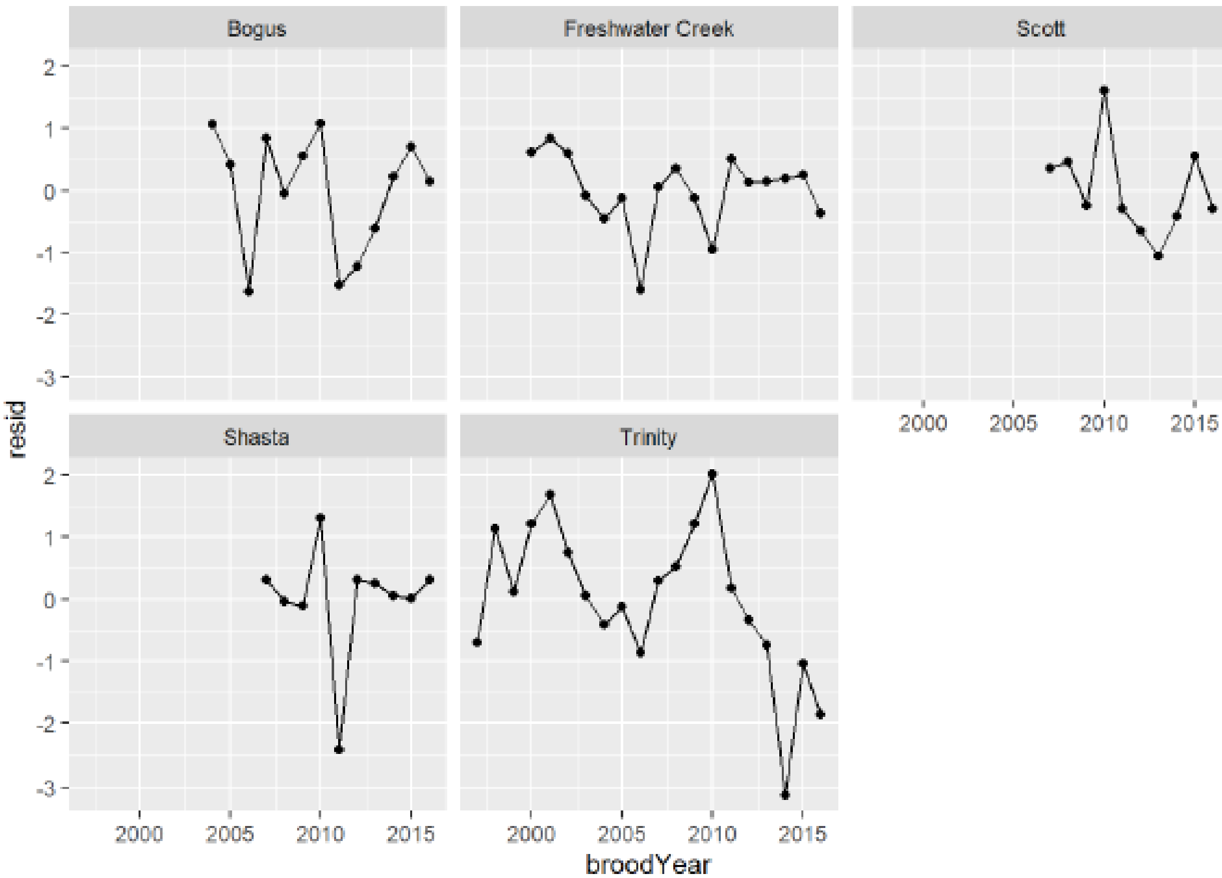

Figure 14. Plot of residuals versus year in least squares spawner-recruit fits for the Beverton-Holt function.

Hockey Stick Functions

The Hockey Stick function was fit using a Bayesian state space hierarchical model to the 6 populations (Figure 15).

Recruits, $R_{p,y}$, for each year, y, and population, p, is modeled using a Hockey Stick spawner-recruit function while assuming log-normal error with a common temporal component shared among populations.

$$R_{p,y} = \min\left(prod_p S_{p,y}, cap_p\right) e^{w_{p,y}+z_y}$$

Here, $S_{p,y}$ is spawners, $prod_p$ is the population specific productivity parameter, cap_p is the population specific capacity parameter, and $w_{p,y}$ and z_y are the population specific and common residuals respectively. Spawners for year, y and population, p, then become recruits for year, y−3 after accounting for harvest, $H_{p,y}$, proportion brood stock take, $pBroodstock_{p,y}$, and hatchery origin fish on the spawning grounds, $pHOS_{p,y}$.

$$S_{p,y} = \frac{R_{p,y-3}(1 - H_{p,y})(1 - pBroodstock_{p,y})}{1 - pHOS_{p,y}}$$

The residuals are modeled as, $w_{p,y}$~normal(0,σp) and z_y~normal(0,σtot), where common temporal pattern is constrained to sum to 0, $\sum z_y=0$.

Notice, we multiply by $1-pBroodstock_{p,y}$ instead of subtracting broodstockp,y. This is to avoid producing negative spawner values. This means that the actual brood stock take varies depending on the estimated natural spawner. This is not ideal, but likely does not have a large effect on parameters estimates.

Productivity is difficult to estimate using typical spawner recruit data. This can lead to very large estimates of productivity that are inconsistent with coho life history. Here we use an informative prior for productivity based on data from other coho populations with more complete data. We discuss this below. Specifically the prior is a truncated log normal distribution.

$$prod_p \sim lognormal(0, 10)T\left(\frac{1}{16}, 16\right)$$

The capacity parameter is modeled using a hierarchical structure, where capacity is assumed to be proportional to some unit of habitat quantity (currently raw basin km^2).

$$log(cap_p) \sim normal(\mu_{cap} + log(hab_p), \sigma_{cap})$$

Notice $\exp(\mu_{cap})$ is the constant of proportionality.

Vague normal, normal(0,100) , and half Cauchy, T(0,ν=1,σ=1)[0,∞), priors are applied to the mean, μcap, and standard deviation σ_{cap} hyper prior parameters respectively.

The observation model compares the observed escapement (total spawners), $S_{obs,p,y}$, to spawner, $S_{p,y}$ generated in the process model described above.

$$log(S_{obs,p,y}) \sim normal(log(S_{p,y}), \sigma_{obs})$$

It is often difficult to estimate both observation error and process variability. Here we have assumed a σobs=0.15 which corresponds to an approximate CV of 15%.

For some of the populations there are two comparable ways of fitting the data. Either, high productivity and low capacity, or low productivity and high capacity. This can be seen in the joint posterior distributions (Figure 16). This can be seen in the SR fits above as well. Notice that for three of the populations (Trinity, Bogus, Shasta) a noticeable proportion of the posterior for productivity fell below replacement (i.e., productivity >1). Also, you can see that the posterior is bumping up against the upper bound on productivity for some of the populations.

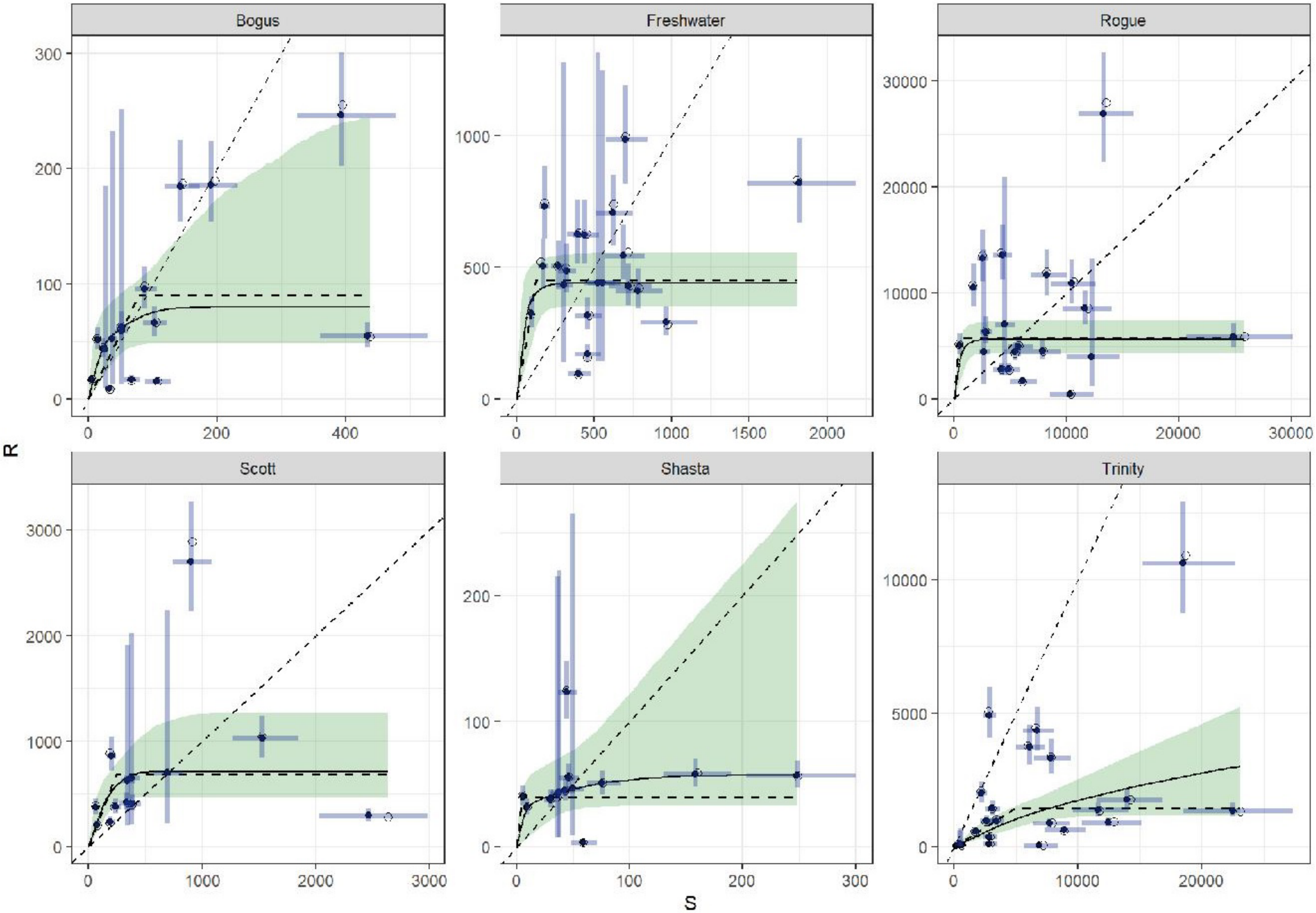

Figure 15. Dashed lines are the individual least squares fits. The solid line and gray band represent the medians and 80% pointwise credible intervals (Not prediction intervals). The black points are the predicted Spawners and Recruits, and the blue bands represent the 80% credible intervals. The open circles are observed spawners and the naive Recruits estimates.

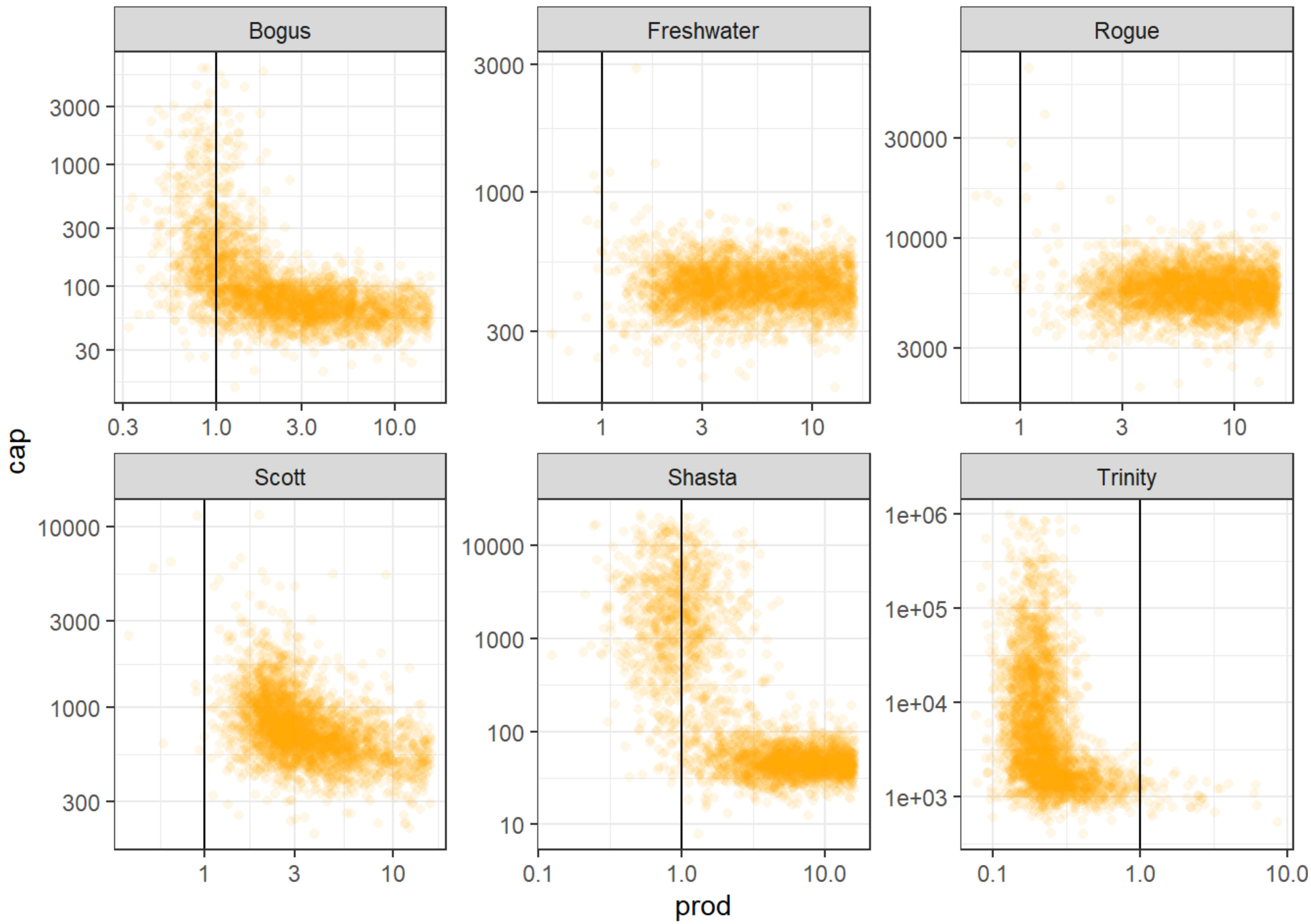

Figure 16. Samples from the joint posterior distribution of productivity and capacity. The vertical line is at a productivity of 1 (replacement).

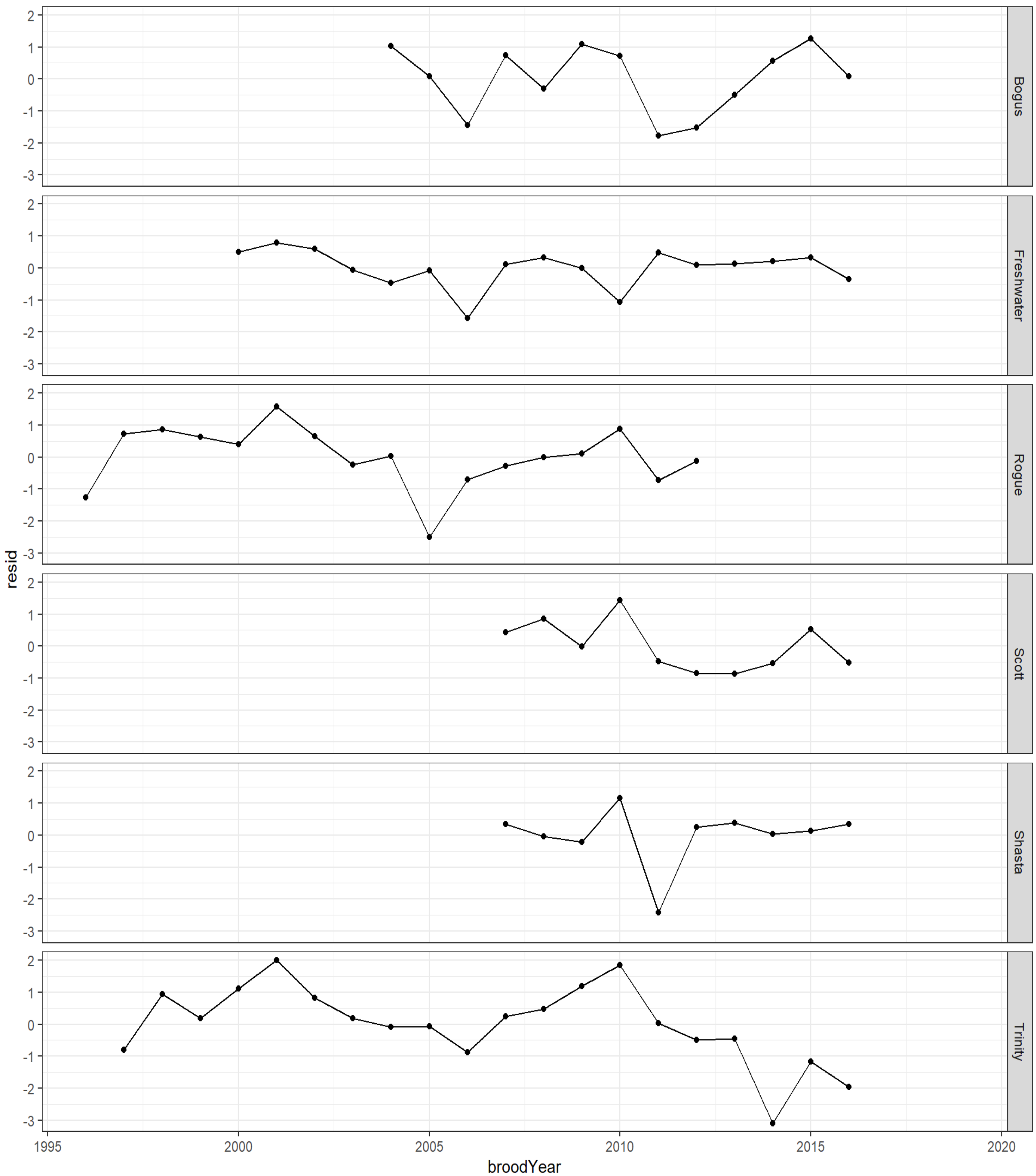

Figure 17. Plot of residuals versus year in least squares spawner-recruit fits of the hockey-stick function.

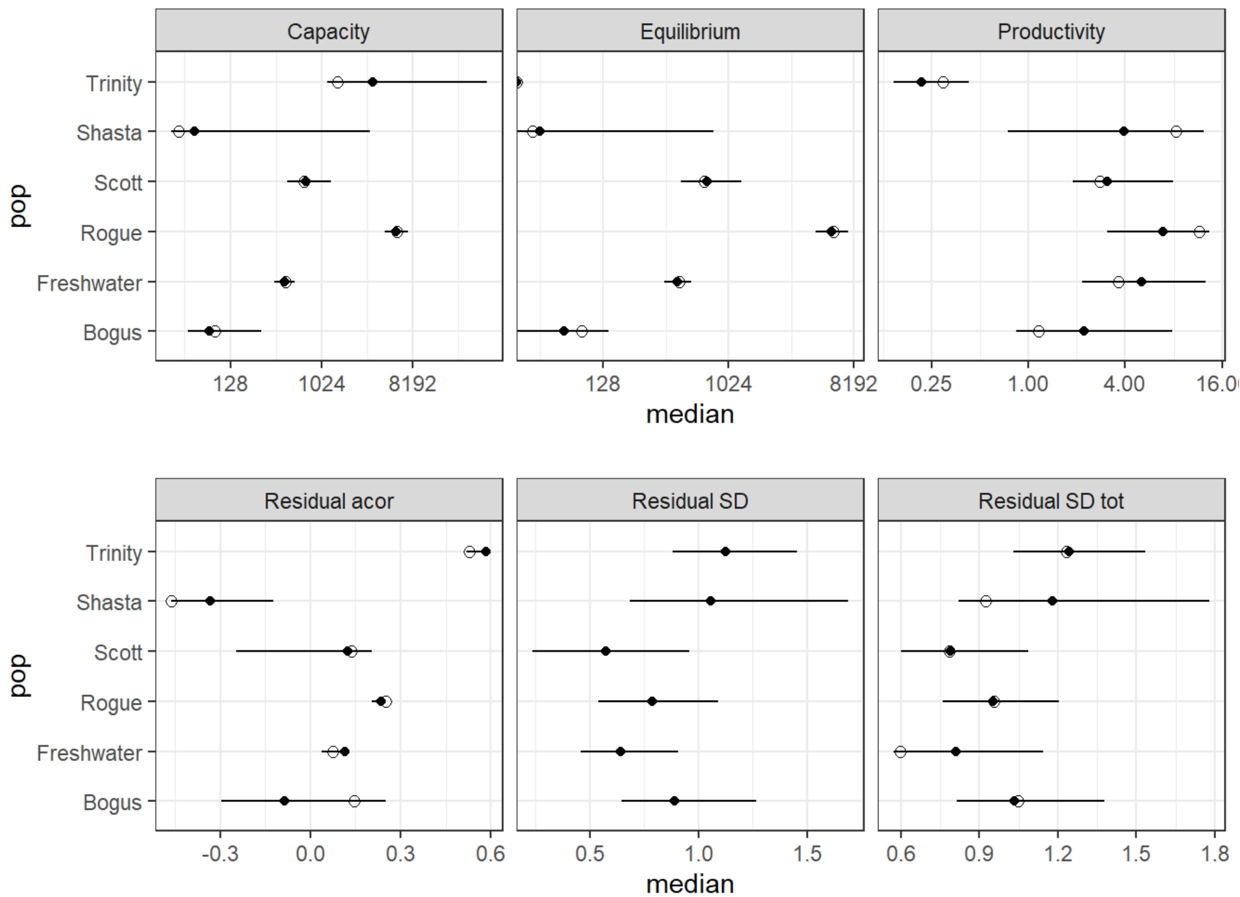

Figure 18. Population parameter estimates from the state-space model. The filled points and lines are the median estimates and 80% credible intervals. The open points are the estimates based on the least -squares fits.

Stock-Recruit Parameters

Table 20 summarizes stock-recruit parameters derived for Beverton-Holt and Hockey stick functions using least squares and Bayesian methodologies for SONCC coho populations. Generally-similar relationships were identified for populations regardless of the function or fitting method (Figure 19 – Figure 24). Parameter estimates for a given population vary somewhat depending on the function form and fitting method. Estimates of capacity, equilibrium abundance and variance are generally similar among methods. The available data does not generally appear to provide a strong basis for identifying population productivity which lead to wide variation in estimates for this parameter. Estimates of extinction-related risks are sensitive to the productivity parameter which drives population dynamics at low abundance. Risk analyses for SONCC populations were based on Bayesian Hockey Stick values for productivity - this method eliminated unreasonably high values of productivity and, as a result, provided a more conservative assessment or fishery related risks. That is to say that higher risks are identified using lower estimates of productivity.

The residual variability about the spawner recruit function was composed of residuals unique to the populations along with a shared temporal pattern ($\exp(z_{p,y}+w_y)$) (Figure 27). The average standard deviation for the population specific residuals, $z_{p,y}$, was 0.87, while the standard deviation for the shared residuals was 0.47. Risk analyses for individual populations were based on population-specific estimates of variability.

Production capacity of adults was closely related to basin size (Figure 26). On the log-log scale, the relationship between capacity, C, and basin size, BB, has slope 1 and intercept equal to the log of the constant of proportionality, a.

$$C = aW \Longrightarrow \log(C) = \log(a)+\log(W)$$

Shasta River has less fish per km^2 than predicted and Freshwater Creek has more.

Table 20. Stock-recruitment parameter fits.

Population	Function	Method of fit	Prod	Cap	Neq	SD	SD_{resid}	acor	Smax	Rmax
Rogue	Beverton-Holt	Approximate	6.0		6,000					
	Hockey stick	Least squares	11.6	5,763	5,763	0.95		0.25	25,823	27,973
		Bayesian	6.8	5,635	5,628	0.95	0.79	0.24		
Bogus	Beverton-Holt	Least squares	2.4	96	56	0.95	--	0.00	438	254
		Bayesian	6.5	81	63	0.99	0.91	-0.18	438	254
	Hockey stick	Least squares	1.1	90	90	1.05		0.15	438	255
		Bayesian	2.2	90	67	1.04	0.89	-0.08		
Freshwater	Beverton-Holt	Least squares	33.5	463	449	0.60	--	0.16	1,807	1,058
		Bayesian	13.8	495	447	0.73	0.64	0.15	1,807	1,058
	Hockey stick	Least squares	3.6	454	454	0.60		0.07	1,807	998
		Bayesian	5.0	441	441	0.81	0.64	0.12		
Scott	Beverton-Holt	Least squares	6.0	774	646	0.76	--	0.02	2,631	3,410
		Bayesian	11.9	634	569	0.83	0.73	-0.10	2,631	3,410
	Hockey stick	Least squares	2.8	682	682	0.78		0.14	2,631	2,888
		Bayesian	3.1	713	712	0.79	0.58	0.12		
Shasta	Beverton-Holt	Least squares	107.4	40	40	0.95	--	-0.51	249	147
		Bayesian	11.9	55	48	1.08	1.00	-0.43	249	147
	Hockey stick	Least squares	8.2	40	40	0.92		-0.46	249	125
		Bayesian	3.9	57	45	1.18	1.05	-0.33		
Trinity	Beverton-Holt	Least squares	0.4	2,604	4,093	1.23	--	0.53	23,117	10,342
		Bayesian	7.5	1,082	794	1.36	1.29	0.57	23,117	10,342
	Hockey stick	Least squares	0.3	1,462	0	1.23		0.53	23,117	10,904
		Bayesian	0.2	3,334	0	1.24	1.12	0.58		

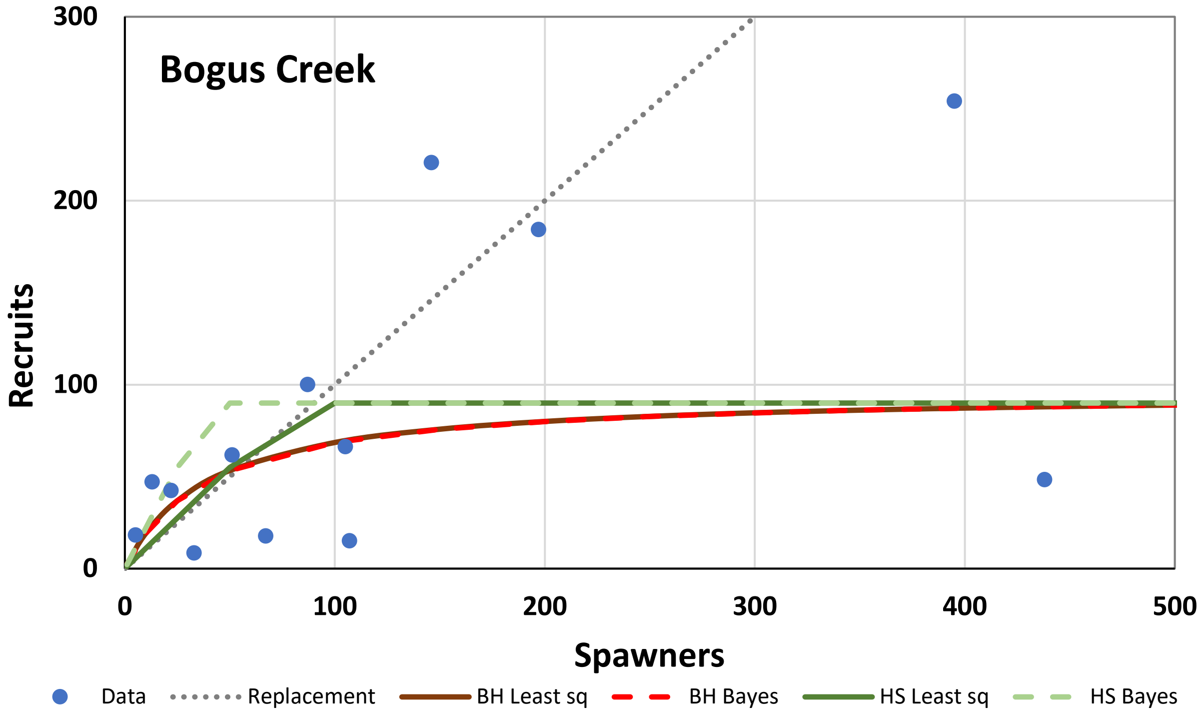

Figure 19. Spawner-recruit relationship for Bogus Creek coho.

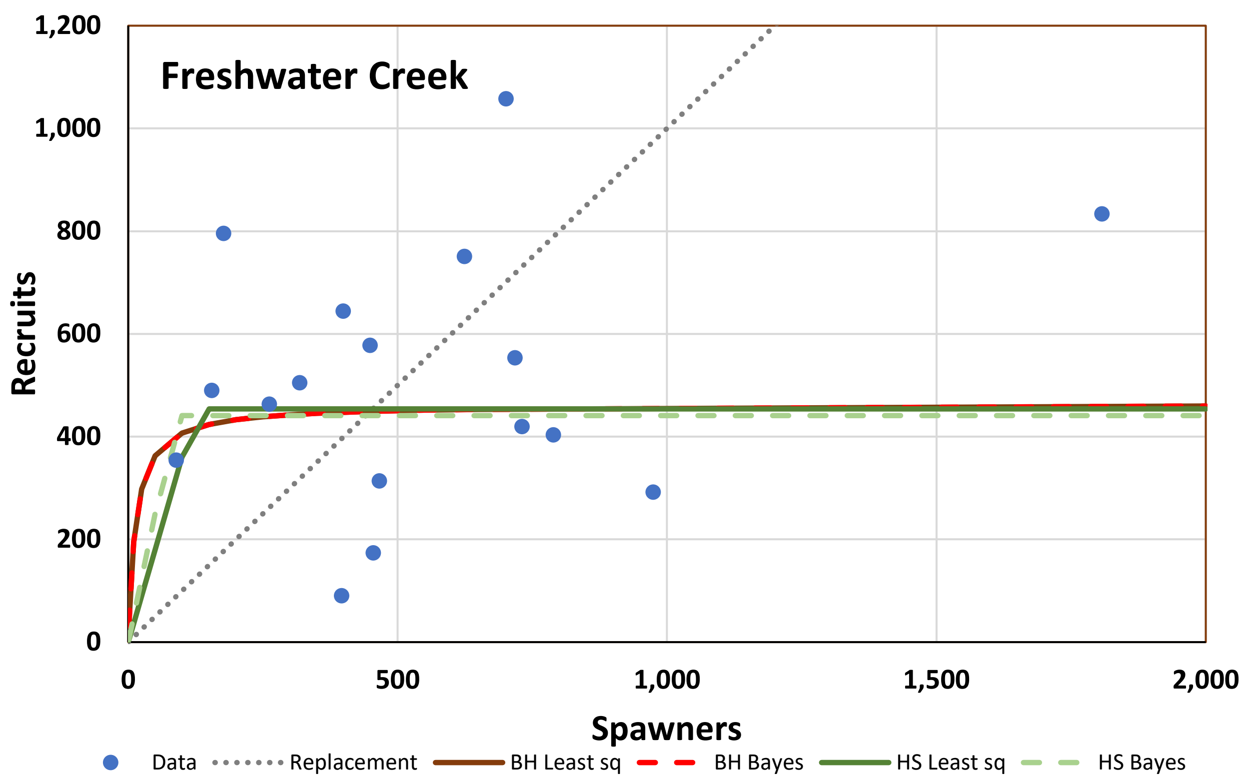

Figure 20. Spawner-recruit relationship for Freshwater Creek coho.

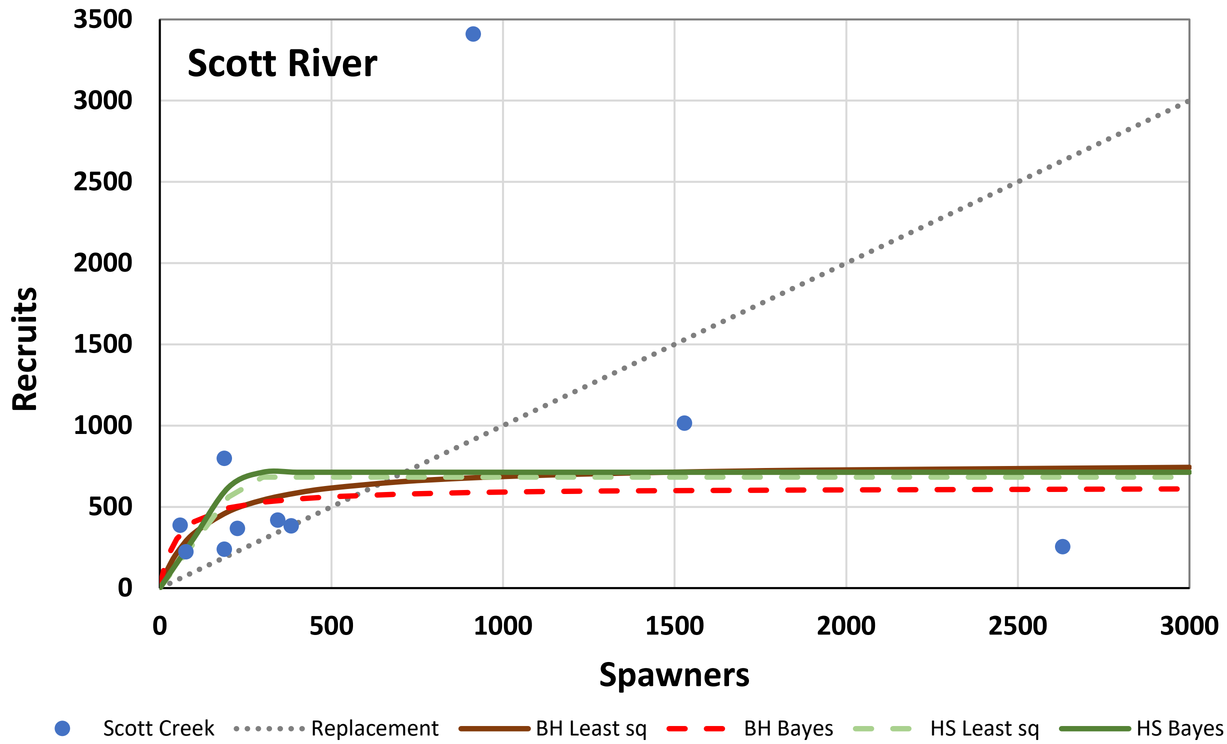

Figure 21. Spawner-recruit relationship for Scott River coho.

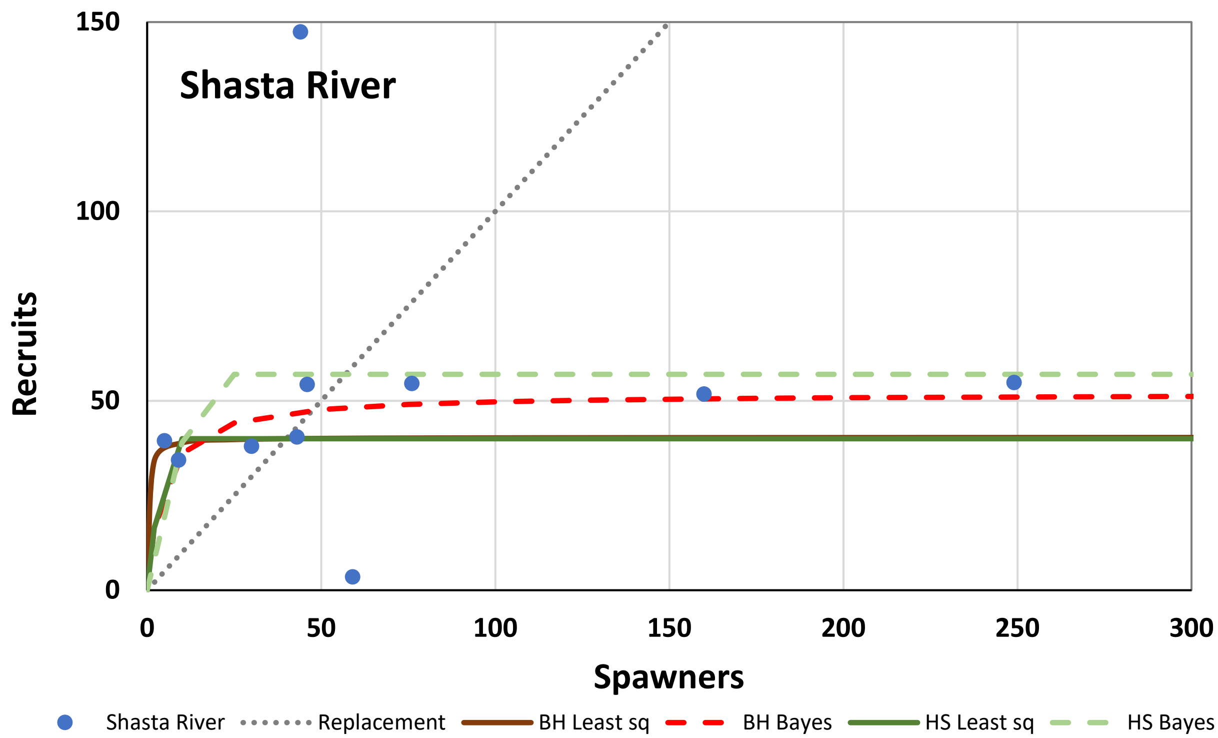

Figure 22. Spawner-recruit relationship for Shasta River coho.

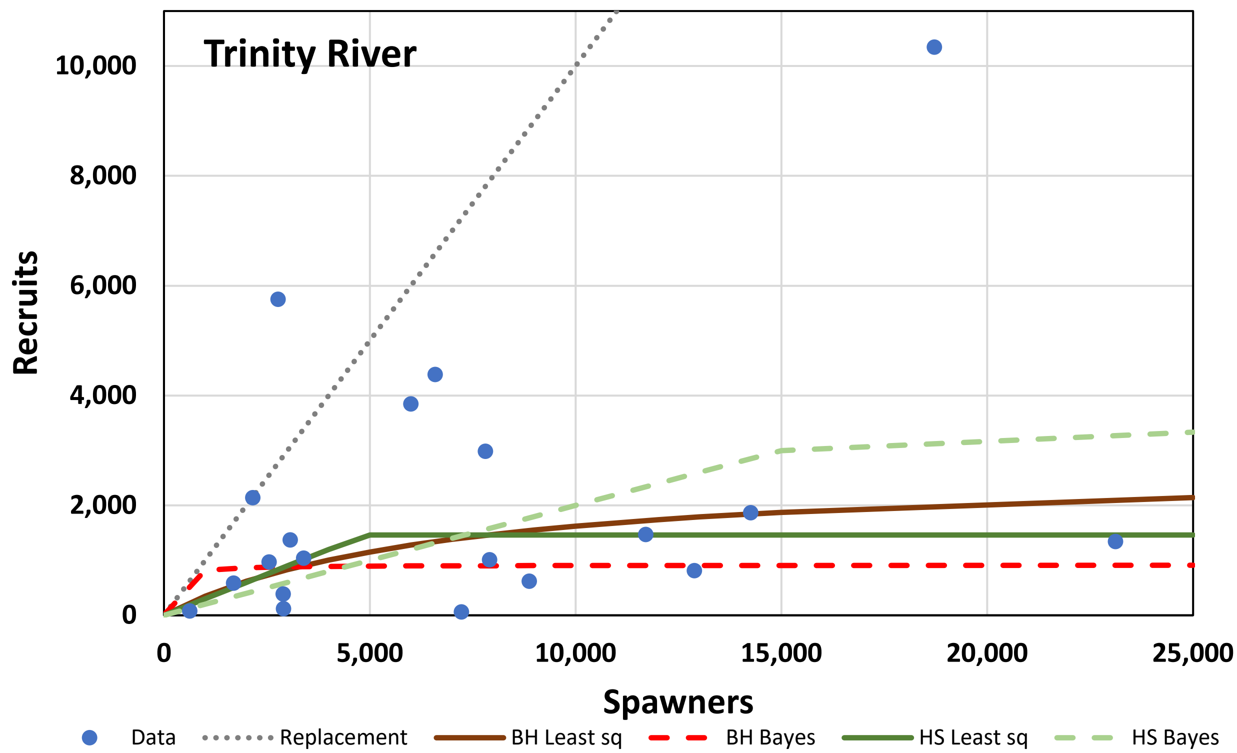

Figure 23. Spawner-recruit relationship for Trinity River coho.

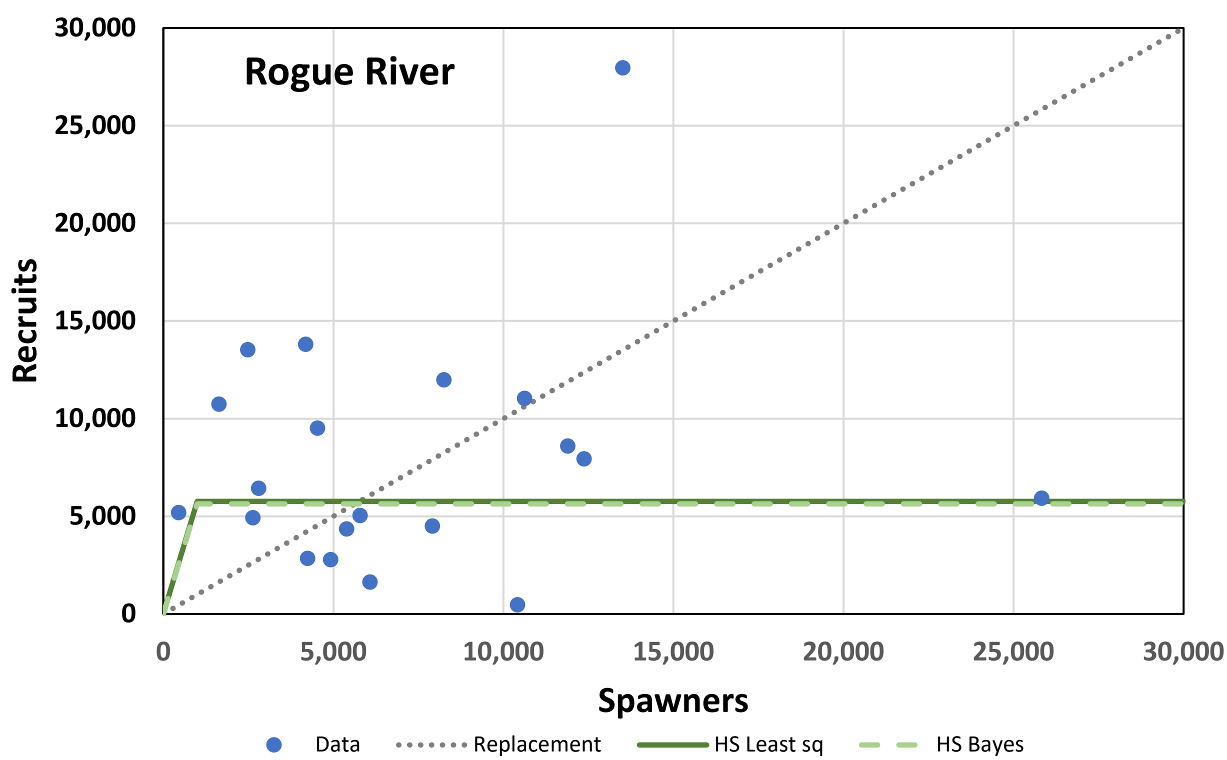

Figure 24. Spawner-recruit relationship for Rogue River coho.

Figure 25. Plot of the shared temporal pattern along with 80% credible interval and example trajectories from the posterior.

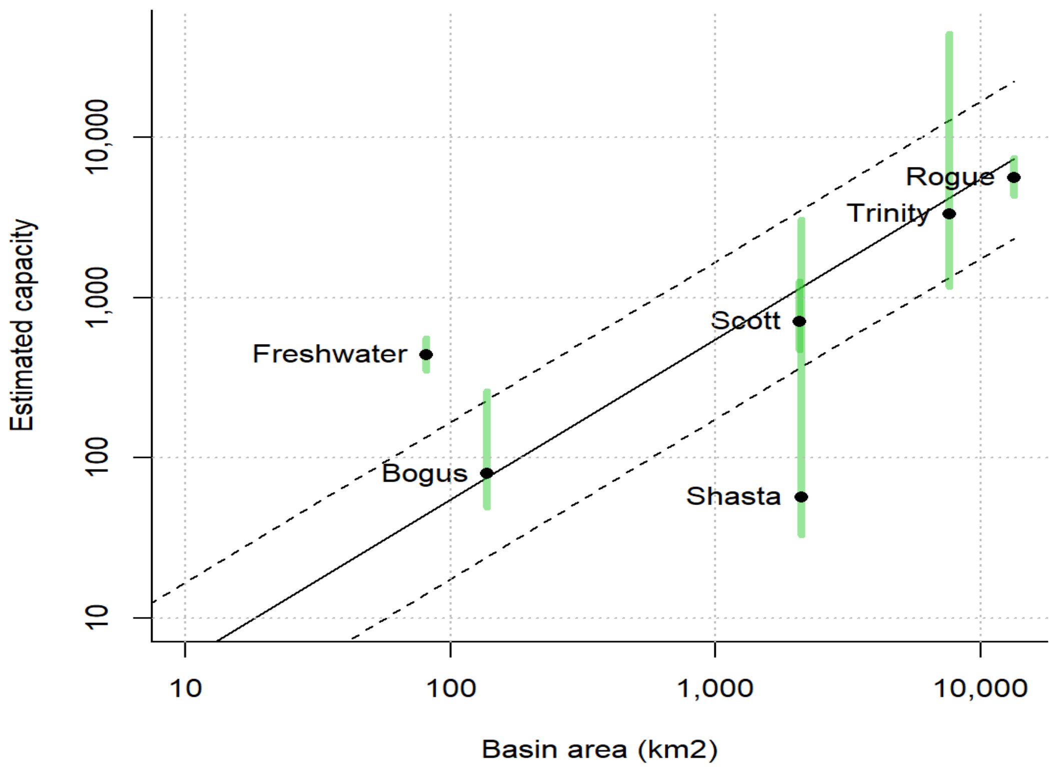

Figure 26. The relationship between basin area and capacity on the log scale. The dashed lines are 80% credible intervals (not prediction intervals).

Other Coho Reference Populations

Information on stock-recruitment relationships is also available for OCN and LCN coho populations (Table 21). The work group also documented this information in order to identify a representative range of potential values in other ESUs. This information is potentially useful for placing estimates for SONCC into a broader context, with the qualification that characteristics of different ESUs may be inherently different. Values for lower Columbia River coho were documented in Kern and Zimmerman (2013). Information for OCN coho was provided by M. Falcy (Oregon Department of Fish and Wildlife) and M. Liermann (NOAA).[3]

Table 21. Example stock-recruitment parameters (Beverton-Holt) for Lower Columbia River and Oregon Coast Natural populations of coho salmon.

Stock	Pop	CRT	prod	cap	Neq	SD	acor	Smax	Rmax
Lower Columbia River	Clackamas	300	3.6	3,356	2,606	0.40	0.33		
	Clatskanie	200	5.3	1,479	2,726	1.00	0.30		
	Coweeman	100	2.6	5,386	919	1.00	0.30		
	Cowlitz L	300	3.5	3,157	3,848	1.00	0.30		
	Eloch/Skam	300	2.9	1,511	2,078	1.00	0.30		
	Grays/Chinook	200	2.1	974	788	1.00	0.30		
	Lewis EF	200	2.3	1,507	546	0.56	-0.09		
	Sandy	300	4.2	4,433	1,146	0.79	-0.26		
	Scappoose	200	2.2	5,025	2,427	1.00	0.30		
	Toutle	200	2.4	3,356	2,959	0.40	0.33		
Oregon Coast Natural	Alsea		2.39	9,908	5,462	1.07	0.57	28,418	30,146
	Beaver		12.66	1,874	1,715	0.89	0.25	6,564	7,633
	Coos		57.54	11,718	11,398	0.95	0.29	38,880	45,209
	Coquille		7.97	15,095	13,172	0.92	0.2	56,109	59,220
	Floras		38.99	1,712	1,646	1.08	0.33	11,329	11,925
	LowUmpqua		65.38	9,160	8,959	0.81	0.16	36,942	42,956
	MidUmpqua		61.38	5,035	4,915	0.8	0.45	20,033	21,236
	Necanicum		13.24	1,213	1,113	0.89	0.48	5,825	6,659
	Nehalem		38.53	8,566	8,175	1.08	0.69	33,052	35,555
	Nestucca		19.6	2,055	1,934	1.07	0.4	16,753	17,577
	NorthUmpqua		15.02	2,588	2,319	0.8	0.74	16,728	9,892
	Salmon		18.79	309	268	1.5	0.32	3,707	4,279
	Siletz		2.67	8,626	5,261	1.08	0.51	33,094	35,206
	Siltcoos		82.74	4,372	4,294	0.86	0.03	8,025	8,693
	Siuslaw		28.34	11,028	10,560	0.93	0.6	55,695	58,363
	Sixes		33.77	198	189	1.31	-0.25	608	659
	SouthUmpqua		20.01	7,778	7,242	1.01	0.38	51,088	53,147
	Tahkenitch		39.21	3,085	2,981	1.01	0.24	10,681	11,243
	Tenmile		57.34	7,490	7,302	0.94	0.2	20,385	21,458
	Tillamook		4.67	5,697	4,403	0.98	0.47	20,550	23,360
	Yaquina		20.66	5,217	4,909	1.03	0.41	25,582	29,747

[3] *Parameter estimates are preliminary and may be refined.*

Note that there is a very strong shared year effect among OCN populations Figure 27. Autocorrelation is also noteworthy for OCN coho populations. The median auto correlation for the common trend is 0.5. This is in distinct contrast to SONCC coho populations where neither shared year effects or autocorrelation were strong.

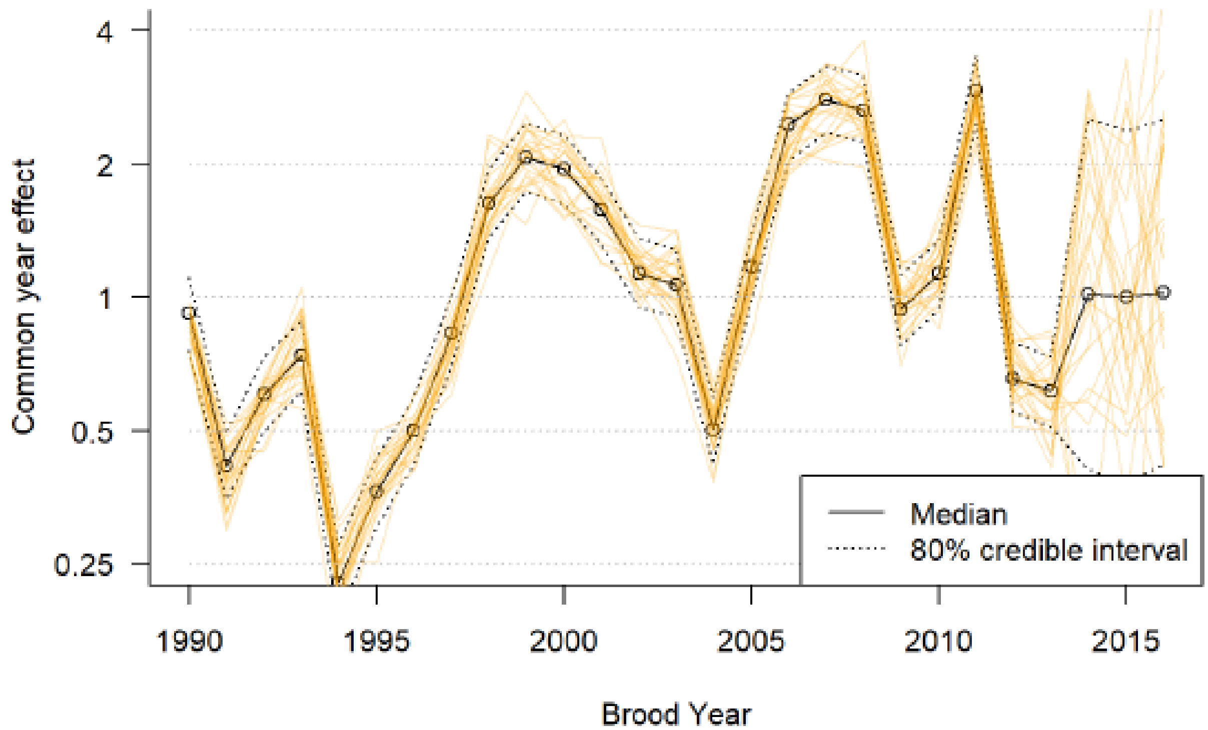

Figure 27. Shared temporal pattern among OCN populations based on Bayesian model along with 80% credible interval and example trajectories from the posterior.

Figure 28 compares stock-recruitment parameters among populations where information is available. Parameters are distributed across a wide range with SONCC stocks generally at low levels of equilibrium abundance and moderate levels of productivity in relation to Oregon Coast and Lower Columbia populations.

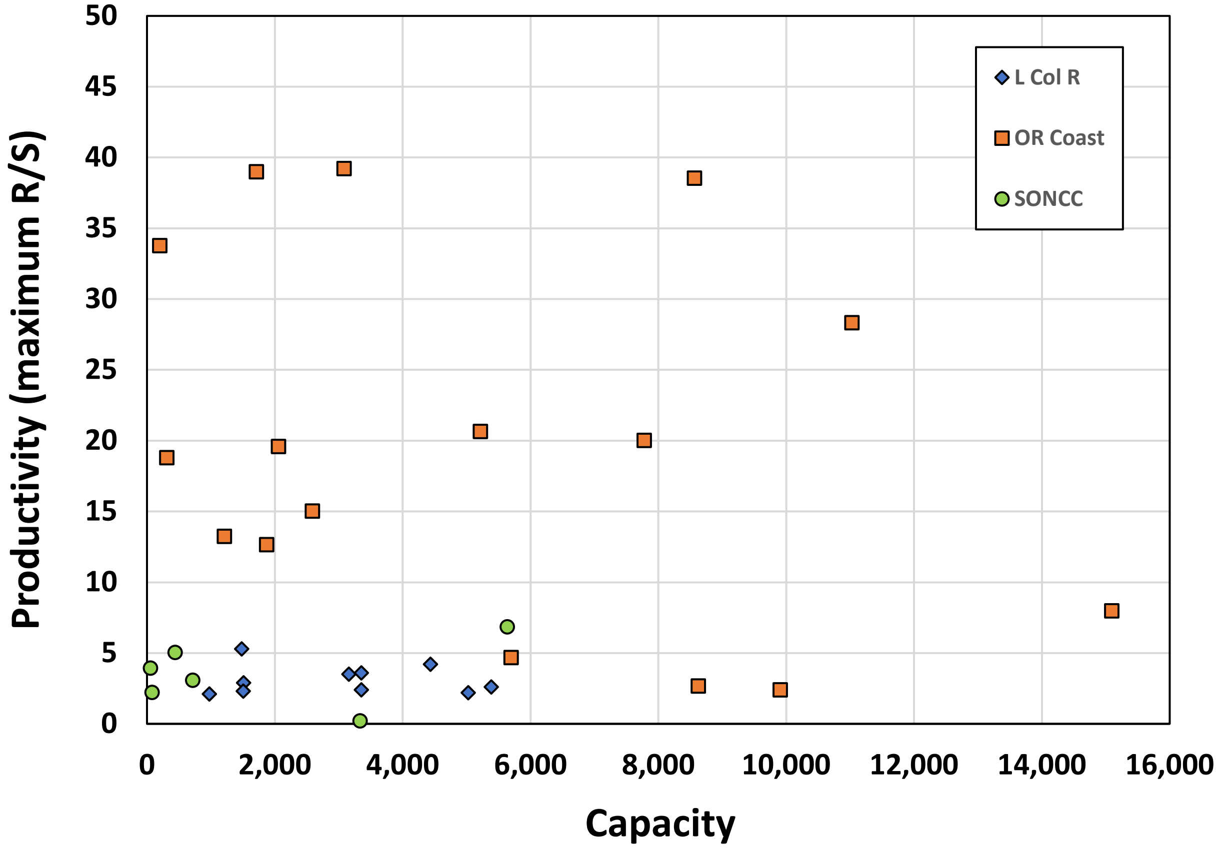

Figure 28. Example stock-recruitment parameters for OCN and LCN and SONCC populations of coho salmon. (OCN populations where productivity exceeds 50 recruits per spawner are omitted from the plot).

Risk Assessment Model

Conservation risks associated with different harvest control rules were estimated using a simple stochastic life cycle model built around the salmon stock-recruitment function. This model estimates annual run size, harvest and spawner numbers over a prescribed number of years (Figure 29). The model estimates average and frequencies of values over a prescribed number of iterations (typically 1,000). The model can simultaneously simulate wild and hatchery populations. The wild population may be parameterized to represent a single population or an aggregate of populations or several populations modeled as an aggregate, or aggregates can be decomposed into constituent populations and run separately. However, for computational efficiency the model is currently programmed to simulate a single unit at a time

The number of wild fish is estimated from recruitment generated by a stock-recruitment function from the brood year number of spawners. Recruits are defined as freshwater equivalent numbers available to the ocean fishery. Recruits are estimated as an ocean adult cohort. The model apportions annual numbers of fish from this cohort among years based on an input age schedule. The annual run is subjected to fishing with the surviving wild population spawning to seed the next wild generation. The model also simulates straying of hatchery fish into the wild population. Thus, total spawners include both natural-origin and hatchery-origin adults. Natural-origin recruits are the progeny of the total spawning escapement.

Random annual variability is introduced into the model in the stock-recruitment relationship for the wild population and at the juvenile-to-adult survival stage for the hatchery population. Variances are proportional to survival or productivity, log-normally distributed, annually autocorrelated, and partially correlated in between hatchery and wild fish. Log-normal distributions provide for the occasional very high survival or productivity years that we see periodically. Autocorrelation means that poor survival or production years are generally more likely to be followed by poor years, and good years by good years.

The model includes optional inputs to apply fishing rates in each year to calculate harvest and fishery effects on population dynamics. Either fixed or abundance-based control rules may be utilized. Input parameters allow for forecast errors which introduce uncertainty and variability into model estimates, notably including errors in predicting which fishing rate tier should be operated in. Inputs also allow for normal differences in target and actual fishing rates which result from a variety of factors mostly related to lack of predictability in stock composition, fishery catch rates, etc.

Viability risk was defined in this analysis as the probability of average abundance of a generation of salmon falling below a critical abundance threshold (CRT) over the course of a simulation. A quasi-extinction risk threshold (QET) was defined as a population size where functional extinction occurs due to the effects of small population processes (McElhany et al. 2006). The model assumes that extinction occurs if the average annual population size over a moving-generational, average falls below a threshold at any point in a modeled trajectory. Extinction risk is thus estimated as the proportion of all iterations where the moving generational average spawner number falls below the threshold at any point in each simulation period.

The model is built in Microsoft Excel using Visual Basic. A simple interface page facilitates model use and review of results (Figure 31).

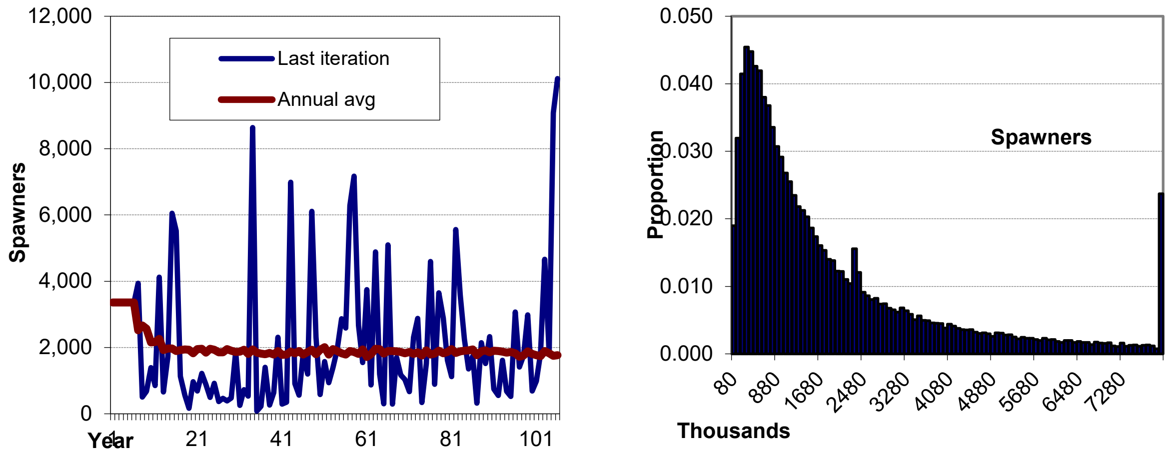

Figure 29. Example stochastic simulation results showing annual patterns and frequency distribution of spawning escapements.

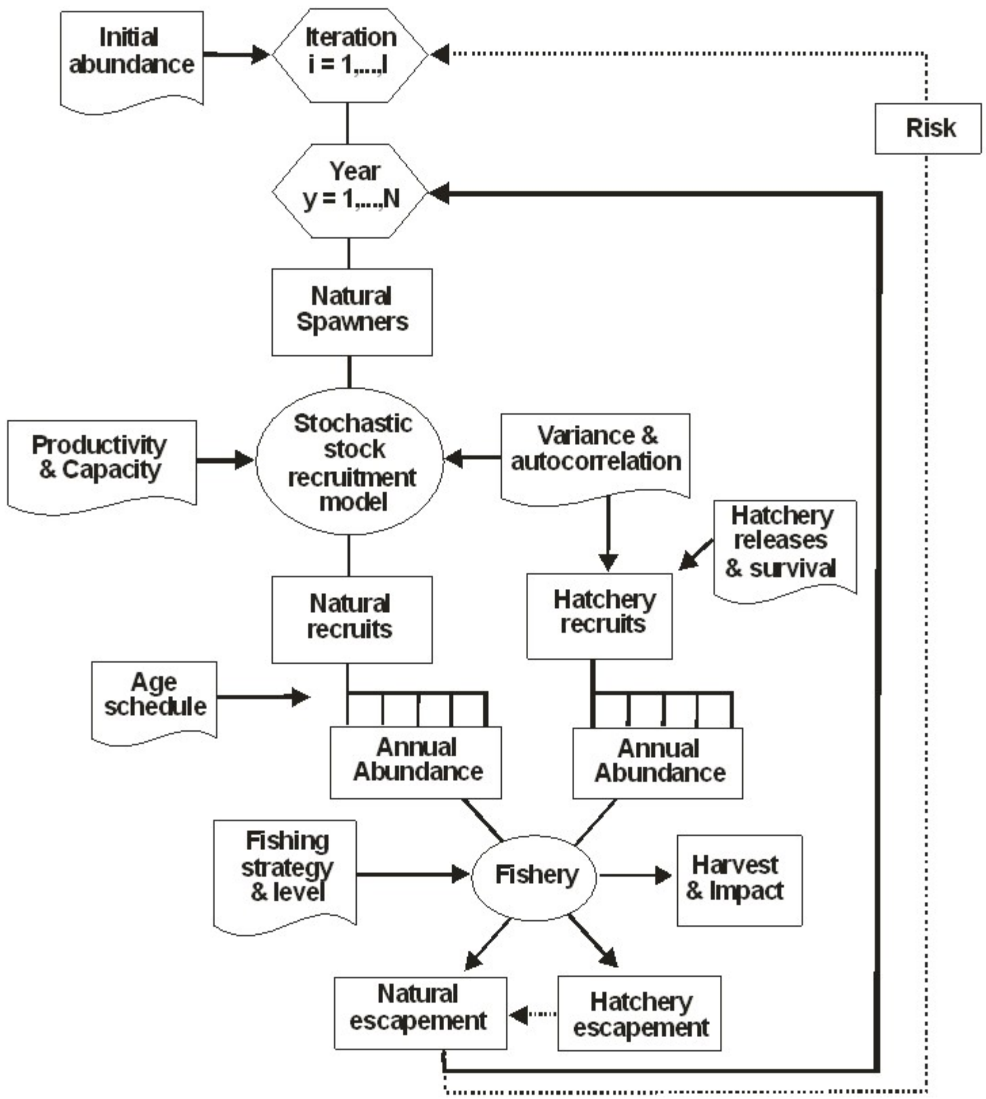

Figure 30. Conceptual depiction of model algorithm.

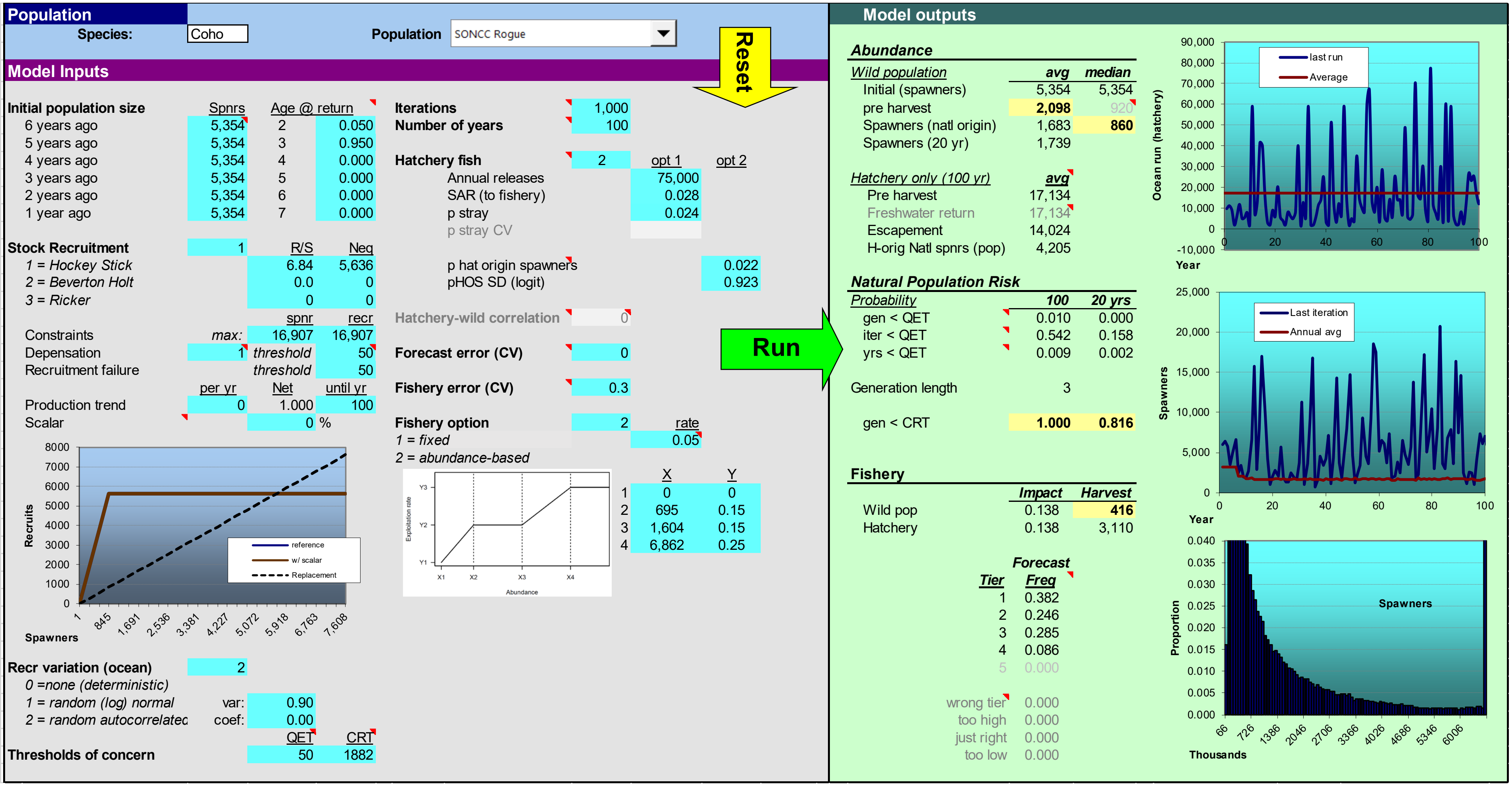

Figure 31. Model interface.

Model Functions

<u>*Stock-Recruitment*</u>
The model stock recruitment function was based on the Beverton-Holt or Hockey Stick functional forms.

The Beverton-Holt form of the relationship is:

$R_y = \{a\ S_y / [1 + (S_y\ (a - 1)/ N_{eq})]\}\ e^{\varepsilon}$

where

R_y = recruits,
S_y = spawners,
a = productivity parameter (maximum recruits per spawner at low abundance),
N_{eq} = parameter for equilibrium abundance,
e = exponent, and
ε = normally-distributed error term ~ $N(0, \sigma^2)$.

Estimation of recruits is described in Appendix B.

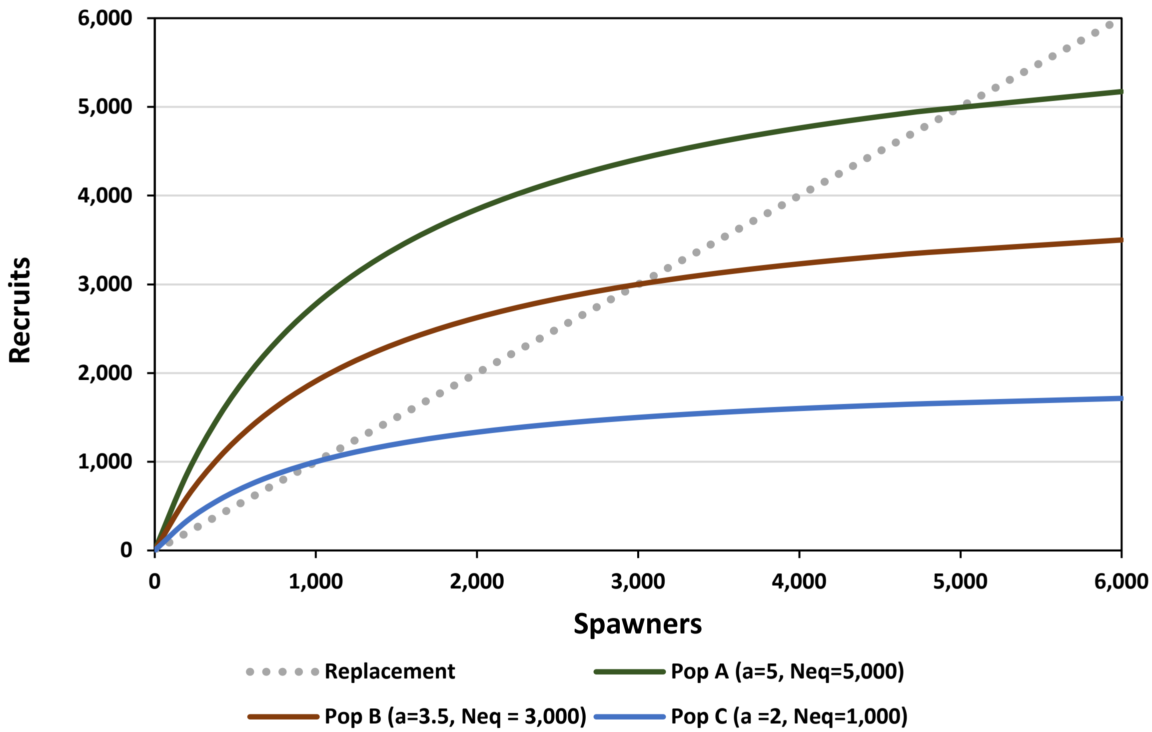

Figure 32. Examples of Beverton-Holt stock-recruitment curves.

The Hockey Stick form of the relationship is:

$$R_y = \text{Min}(S_y\, a, C)\, e^{\varepsilon}$$

where

R_y =	recruits,
S_y =	spawners,
a =	productivity parameter (maximum recruits per spawner at low abundance),
C =	capacity for adults,
e =	exponent, and
ε =	normally-distributed error term ~ $N(0, \sigma^2)$.

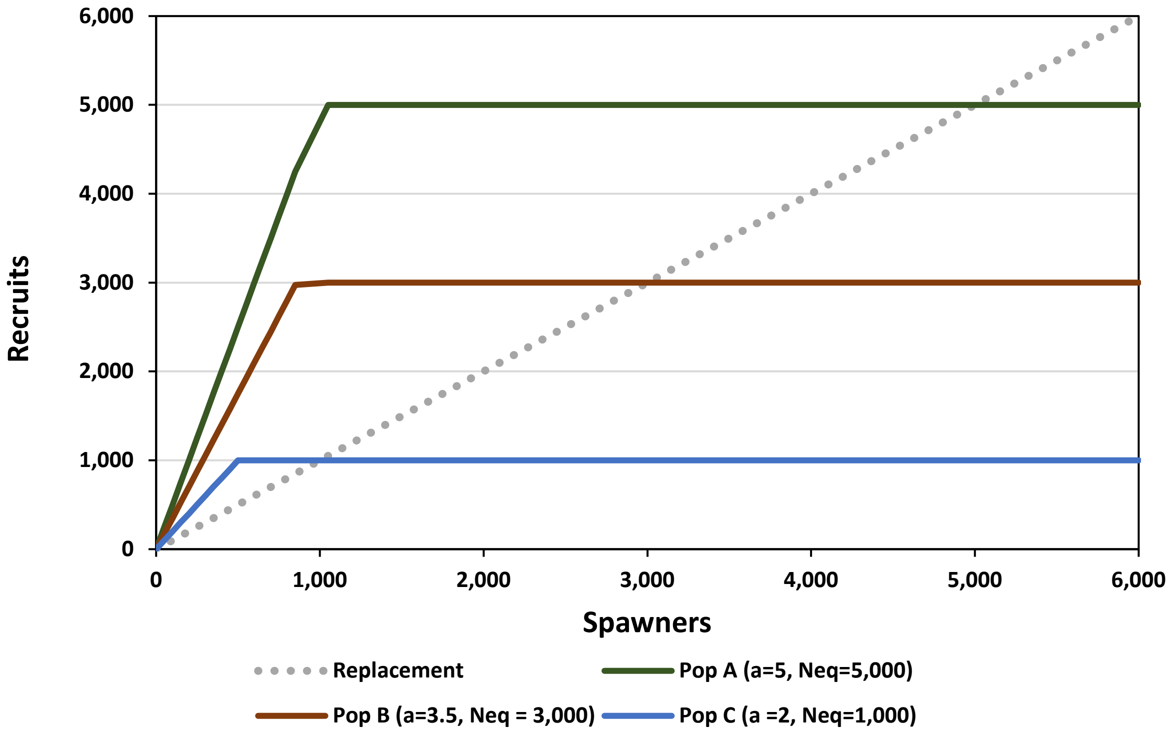

Figure 33. Examples of Hockey stick stock-recruitment curves.

Stock-Recruitment Variance

The stochastic simulation model incorporated variability about the stock-recruitment function to describe annual variation in fish numbers and productivity due to the effects of variable freshwater and marine survival patterns (as well as measurement error in stock assessments). This variance is modeled as a lognormal distribution (e^{ε}) where ε is normally distributed with a mean of 0 and a variance of σ_z^2.

The model allows for simulation of autocorrelation in stock-recruitment variance as follows:

$$Z_t = Ø\, Z_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_e^2)$$

where

Z_t = autocorrelation residual,
$Ø$ = lag autoregression coefficient,
ε_t = autocorrelation error, and
σ_e^2 = autocorrelation error variance.

The autocorrelation error variance (σ_e^2) is related to the stock-recruitment error variance (σ_z^2) with the lag autoregression coefficient:

$$\sigma_e^2 = \sigma_z^2\,(1 - Ø^2)$$

Model simulations using the autocorrelated residual options were seeded in the first year with a randomly generated value from $N(0, \sigma_z^2)$.

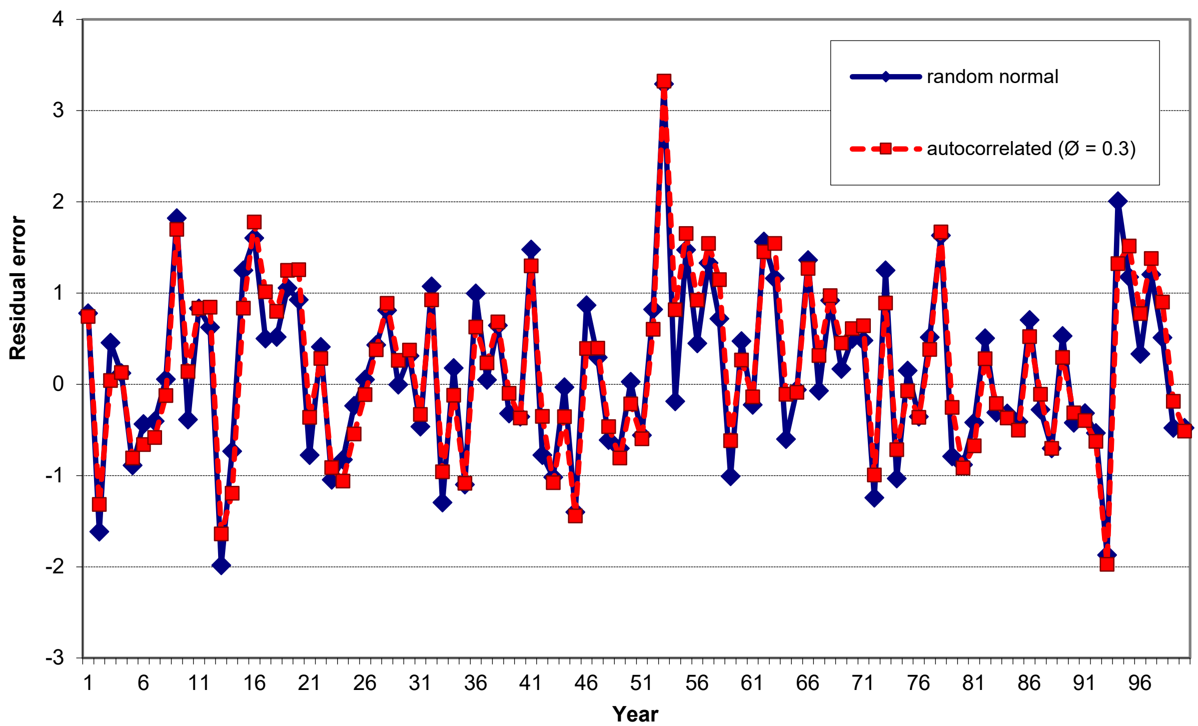

Figure 34. Examples of autocorrelation effect on randomly generated error patterns (σ_z^2 = 1).

Depensation & Recruitment Failure Thresholds

The model provides options to limit recruitment at low spawner numbers consistent with depensatory effects of stock substructure and small population processes. Options include 1) progressively reducing productivity at spawner numbers below a specified recruitment depensation threshold (RDT) and/or 2) setting recruitment to zero at spawner numbers below a specified recruitment failure threshold (RFT):

$$R' = R * (1 - Exp((Log(1 - 0.95) / (RDT - 1)) * S)) \text{ when } S > RFT$$

$$R' = 0 \text{ when } S < RFT$$

where

R' = Number of adult recruits after depensation applied,
R = Number of adult recruits estimated from stock-recruitment function,
S = spawners, and
RDT = Recruitment depensation threshold (spawner number).

Analyses of fishery effects were based on a recruitment failure threshold of 50 (equal to the QET) and a recruitment depensation threshold equal to the CRT. Thus, spawning escapements of fewer than 50 spawners are assumed to produce no recruits and the depensation function reduces productivity of spawning escapements under the CRT value in any one year.

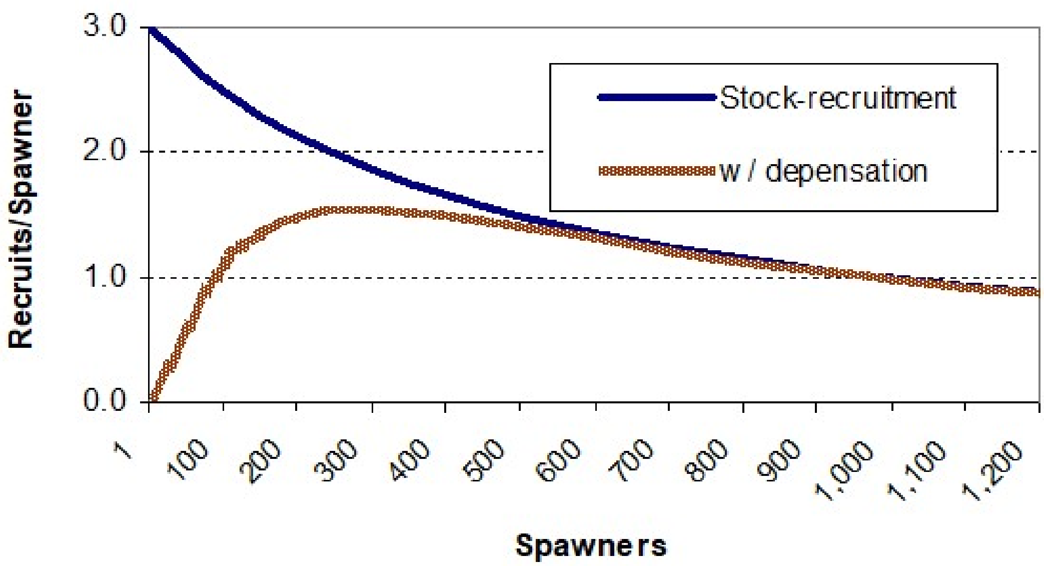

Figure 35. Example of depensation function effect on recruits per spawner at low spawner numbers based on a Beverton-Holt function (a = 3.0, Neq =1,000, γ =500).

Annual Abundance

Numbers of naturally-produced fish ($N_{.y}$) destined to return to freshwater in each year are estimated from a progressive series of recruitment cohorts based on a specified age composition:

$$N_{.y} = \Sigma N_{xy}$$

$$N_{xy} = R^*_{y-x} m_x$$

where

N_{xy} = Number of mature naturally-produced adults of age x destined to return to freshwater in year y, and

m_x = Proportion of adult cohort produced by brood year spawners that returns to freshwater in year x

Fisheries & Harvest

Annual numbers are subject to optional fishing rates. This option is useful for adjusting future projections for changes in fisheries and evaluating the effects of alternative fishing strategies and levels. Fishery impact is defined in the model in terms of the adult equivalent number of fish that die as a result of direct and indirect fishery effects:

$$IN_y = N_{.y} fN_y$$

where

IN_y = fishery impact in number of naturally-produced fish,

fN_y = fishery impact mortality rate on naturally produced fish including harvested catch and catch-release mortality where applicable.

In this assessment the term 'harvest' is synonymous with the number of 'fishing-related mortalities' of which incidental mortality is a primary component. Natural-origin SONCC coho salmon are generally not targeted in fisheries, particularly in marine waters (e.g., coho mark-selective fisheries in Oregon, retention prohibited in California fisheries). Some harvest may occur in freshwater under certain circumstances.

Hatchery Contributions

The model is configured to account for population-specific contributions of hatchery-origin spawners to natural production. Recruit calculations are based on total spawners which include both natural-origin and hatchery-origin spawners. Two options are provided for calculating hatchery contributions. The first assumes an average pHOS and a logit distribution. The second assumes the number of smolts released from the hatchery and net smolt-to-adult and stray rate values which produce hatchery strays into a population.

Model Input Parameters

Model inputs were based on data available for SONCC coho and supplemented with information on Oregon Coast and Lower Columbia River coho populations and/or risk assessments (Table 22).

Table 22. Model input variables and parameters used for fishery risk analysis.

Variable or parameter	Notation	Value
Initial spawner abundance	$S_{y-6},\ldots,S_{y-1}$	Equilibrium abundance @ avg. fishing rate
Stock-recruitment		
Function type	Option 1	Hockey Stick
	Option 2	Beverton-Holt
Productivity	P	Population-specific
Equilibrium abundance	N_{eq}	Population-specific
Maximum spawner constraint	lim S_y	(10) (N_{eq})
Maximum recruit constraint	lim R_y	(10) (N_{eq})
Production trend	PT	0%
Quasi-extinction threshold	RFT	50
Critical risk threshold	CRT	Population-specific
Recruitment stochasticity		
Variance	σ^2	Population-specific
Autocorrelation	Ø	Not utilized based on population analyses
Hatchery		
Function	Option 1	Release-based
	Option 2	pHOS-based
Annual releases	REL_H	Hatchery associated with population
Smolt-to-adult survival	SAR	To Ocean adults
Percentage staying	pStray	Population-specific
Percentage hatchery-origin spawners	pHOS	Population-specific
Variance in % hatchery-origin spawners	SD(pHOS)	Population-specific (logit)
Age schedule	$m_2,\ldots,m_7$	Age 2 = 0.05; Age 3 = 0.95
Fishery implementation error (CV)	E_i	0.3

<u>*Stock-Recruitment Parameters*</u>

Model input parameters for the stock-recruitment function (Table 23) were based on analyses of SONCC populations documented earlier in this chapter. Productivity and equilibrium abundance values were based on Bayesian estimates for Hockey Stick functions. Variance estimates were based on population-specific values. Variance was not assumed to be autocorrelated because of the lack of a strong, consistent effect in SONCC populations.

In addition, model sensitivity analyses were conducted for three generic populations representing a range of abundance and productivity levels. The range of population values was based on values identified for SONCC coho (this report), OCN coho (this report) and LCN coho (Kern and Zimmerman (2013). Generic values for stock-recruitment parameters were selected to represent a range values observed for all populations. Variance and autocorrelation parameters were based on the OCN population average which represents the best available long-term data set available for coho.

Age Composition

Analyses use values of 5% age 2 and 95% age 3. We assumed these values to be generally representative of natural coho in the absence of empirical estimates (e.g., Groot and Margolis 1991). Our analyses indicate that model results are generally little affected by age composition of coho which return almost entirely at one age.

Variation in Survival & Recruitment

Annual variability in natural production of the wild population is incorporated in the stock-recruitment relationship. The variance in recruits per spawner was parameterized with population-specific variances estimated for stock-recruit functions.

Table 23. Model input parameters.

	Function	R/S	Neq	CRT	σ^2	HOR Option	Associated hatchery	Hat releases	Hat Spnrs	pHOS	Logit pSD
Rogue	Hockey	6.84	5,636	1,882	0.9	2	Cole Rivers	75,000	50	0.02	0.923
Bogus	Hockey	2.21	80	50	1.08	1	Iron Gate	75,000[a]	59	0.42	1.235
Freshwater	Hockey	5.05	441	100	0.66	--	--	--	0	0	0
Scott	Hockey	3.08	713	250	0.62	2	Iron Gate	75,000 [a]	1	0.01	0.015
Shasta	Hockey	3.93	57	144	1.39	1	Iron Gate	75,000 [a]	17	0.42	1.769
Trinity	Hockey	0.22	3,334	719	1.54	1	Trinity	300,000	2,959	0.83	1.300
A pop	Bev-Holt	5.0	5,000	500	0.4761	-	--	--	--	0	0
B pop	Bev-Holt	3.5	3,000	300	0.4761	--	--	--	--	0	0
C pop	Bev-Holt	2.0	1,000	100	0.4761	--	--	--	--	0	0

[a] *Iron Gate Hatchery releases a total of 75,000 coho smolts in the Klamath basin.*

Conservation risks

Critical risk thresholds for SONCC coho populations were based on depensation thresholds identified in the ESU Recovery Plan (Table 1 and Table 23). Combined values of individual populations were used where SONCC populations included an aggregate of individual populations. Generic populations used a range of CRTS based on 30% of the current equilibrium abundance.[4]

All simulations assumed that extinction occurs at a quasi-extinction threshold (QET) of 50 estimated as a moving average of years in one generation of the species in question (3 years for coho) as per (McElhany et al. 2006). Estimates of absolute risk are extremely sensitive to the selection of this parameter which is why model-derived risks are most useful for relative comparisons among risk factors. While there is an extensive amount of literature on the relationships among extinction risk, persistence time, population abundance, and level of variation in demographic parameters, there are no simple generic abundance levels that can be identified as viable (McElhany et al. 2000). Because empirical data on actual extinction and conservation risk levels is lacking, this QET value was based on theoretical numbers identified in the literature based

[4] *Considered to generally be consistent with the scale of CRTs defined for SONCC populations.*

on genetic risks. Effective population sizes between 50 and 500 have been identified as levels which theoretically minimize risks of inbreeding depression and losses of genetic diversity, respectively (Franklin 1980, Soule 1980, Thompson 1991, Allendorf et al. 1997).

Forecast Error

Forecast error affect target fishing rates where the rate is based on an abundance forecast. Forecast errors can result in target rates different from rates that would have been identified based on actual run size. Forecast error was estimated to have a CV of 1.0 based on the observed range of annual variability in forecasts Oregon Coast natural coho. Forecast error was assumed to be independent of run size based on experience with OCN coho (Figure 36). Forecast errors do not explicitly incorporate any bias in forecast.

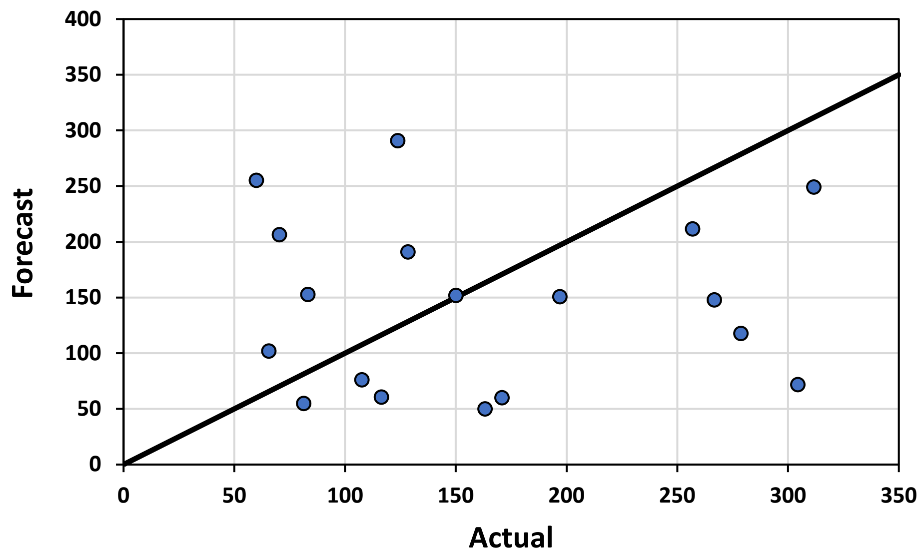

Figure 36. Forecast and actual run size of Oregon Coast Natural coho in relation to 1:1 line, 2001-2019.

Fishery Errors

Fishery errors were based on data reported earlier in this report. Fishery implementation error was estimated to have a CV of 0.30 based on the observed range of annual variability in exploitation rates estimated for SONCC coho.

Simulations

A series of model simulations were conducted to:

1. Evaluate the effects of fixed exploitation rates on risk for wild populations of SONCC coho. Simulations include fixed total rates identified by the work group (0, 7, 13, 26) as well as higher rates intended to illustrate risk sensitivity for a range of populations.[5]

[5] Simulations are based on total exploitation rates which include both ocean and freshwater harvest rates.

2. Describe sensitivity of generic populations A, B, and C to a series of fixed annual ERs ranging from 0.0 to 0.50. Generic populations are intended to provide reference values for other west coast coho populations.
3. Evaluate the effects of abundance-based exploitation rates on risk for wild populations of SONCC coho. These simulations are intended to illustrate tradeoffs between fixed and variable exploitation rates that might result if abundance-based harvest control rules could be practically implemented.
4. Evaluate the effects of abundance-based on risk for wild populations of SONCC coho.
5. Describe short versus long term risks associated with exploitation rates.
6. Describe model sensitivity to key inputs including contributions of hatchery-origin fish to natural spawning, normal fishery implementation "errors", and abundance forecast errors.

Modeling Aggregate HCRs

Simulations of aggregate HCRs should ideally mirror the real-life application, wherein components are forecast (or simulated, in this case) *concurrently*, abundance values are summed across components, and the allowable ER is ultimately determined and applied each year. However, as noted above, the Risk Assessment's population modeling framework allows for the simulation of one population at a time (i.e., using a single set of stock-recruit parameters), i.e., *disaggregated-independent modeling*. This approach addressed additional risks associated with nonsynchrony in individual populations based on outcomes associated with correspondingly higher forecast and fishery errors. Given this, assessments of HCRs 8-11 were conducted using an approach that attempts to approximate the ideal concurrent modeling situation. That is, the aggregate abundance *x*-axis for each HCR function was divided into the fractional contribution attributable to each component population, and then applied in separate population simulations. This approach allowed the Workgroup to conduct simulations for all abundance-based HCRs. However, it also introduced some uncertainty to results, potentially affecting the picture of relative risk across scenarios and fishery benefits, due to an effect on how harvest responds to abundance changes at the individual population level (Appendix C).

Under the concurrent modeling approach, a small population could experience a higher exploitation rate than it might support on its own if other populations within the aggregate happened to be abundant in the same year. The disaggregated-independent modeling approximation, in contrast, could apply a lower exploitation rate to this small population under these same conditions. The net effect is that this portrayal of aggregate management may be more closely aligned with the more conservative (lower risk) weak-stock management. A parallel assessment of these two approaches illustrates that this theoretical expectation is in fact borne out in results (Appendix C). The analyses summarized in Appendix C suggest that the effect on quasi-extinction risk of modeling HCRs using the disaggregated-independent approximation, compared to the concurrent approach, may be great enough to affect how different HCRs rank along a relative risk continuum. In short, this matter may necessitate a modification to the risk assessment framework before the results from abundance-based HCRs can be fully evaluated and compared to others

Results

Fishery Effects - Constant Exploitation Rate Control Rules: Total Exploitation Rates (HCR 1-4)

The effects of constant exploitation rate HCRs on short-term (20 year) and long-term (100 year) risk is summarized in Table 24. The sensitivity of long-term risks to fishery impacts varies with population status. Long-term population risks can be substantially reduced by reducing fishery impacts only for populations with significant intrinsic capacity or productivity (e. g., category B populations). Smaller less productive populations are less affected and cannot generally be brought to high levels of viability over the long term even at very low fishing rates (e.g., category C populations).

Shasta, Bogus and Trinity populations are all at high risk regardless of fishing rates due to their low productivity and/or capacity. Each of these populations are subject to significant spawning by hatchery-origin fish but risks are so high that the hatchery subsidy doesn't provide much of a benefit. Freshwater Creek appears to be one of the stronger SONCC populations with risks relatively unaffected by fishing rates under 20% or so. Rogue and Scott are in between and are the most sensitive to low fishing rates.

20-year risks are lower than 100-year risks for a given population, partly because all simulations are initialized to start at equilibrium population levels and partly because the shorter time period provides less opportunity for populations to suffer the progressive effects of sequential low spawning escapements.

Incremental benefits of fishery reductions progressively decrease at lower and lower fishing rates. Fishing rates below which population viability is largely independent of the effects of fishing are sometimes referred to as *de minimis* fishing rates. Definition of an appropriate *de minimis* rate depends on the specification of an acceptable risk level. Rates may vary among populations in relation to differences in abundance and productivity.

Average abundance of a natural population increases in direct proportion to the decrease in fishing rate over the 100-year period of the simulation. Improvements are greatest in the most productive populations and least in relatively unproductive populations. While risk of falling below a critical small-population threshold may be relatively insensitive to fishing at low impact rates, abundance is consistently sensitive to fishing at all impact levels. Thus, while reductions to very low fishing rates do not substantially affect risk, they do translate into ever larger numbers of spawners.

Table 24. Modeled effects of constant exploitation rates on short term risk (20 year), long term risk (100 year), median abundance (100 year), and average harvest (100 year) for generic and SONCC natural coho populations.

Outcome	Population	Exploitation rate					
		0	7	13	26	40	50
Risk (20 yr)	Generic A	0.000	0.000	0.001	0.009	0.049	0.148
	Generic B	0.000	0.001	0.003	0.025	0.086	0.281
	Generic C	0.008	0.023	0.033	0.088	0.330	0.601
	Rogue	0.135	0.172	0.210	0.375	0.652	0.851
	Bogus	0.747	0.811	0.857	0.943	0.992	0.999
	Freshwater	0.001	0.004	0.007	0.039	0.181	0.471
	Scott	0.079	0.115	0.155	0.33	0.676	0.898
	Shasta	1.000	1.000	1.000	1.000	1.000	1.000
	Trinity	0.640	0.725	0.792	0.898	0.978	0.999
Risk (100 yr)	Generic A	0.005	0.009	0.017	0.072	0.315	0.678
	Generic B	0.015	0.021	0.044	0.174	0.539	0.891
	Generic C	0.085	0.176	0.258	0.607	0.949	0.999
	Rogue	0.498	0.609	0.716	0.908	0.994	1.000
	Bogus	0.999	1.000	1.000	1.000	1.000	1.000
	Freshwater	0.033	0.058	0.099	0.318	0.808	0.993
	Scott	0.318	0.450	0.577	0.870	0.994	1.000
	Shasta	1.000	1.000	1.000	1.000	1.000	1.000
	Trinity	0.993	0.999	1.000	1.000	1.000	1.000
Median Abundance (100 yr)	Generic A	4,800	4,400	4,000	3,200	2,300	1,600
	Generic B	2,820	2,580	2,280	1,740	1,140	660
	Generic C	900	760	640	360	60	0
	Rogue	5,600	5,260	4,930	4,140	3,250	2,580
	Bogus	70	70	60	50	30	10
	Freshwater	440	410	380	300	190	60
	Scott	700	640	600	500	360	200
	Shasta	10	0	0	0	0	0
	Trinity	1,190	1,060	860	590	330	200
Average Harvest (100 yr)	Generic A	0	401	732	1,390	1,945	2,150
	Generic B	0	234	424	780	1,023	999
	Generic C	0	71	121	176	130	75
	Rogue	0	504	937	1,870	2,859	3,516
	Bogus	0	7	12	22	28	27
	Freshwater	0	38	71	134	167	137
	Scott	0	60	112	220	312	283
	Shasta	0	1	3	5	4	4
	Trinity	0	152	271	470	589	611

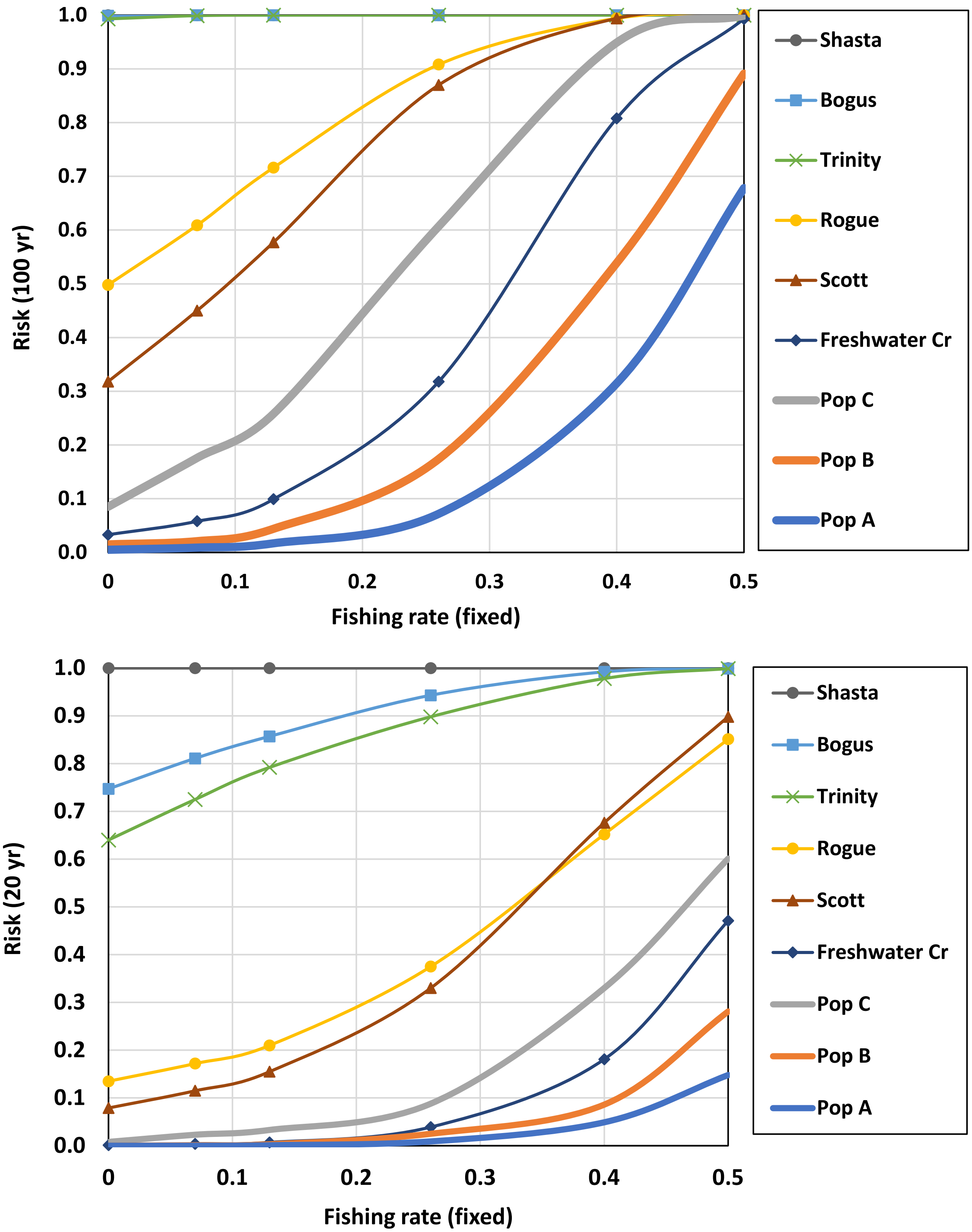

Figure 37. Modeled effects of fixed exploitation rates on long- and short-term risk of falling below critical wild population abundance thresholds.

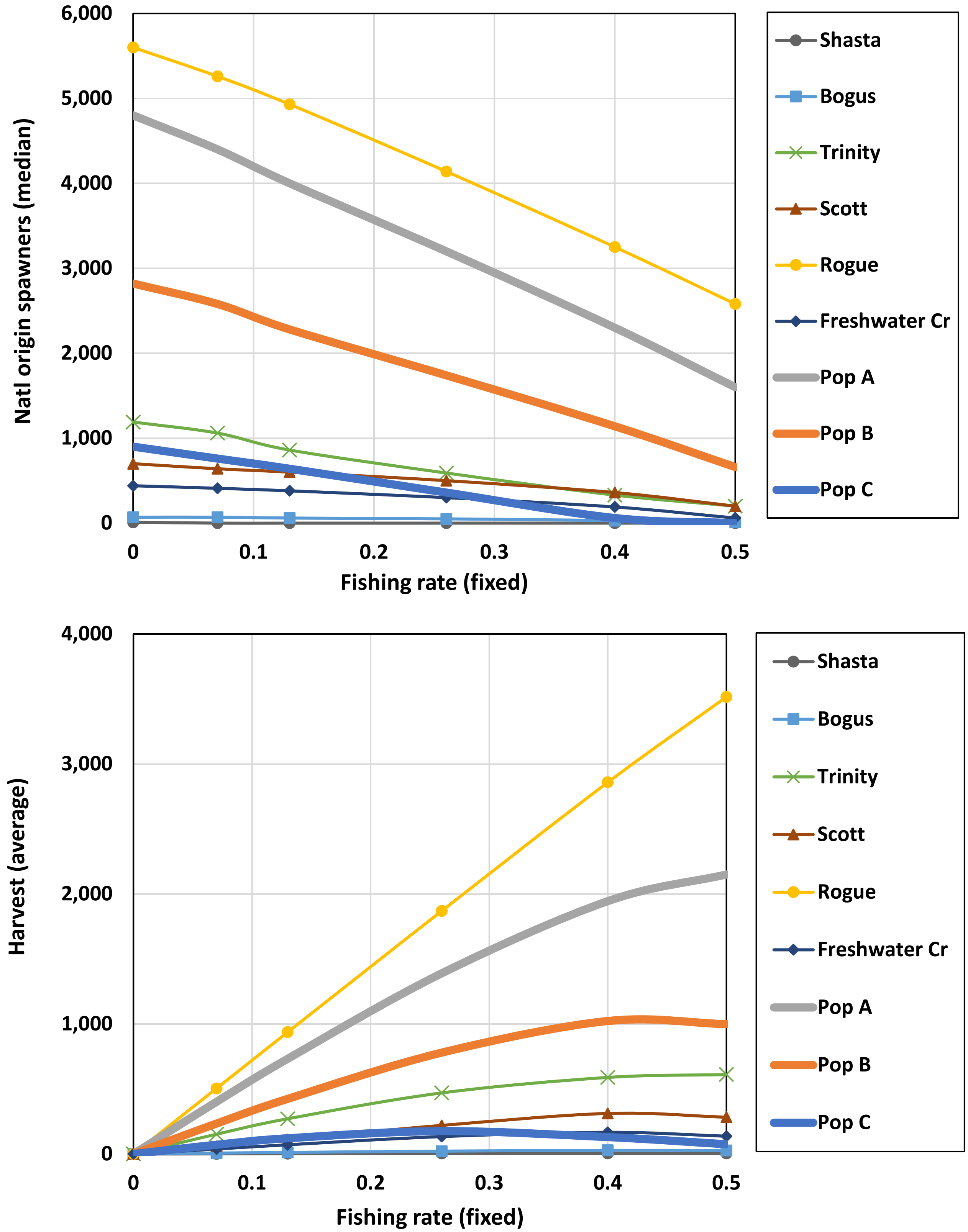

Figure 38. Modeled effects of different exploitation rates on long-term median abundance and average harvest.

Fishery Effects – Constant Exploitation Rate Control Rules: ocean only (HCR 5–7)

Constant exploitation rate control rules evaluated by the work group are based on total exploitation and ocean-only rates. The risk analysis estimates population effects of total exploitation rate in all fisheries. Therefore, analysis of ocean-based rules must also make assumptions for fishing rates in freshwater. This analysis used population-specific-average total freshwater and ocean rates documented in Table 5 through Table 9 and summarized in Table 25. Averages for freshwater rates are based on the common year range of 2007-2019. The freshwater ER for the Trinity population unit in 2018 was omitted from the mean due to small sample size and corresponding high uncertainty.

Table 25. Average freshwater and ocean exploitation rates for SONCC populations for 2007-2019.

	Rogue	Bogus	Freshwater	Scott	Shasta	Trinity
Freshwater	0.050	0.062	0	0.062	0.062	0.095
Ocean	0.056	0.056	0.056	0.056	0.056	0.056
Total	0.106	0.118	0.056	0.118	0.118	0.151

Table 26. Modeled effects of fixed exploitation rates on long term risk (100 year), short term risk (20 year), median abundance (100 year), and average harvest (100 year) for generic and SONCC natural coho populations.

HCR	Population	Exploitation rate			p(100)	p(20)	Median Abund.	Avg Harv.
		Ocean	Freshwater	Total				
1	Rogue	--	--	0	0.498	0.135	5,600	0
	Bogus	--	--	0	0.999	0.747	70	0
	Scott	--	--	0	0.318	0.079	700	0
	Shasta	--	--	0	1.000	1.000	10	0
	Trinity	--	--	0	0.993	0.640	1,190	0
	Freshwater	--	--	0	0.033	0.001	440	0
2	Rogue	--	--	0.07	0.609	0.172	5,260	504
	Bogus	--	--	0.07	1.000	0.811	70	7
	Scott	--	--	0.07	0.450	0.115	640	60
	Shasta	--	--	0.07	1.000	1.000	0	1
	Trinity	--	--	0.07	0.999	0.725	1,060	152
	Freshwater	--	--	0.07	0.058	0.004	410	38
3	Rogue	--	--	0.13	0.716	0.210	4,930	937
	Bogus	--	--	0.13	1.000	0.857	60	12
	Scott	--	--	0.13	0.577	0.155	600	112
	Shasta	--	--	0.13	1.000	1.000	0	3
	Trinity	--	--	0.13	1.000	0.792	860	271
	Freshwater	--	--	0.13	0.099	0.007	380	71
4	Rogue	--	--	0.26	0.908	0.375	4,140	1,870
	Bogus	--	--	0.26	1.000	0.943	50	22
	Scott	--	--	0.26	0.870	0.330	500	220
	Shasta	--	--	0.26	1.000	1.000	0	5
	Trinity	--	--	0.26	1.000	0.898	590	470
	Freshwater	--	--	0.26	0.318	0.039	300	134
5	Rogue	0.07	0.050		0.688	0.201	4,930	865
	Bogus	0.07	0.062		1.000	0.858	60	12
	Scott	0.07	0.062		0.578	0.155	600	114
	Shasta	0.07	0.062		0.956	0.467	450	267
	Trinity	0.07	0.095		1.000	0.831	790	333
	Freshwater	0.07	0		0.058	0.004	410	38
6	Rogue	0.13	0.050		0.792	0.261	4,590	1,297
	Bogus	0.13	0.062		1.000	0.902	50	17
	Scott	0.13	0.062		0.722	0.217	560	164
	Shasta	0.13	0.062		1.000	1.000	0	4
	Trinity	0.13	0.095		1.000	0.876	660	425
	Freshwater	0.13	0		0.099	0.007	380	71
7	Rogue	0.26	0.050		0.962	0.467	3,810	2,227
	Bogus	0.26	0.062		1.000	0.971	40	25
	Scott	0.26	0.062		0.956	0.467	450	267
	Shasta	0.26	0.062		1.000	1.000	0	5
	Trinity	0.26	0.095		1.000	0.959	400	562
	Freshwater	0.26	0		0.318	0.039	300	134

Fishery Effects - Abundance-based Control Rules (HCR 8-11)

Analyses of abundance-based (ABM) HCRs are presented to demonstrate effects in the event that reasonably-accurate preseason forecasts of returning adults might be developed. Example HCRs were previously identified based on various population aggregations, corresponding abundance tiers and exploitation rates. This analysis considers effects at the individual population level where conservation risks are measured. This is the case even where HCRs are based on aggregate-based HCRs. Variance in actual rates for any given population captures the effects of partial correlations of individual populations with aggregate values (Figure 39). All simulations were based on combined exploitation rates in the ocean and freshwater. Analysis of fishery-specific rates would require assumptions of rates for each fishery in order to assess population-level effects.

Results of ABM strategies are summarized in Table 26 and compared with constant exploitation rate strategies in Figure 40. Abundance-based HCR produce risks and fishing-related mortality as a function of the frequencies of exploitation rates occurring in the corresponding abundance tiers. Frequencies are the product of the combined effect of natural population dynamics and fishing effects on escapement. Thus, any given ABM HCR produces an equivalent average exploitation rate which is also documented in Table 26.

Abundance-based strategies typically allow for greater levels of fishing-related mortality of the target populations than constant rate strategies which produce an equivalent risk level (Figure 40). This is because risks are affected by fishing rates during low runs. Higher fishing rates on low runs can exacerbate low escapements and increase risk. Conversely, low run size risks are reduced by ABM strategies which reduce exploitation rates on low runs. Average harvest increases with ABM strategies which allow for higher exploitation rates when fish are more abundant. The results suggest the fishery benefits of greater fishing on large runs exceeds the foregone value of reduced fishing on small runs. However, this is only true where fishery value is measured primarily in harvest of SONCC coho.

Even greater benefits accrue from ABM strategies where stock limits constrain access to significant harvestable surpluses of hatchery fish of the same stock or other species and stocks in mixed species/stock fisheries. For instance, if SONCC coho limits constrain harvest of fall Chinook, an abundance-based SONCC coho rule could allow for greater fall Chinook harvest in years of higher SONCC coho abundance. If SONCC coho are not generally a constraining stock, then ABM rules may be less of a benefit.

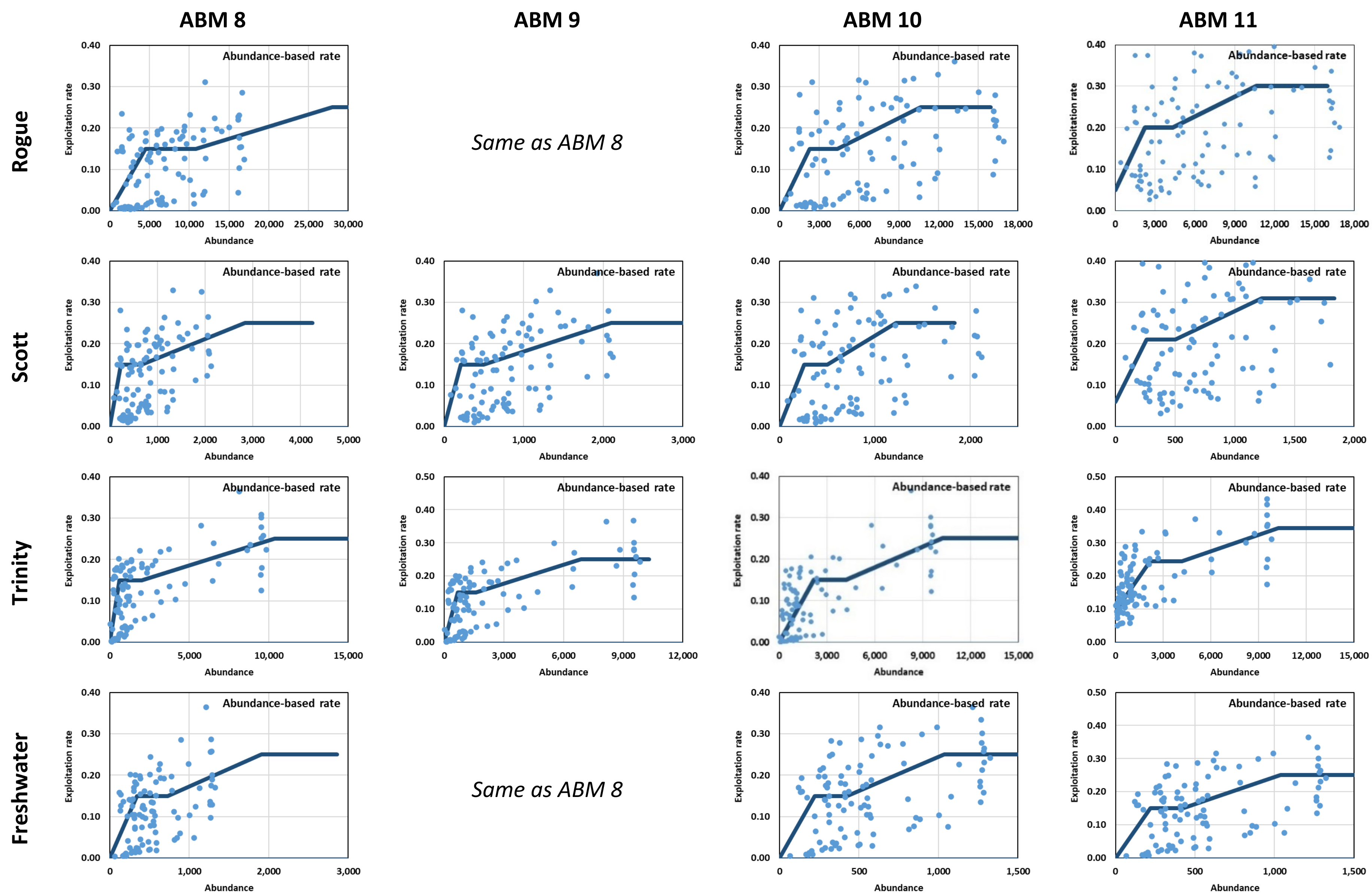

Figure 39. Modeled exploitation rates (100-year samples) for ABM HCRs assuming a forecast error (CV) of 1.0 and a fishery implementation error (CV) of 0.30.

Table 27. Modeled effects of abundance-based exploitation rates on long term risk (100 year), short term risk (20 year), median abundance (100 year), and average harvest (100 year) for generic and SONCC natural coho populations.

HCR	Population[a]	% of Aggr.	Abundance tiers				Tier frequency				p(100)	p(20)	Median Abund.	Avg Harv.	Avg ER
			X1	X2	X3	X4	1	2	3	4					
8	Rogue	100	0	4,473	10,820	27,972	0.39	0.29	0.31	0.01	0.627	0.174	4,930	1,048	0.145
	Scott	75	0	233	665	2,834	0.28	0.16	0.53	0.03	0.521	0.140	600	145	0.167
	Trinity	100	0	605	2,004	10,342	0.37	0.23	0.38	0.03	1.000	0.790	920	374	0.175
	Freshwater	100	0	344	726	1906	0.39	0.24	0.35	0.02	0.062	0.005	380	81	0.149
9	Scott	22	0	212	490	2097	0.27	0.10	0.52	0.11	0.542	0.146	590	157	0.182
	Trinity	72	0	695	1604	6862	0.39	0.16	0.36	0.10	1.000	0.796	860	401	0.466
10	Rogue	45	0	2,264	4,342	10,630	0.29	0.09	0.29	0.33	0.700	0.210	4,700	1,418	0.197
	Scott	5	0	260	500	1,223	0.29	0.09	0.28	0.35	0.579	0.155	570	169	0.196
	Trinity	44	0	2,179	4,179	10,230	0.61	0.18	0.18	0.03	1.000	0.758	990	344	0.157
	Freshwater	4	0	220	423	1,035	0.32	0.12	0.34	0.22	0.073	0.005	370	99	0.182
11	Rogue	45	0	2,264	4,342	10,630	0.29	0.09	0.29	0.33	0.785	0.256	4,370	1,778	0.247
	Scott	5	0	260	500	1,223	0.29	0.09	0.28	0.34	0.734	0.221	530	219	0.255
	Trinity	44	0	2,179	4,179	10,230	0.64	0.17	0.16	0.02	1.000	0.854	730	494	0.248
	Freshwater	4	0	220	423	1,035	0.32	0.12	0.34	0.22	0.073	0.005	370	99	0.182

[a] *Results for Shasta and Bogus populations in the upper Klamath not displayed because they are at very high risk regardless of exploitation rates*

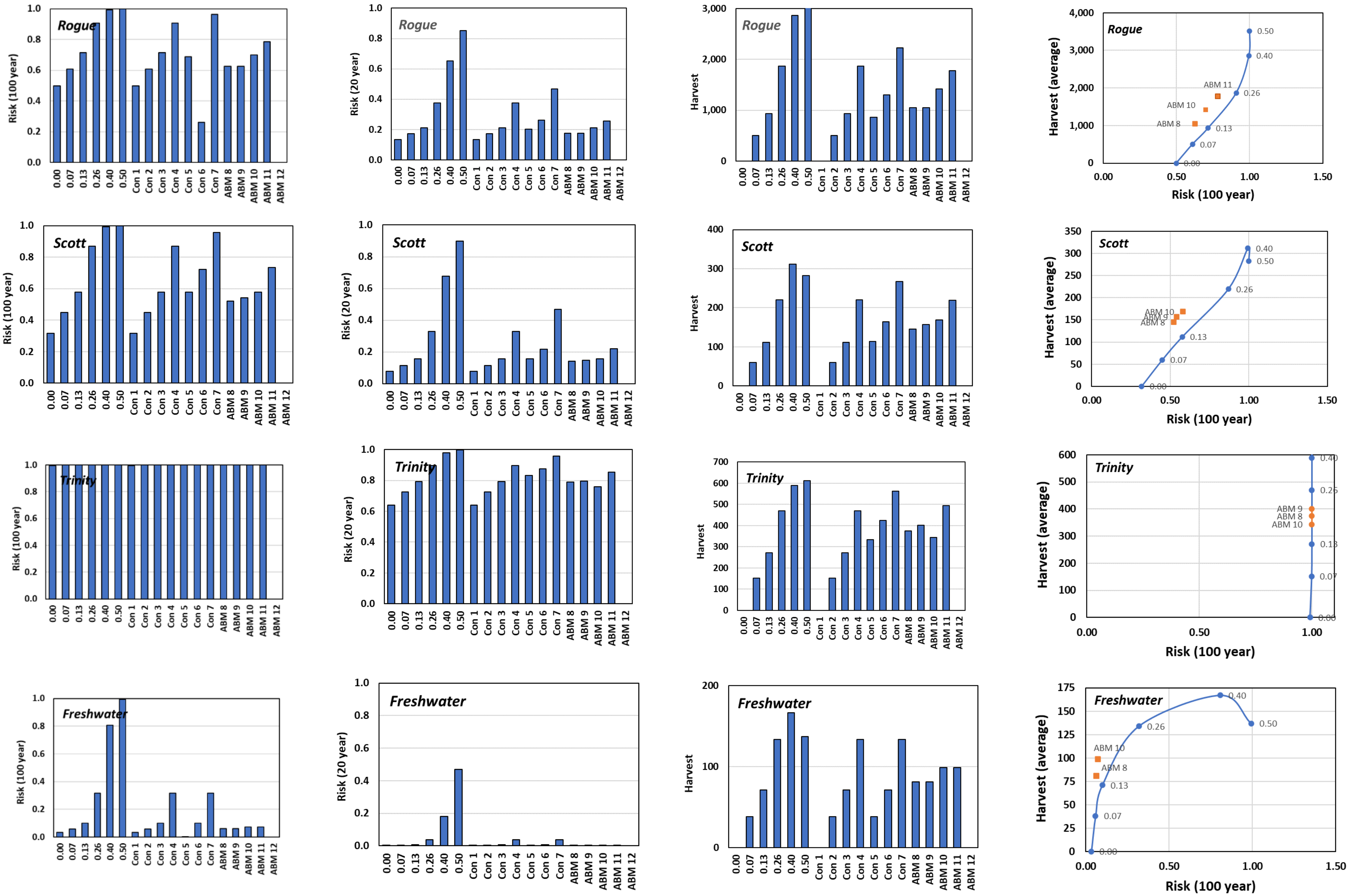

Figure 40. Comparison of population risks and harvest for fixed and abundance-based harvest control rules.

Considerations for Abundance-based Management of SONCC Coho

The risk analysis of example abundance-based management strategies illustrated the potential fishery benefits of an ABM strategy which reduces fishing rates at low run sizes in exchange for higher harvest rates at large run sizes. Potential benefits include higher levels of fishing-related mortality on SONCC coho and increased opportunity to access hatchery and other stocks when SONCC coho limits are constraining.

Two conditions are necessary for effective implementation of abundance-based management. First, individual populations of SONCC coho need to vary in common such that all are similarly affected by variable exploitation rates. Second, abundance of SONCC needs to be reasonably forecast prior to the fishing season in order to be able to identify appropriate fishing levels. The following analysis examines correlations among natural and hatchery components with which address these two questions.

The following metrics were examined:

- Adult run size (ocean abundance) of natural-origin SONCC coho populations for which escapement is estimated (Bogus, Shasta, Scott, Trinity, Freshwater, and Rogue River aggregate).
- Klamath-Trinity and Klamath-Trinity-Rogue aggregates of natural-origin SONCC coho populations.
- Adult coho returns (swim-ins) for Iron Gate, Trinity, and Cole River hatcheries.
- Smolt-to-adult survival rates of coho for Iron Gate, Trinity, and Cole River hatcheries.
- Jack coho returns (swim-ins) for Iron Gate, Trinity, and Cole River hatcheries in the year prior to adults.
- Jack per brood year smolt-index for Iron Gate, Trinity, and Cole River hatcheries for the jack return in the year prior to adults.

Jacks of natural-origin populations were not included because of low numbers and uncertain availability in time for use in forecasts.

Data and correlations are summarized in Table 28 and Table 29. Annual abundance is significantly ($p<0.05$) and positively correlated among Klamath, Trinity and Rogue populations. Individual populations are well-represented by a Klamath-Trinity-Rogue aggregate (r^2 of 0.74 to 0.98). The Freshwater Creek population is weakly and negatively correlated with Bogus, Shasta, and Scott populations.

Hatchery and natural returns are significantly and positively correlated (Table 29, Figure 43).

Hatchery adults are moderately correlated with hatchery jack numbers in the preceding year (Table 29, Figure 44). Significant positive correlations occur for individual hatcheries and all hatcheries combined. For the aggregate, simple jack numbers account for 65% of the annual variation in adult returns. A jack index based on jacks per smolt release does not substantially improve the correlations.

Natural-origin adults are moderately correlated with hatchery jack numbers in the preceding year when considered in aggregate (Table 29, Figure 45). For the aggregate, simple jack numbers account for 48% of the annual variation in adult returns. Most of this correlation is driven by the Trinity population with an additional increment by the Rogue population. The Klamath populations, considered individually, do not appear to be significantly correlated to the aggregate jack number. The hatchery survival index based on jacks / smolts released does not substantially improve fits (Figure 46). Smolt releases have only recently been reduced so corresponding observations are limited. We might expect an index to be a better predictor after more years.

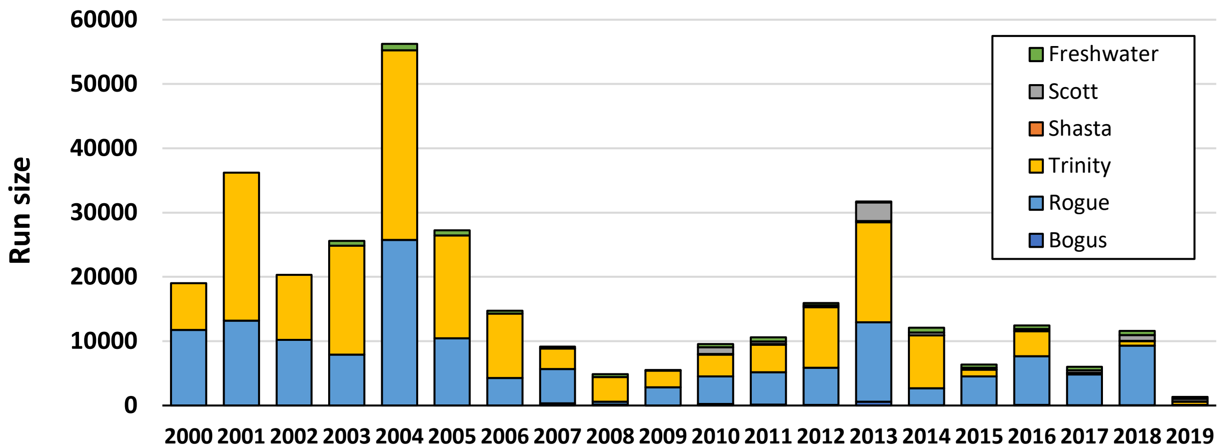

Figure 41. Annual run size of adult natural-origin SONCC coho populations where assessment information is available.

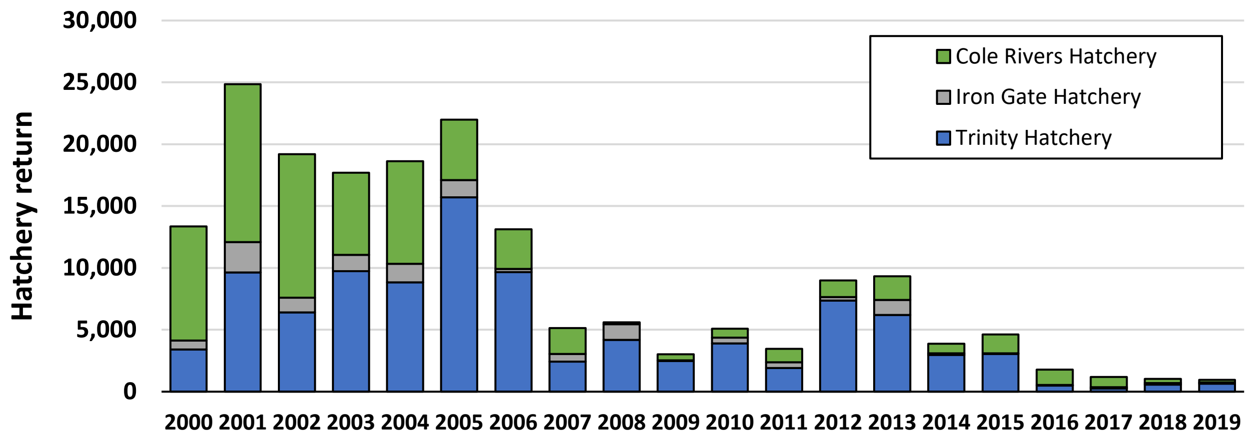

Figure 42. Annual return of adult coho to Rogue, Klamath and Trinity populations.

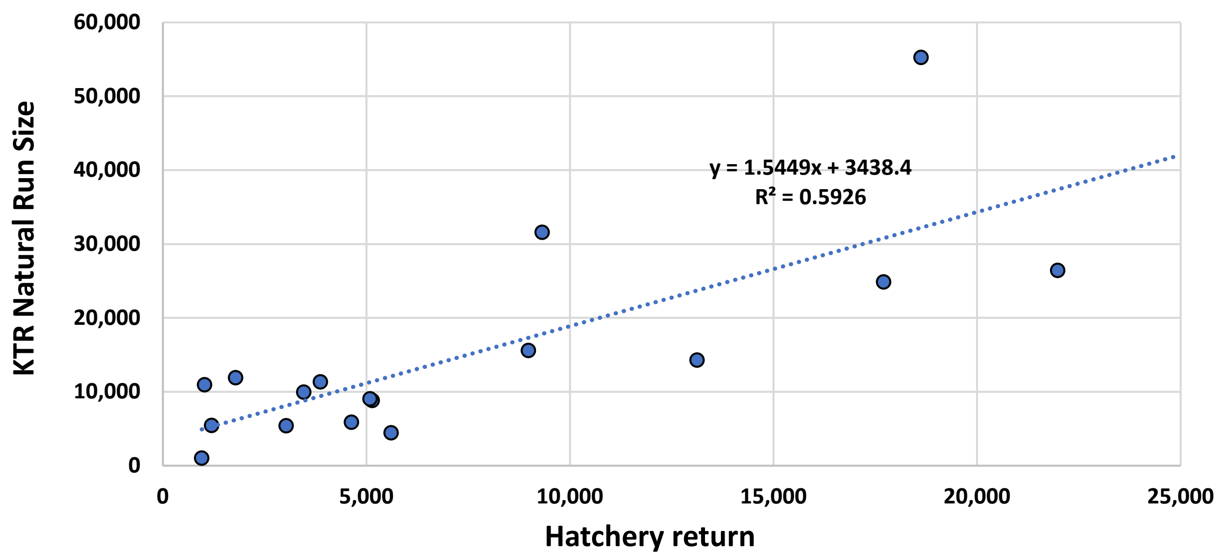

Figure 43. Correlation of total hatchery and natural abundance of SONCC coho (all hatcheries and populations combined).

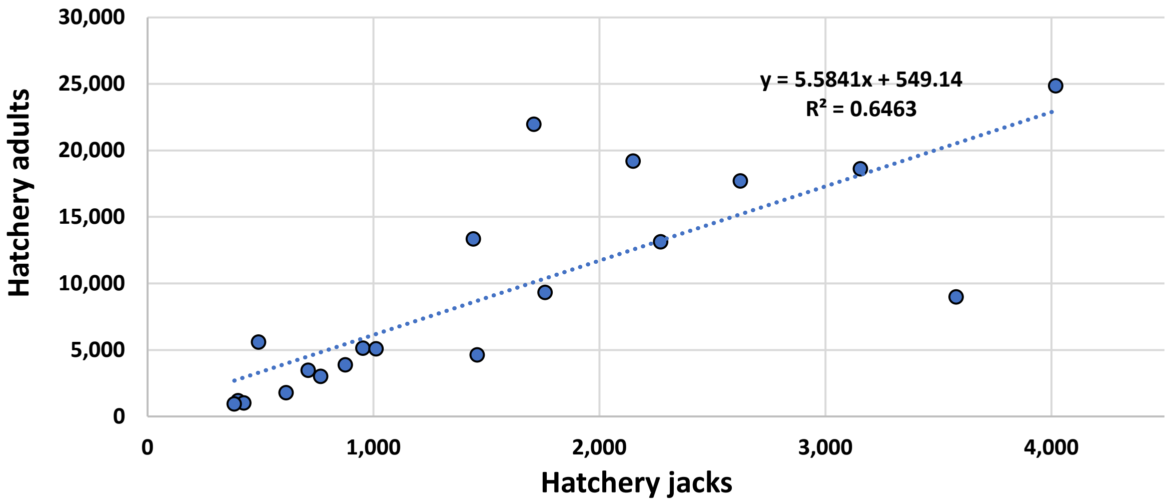

Figure 44. Correlation of hatchery jacks and adults (all hatcheries combined).

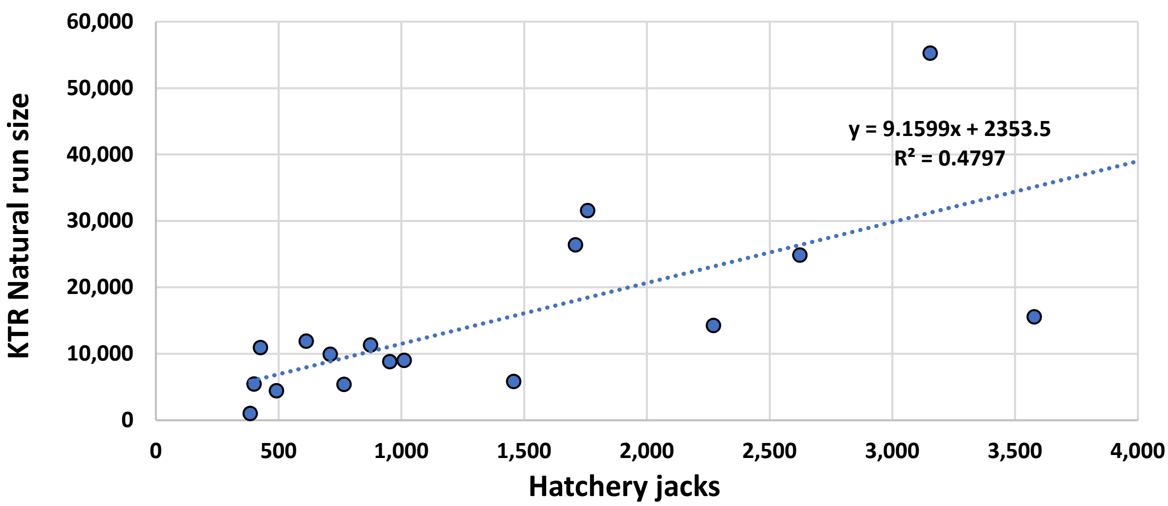

Figure 45. Correlation of hatchery jacks and natural origin adults in the following year.

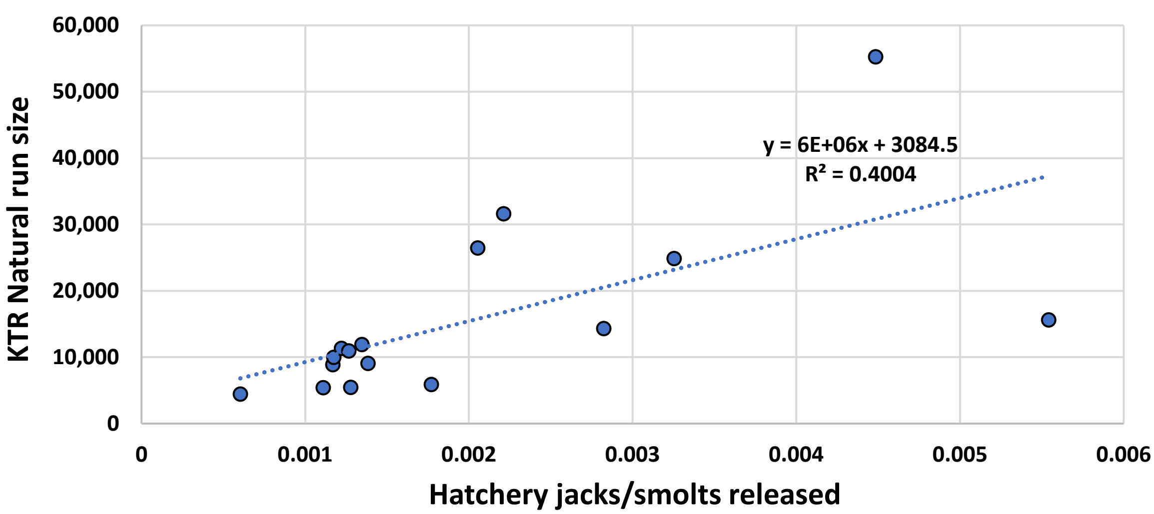

Figure 46. Correlation of hatchery jacks / smolt and natural origin adults in the following year

Table 28. Natural-origin and hatchery numbers for SONCC coho.

Run	Run size (adults)								Hatchery return (adults)				Smolt to adult survival				Hatchery return jacks (year-1)				jacks / smolt (year -1)			
Year	Bogus	Shasta	Scott	Trinity	Freshwate	Rogue	KT total	KTR total	Trinity H	IG Hat	CR Hat	All Hat	Trinity H	IG Hat	CR Hat	All Hat	Trinity H	IG Hat	CR Hat	All Hat	Trinity H	IG Hat	CR Hat	All Hat
2000				7,296		11,754			3,407	723	9,224	13,354		0.010	0.045		389	18	1,034	1,441		0.000	0.0050	
2001				22,982		13,210			9,625	2,466	12,759	24,850		0.032	0.073		916	631	2,471	4,018		0.008	0.0142	
2002				10,126		10,188			6,409	1,193	11,599	19,201	0.012	0.026	0.055	0.025	1,024	107	1,017	2,148	0.002	0.002	0.0048	0.0028
2003				16,956	746	7,910	16,956	24,866	9,730	1,317	6,656	17,703	0.018	0.019	0.032	0.022	688	108	1,827	2,623	0.001	0.002	0.0088	0.0033
2004				29,498	994	25,763	29,498	55,261	8,835	1,495	8,289	18,619	0.021	0.020	0.039	0.026	1,449	241	1,464	3,154	0.003	0.003	0.0069	0.0045
2005				15,977	831	10,455	15,977	26,432	15,704	1,395	4,876	21,975	0.030	0.013	0.024	0.026	1,068	239	402	1,709	0.002	0.002	0.0020	0.0021
2006				10,044	430	4,259	10,044	14,303	9,669	263	3,188	13,120	0.019	0.004	0.015	0.016	1,721	30	520	2,271	0.003	0.000	0.0025	0.0028
2007	336			3,183	285	5,336	3,518	8,854	2,436	625	2,085	5,146	0.004	0.007	0.012	0.006	657	69	227	953	0.001	0.001	0.0013	0.0012
2008	135			3,851	420	465	3,985	4,450	4,177	1,278	148	5,603	0.008	0.011	0.001	0.007	270	154	67	491	0.001	0.001	0.0004	0.0006
2009	11			2,608	95	2,799	2,619	5,418	2,477	46	503	3,026	0.005	0.001	0.003	0.004	643	18	105	766	0.001	0.000	0.0006	0.0011
2010	238	69	1,049	3,406	506	4,284	4,762	9,046	3,899	457	730	5,086	0.008	0.004	0.005	0.007	874	24	113	1,011	0.002	0.000	0.0007	0.0014
2011	156	85	387	4,295	630	5,033	4,923	9,956	1,924	454	1,086	3,464	0.005	0.004	0.016	0.006	526	28	156	710	0.001	0.000	0.0023	0.0012
2012	82	92	209	9,429	321	5,792	9,812	15,604	7,357	301	1,322	8,980	0.015	0.014	0.010	0.014	2,866	132	580	3,578	0.006	0.006	0.0044	0.0055
2013	575	192	2,891	15,576	158	12,354	19,235	31,589	6,204	1,200	1,911	9,315	0.013	0.008	0.013	0.012	879	343	537	1,759	0.002	0.002	0.0036	0.0022
2014	36	8	426	8,210	740	2,664	8,679	11,343	2,971	117	784	3,872	0.006	0.003	0.005	0.005	427	68	380	875	0.001	0.002	0.0023	0.0012
2015	21	51	224	1,088	499	4,487	1,385	5,872	3,059	34	1,540	4,633	0.006	0.000	0.007	0.006	937	267	254	1,458	0.002	0.003	0.0012	0.0018
2016	81	58	286	3,914	524	7,568	4,340	11,908	482	56	1,248	1,786	0.002	0.001	0.016	0.004	278	38	297	613	0.001	0.000	0.0038	0.0013
2017	53	41	407	189	557	4,773	690	5,463	267	93	836	1,196	0.001	0.003	0.015	0.004	45	30	325	400	0.000	0.001	0.0059	0.0013
2018	56	45	890	725	629	9,238	1,717	10,955	556	139	326	1,021	0.002	0.008	0.006	0.003	150	29	247	426	0.001	0.002	0.0042	0.0013
2019	69	56	376	525	319		1,025	1,025	643	110	203	956	0.002		0.003	0.000	186	61	137	384	0.001		0.0022	
median	81	57	397	5,795	506	5,792	4,762	10,955	3,653	456	1,431	5,375	0.007	0.008	0.014	0.007	673	69	353	1,226	0.001	0.002	0.003	0.001
min	11	8	209	189	95	465	690	1,025	267	34	148	956	0.001	0.000	0.001	0.000	45	18	67	384	0.000	0.000	0.000	0.001
max	575	192	2,891	29,498	994	25,763	29,498	55,261	15,704	2,466	12,759	24,850	0.030	0.032	0.073	0.026	2,866	631	2,471	4,018	0.006	0.008	0.014	0.006

Table 29. Correlation table among natural and hatchery abundance metrics for SONCC coho.

	Run size							Hatchery rack return												
	Shasta	Scott	Trinity	Freshwater	Rogue	K-T total	KTR total	TrH ad	IG Hat ad	CR Hat ad	TrH SAR	IGH SAR	CRH SAR	TrH jk-1	IGH jk-1	CRH jk-1	all H jk-1	TrH j/sm -1	IG j/sm -1	CR jk/sm -1
Bogus	0.910	0.944	0.652	-0.414	0.566	0.715	0.735	0.457	0.747	0.590	0.458	0.302	0.301	0.096	0.518	0.295	0.196	0.072	-0.087	0.036
Shasta		0.809	0.719	-0.792	0.748	0.775	0.820	0.613	0.922	0.655	0.640	0.424	0.340	0.343	0.666	0.455	0.440	0.345	0.173	0.081
Scott	--		0.665	-0.552	0.762	0.755	0.819	0.422	0.906	0.411	0.440	0.258	0.090	0.028	0.588	0.341	0.100	-0.044	0.096	0.033
Trinity	--	--		0.513	0.793	0.994	0.961	0.772	0.797	0.696	0.810	0.730	0.670	0.439	0.649	0.790	0.809	0.494	0.540	0.641
Freshwater	--	--	--		0.503	0.468	0.517	0.372	0.371	0.622	0.413	0.467	0.660	0.036	0.107	0.517	0.232	0.002	0.108	0.487
Rogue	--	--	--	--		0.817	0.937	0.404	0.566	0.644	0.486	0.578	0.629	0.201	0.448	0.617	0.548	0.318	0.360	0.559
K-T total	--	--	--	--	--		0.968	0.732	0.770	0.652	0.787	0.746	0.221	0.452	0.609	0.776	0.746	0.479	0.370	0.536
KTR total	--	--	--	--	--	--		0.631	0.716	0.854	0.702	0.722	0.824	0.396	0.594	0.747	0.693	0.446	0.373	0.575
Trinity Hat	--	--	--	--	--	--	--		0.679	0.542	0.993	0.585	0.470	0.581	0.514	0.535	0.726	0.547	0.425	0.338
IG Hat	--	--	--	--	--	--	--	--		0.751	0.706	0.865	0.744	0.151	0.761	0.764	0.640	0.158	0.546	0.638
CR Hat	--	--	--	--	--	--	--	--	--		0.605	0.849	0.976	0.195	0.510	0.865	0.690	0.296	0.460	0.729
TrH SAR	--	--	--	--	--	--	--	--	--	--		0.584	0.513	0.578	0.518	0.569	0.743	0.578	0.367	0.274
IG SAR	--	--	--	--	--	--	--	--	--	--	--		0.839	0.275	0.619	0.847	0.753	0.332	0.674	0.847
CR SAR	--	--	--	--	--	--	--	--	--	--	--	--		0.140	0.548	0.877	0.670	0.245	0.505	0.811
TrH jk-1	--	--	--	--	--	--	--	--	--	--	--	--	--		0.233	0.224	0.752	0.990	0.502	0.100
IGH jk-1	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.628	0.642	0.280	0.819	0.594
CRH jk-1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.803	0.328	0.624	0.923
all H jk-1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.866	0.783	0.680
TrH j/sm -1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.688	0.171
IG j/sm -1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		0.652
CR jk/sm -1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	

≥0.75	0.50-0.74	-0.50-0.50	-0.50-0.74	≤0.75

Model Sensitivity Analyses

Hatchery Effects

Inclusion of hatchery spawners had little effect on risk calculations for SONCC populations due to the particularities of these populations. Low productivity in SONCC populations where hatchery strays are currently significant, results in high risk even when natural production is bolstered by hatchery spawners. Hatchery spawners obviously have little effect on risk profiles of natural populations where hatchery contributions are negligible. In larger, more-productive generic populations, sensitivity analyses show that the addition of hatchery-origin spawners reduces risks where hatchery fish are assumed to produce no corresponding change in productivity) (Figure 47).[6]

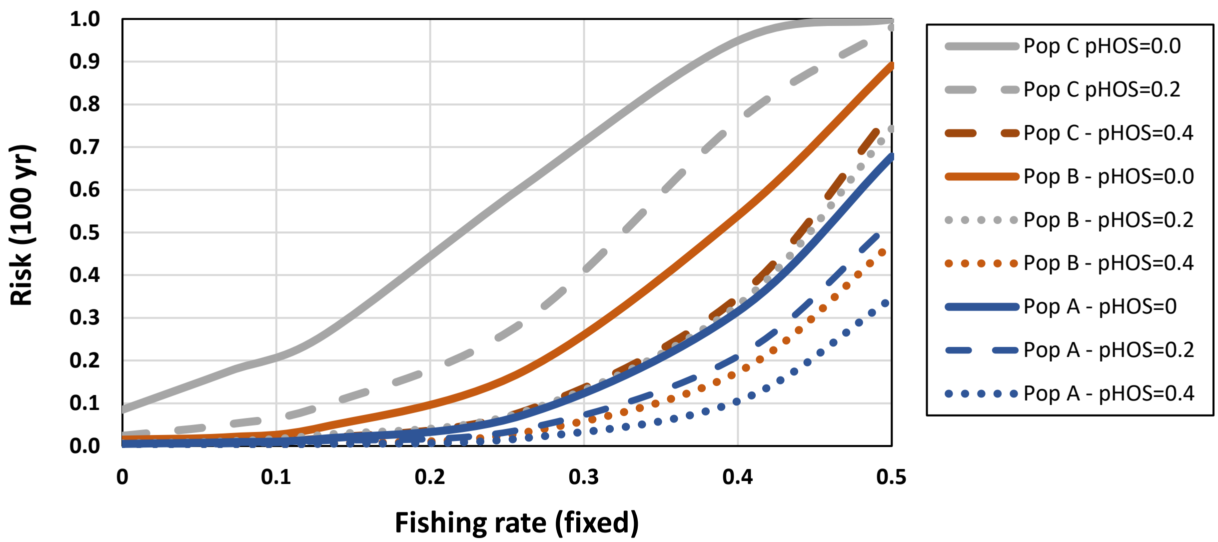

Figure 47. Sensitivity analysis of effects of hatchery contributions to fishery risk profiles.

The model formulation examined two approaches to calculating hatchery contributions. The first assumed current hatchery releases and net smolt-to-adult and stray rate values which produce current average numbers of hatchery strays into a population. The second assumed current average pHOS and a logit distribution. For relatively productive populations (e.g., Scott), the two approaches produced equivalent results. For small and unproductive populations supported by large hatchery subsidies, the second method gave more realistic abundance profiles in response to fishing.

Fishery Implementation "Error"

Sensitivity analyses considered the effects of variable exploitation rates on conservation risks. Variable exploitation rates describe normal annual patterns of departure in actual rates relative to target fishing rates (Figure 48). Conservation risks are not particularly sensitive to variability in

[6] *Current estimates of productivity presumably included effects of past and current levels of hatchery contribution. In certain cases, hatchery fish have been observed to reduce natural population productivity. Therefore, substantial changes in hatchery contributions might result in significant changes in natural productivity. Productivity changes are not reflected in model sensitivity analyses of hatchery effects. The model only reflects the demographic effects of hatchery spawners.*

exploitation rate about target values, particularly for low to moderate rates (Figure 49). Sensitivity increases slightly as fishing rates increase. It appears that the impacts of higher fishing rates in some years are balanced by the benefits of lower rates in other years.

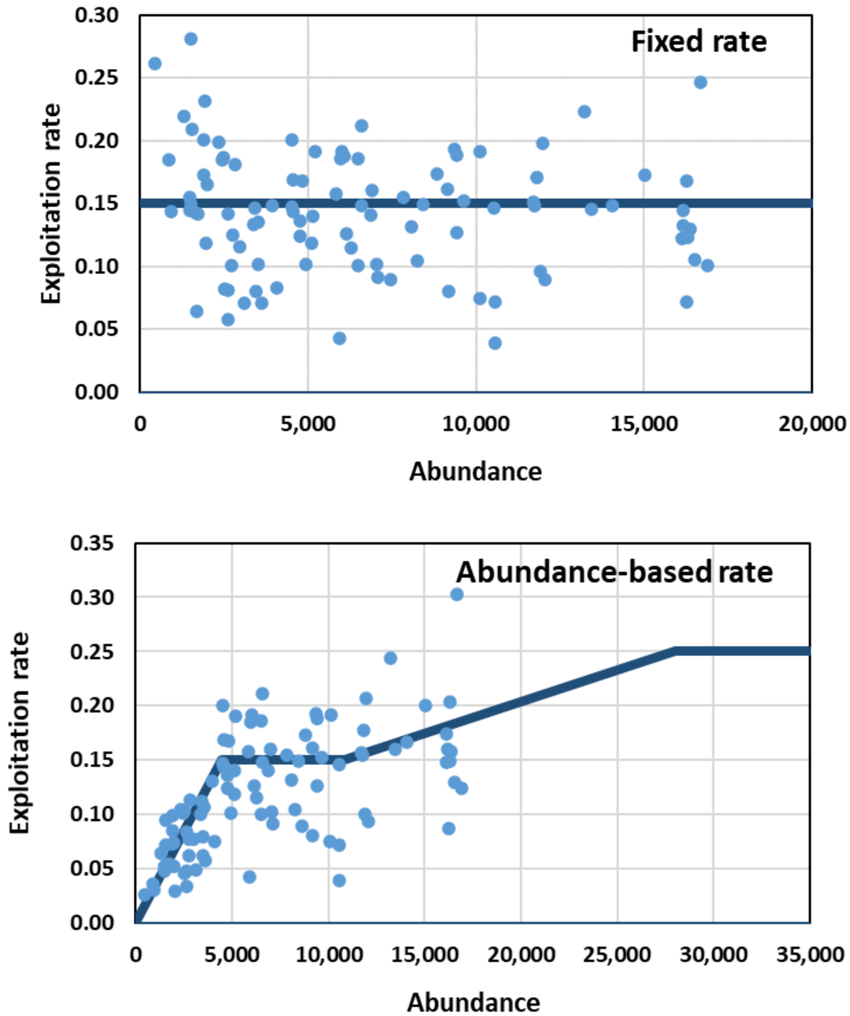

Figure 48. Examples of modeled variability in exploitation rates for fixed and abundance-based harvest control rules for Rogue River coho (CV = 0.3).

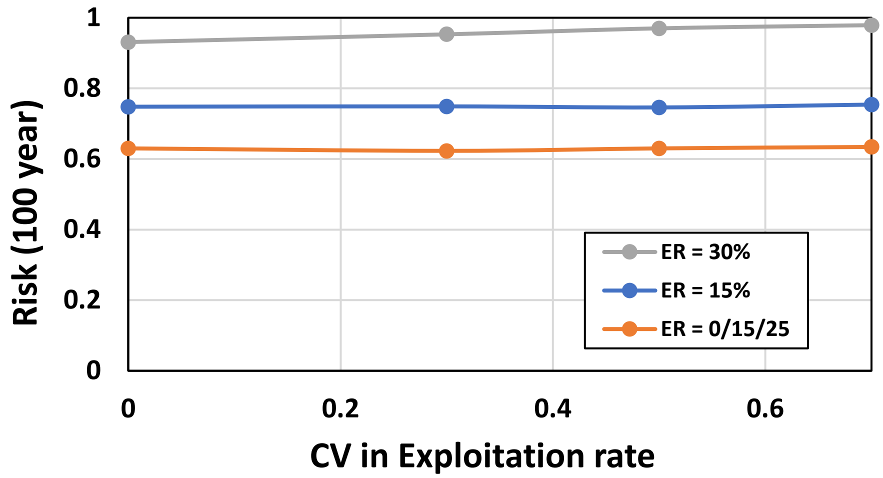

Figure 49. Sensitivity of risk to variability in fishing rates (implementation error identified as CV in exploitation rate) around target values for various harvest control rules for Rogue River coho.

Forecast & Fishery Implementation Error - Abundance-based Control Rules

A sensitivity analysis was conducted to the effects of forecast and fishery implementation "error" on resulting risk calculations of abundance-based management rules. Forecast "error" occurs when differences in forecast and actual abundance result in target exploitation rates higher or lower than those prescribed by harvest control rules. Implementation "error" occurs when target and actual exploitation rates are different for instance due to normal variation in fishery effort, catchability, etc.

Initial analyses assumed an implementation error with a CV of 0.30 intended to produce a range in exploitation rates similar to those observed historically in the ocean fishery. Previous sensitivity analyses to a range of implementation errors found that low run size risks were not sensitive to the magnitude of fishery implementation error.

Additional sensitivity analysis examined joint effects of ranges of forecast and implementation errors. The magnitude of potential forecast error is unknown as an effective forecast method for natural abundance of SONCC has not been identified to date. CVs for Lower Columbia Natural (LCN) and Oregon Coast Natural (OCN) coho forecasts are 56% and 102%, respectively.

The joint error sensitivity analysis was based on ABM 8 and the Rogue River population. This population is among the most sensitive of SONCC coho populations to exploitation rates on risk.

Low run size risks were not sensitive to the combined effects of forecast and fishery implementation errors (Figure 50, Table 30). The scatter of actual versus objective exploitation rates increased substantially as errors increased in magnitude (Figure 51) but low run size risk was little effected.

Interestingly, the risks associated with the ABM rule was less than that produced by a fixed rate HCR with an equivalent average exploitation rate (15.5%). It appears that the effects of low and high exploitation rate errors generally cancel out but an ABM HCR that goes to zero at low abundance, continues to provide a risk benefit (assuming such a rule can be practically implemented).

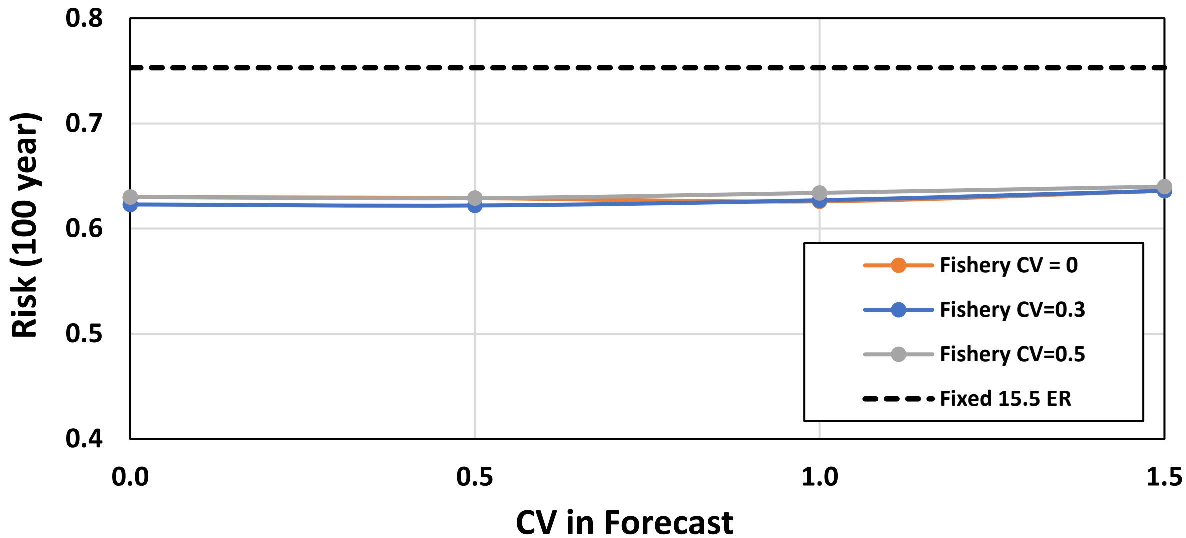

Figure 50. Sensitivity of risk to forecast and fishery implementation error for Rogue River coho.

Table 30. Sensitivity of risk to forecast and fishery implementation error for Rogue River coho.

Forecast CV	Fishery CV	p(100)	p(20)	Avg abun pre hrv	median esc	avg harvest	effective ER	Tier frequency 1	2	3	4
0	0	0.630	0.177	7,213	4,820	1,121	0.155	0.392	0.368	0.240	0.000
0.5	0	0.629	0.176	7,212	4,930	1,078	0.149	0.367	0.366	0.267	0.000
1	0	0.626	0.176	7,211	5,040	1,046	0.145	0.392	0.289	0.308	0.010
1.5	0	0.636	0.176	7,211	4,930	1,028	0.143	0.418	0.230	0.316	0.036
0	0.3	0.623	0.181	7,213	4,820	1,122	0.156	0.392	0.368	0.240	0.000
0.5	0.3	0.622	0.175	7,211	4,930	1,079	0.150	0.367	0.366	0.267	0.000
1	0.3	0.627	0.174	7,211	4,930	1,048	0.145	0.392	0.289	0.308	0.010
1.5	0.3	0.636	0.178	7,211	4,930	1,029	0.143	0.418	0.230	0.316	0.036
0	0.5	0.63	0.188	7,213	4,820	1,134	0.157	0.392	0.368	0.240	0.000
0.5	0.5	0.629	0.18	7,211	4,930	1,090	0.151	0.367	0.366	0.267	0.000
1	0.5	0.634	0.181	7,211	4,930	1,058	0.147	0.392	0.289	0.309	0.010
1.5	0.5	0.64	0.183	7,210	4,930	1,039	0.144	0.418	0.230	0.316	0.036

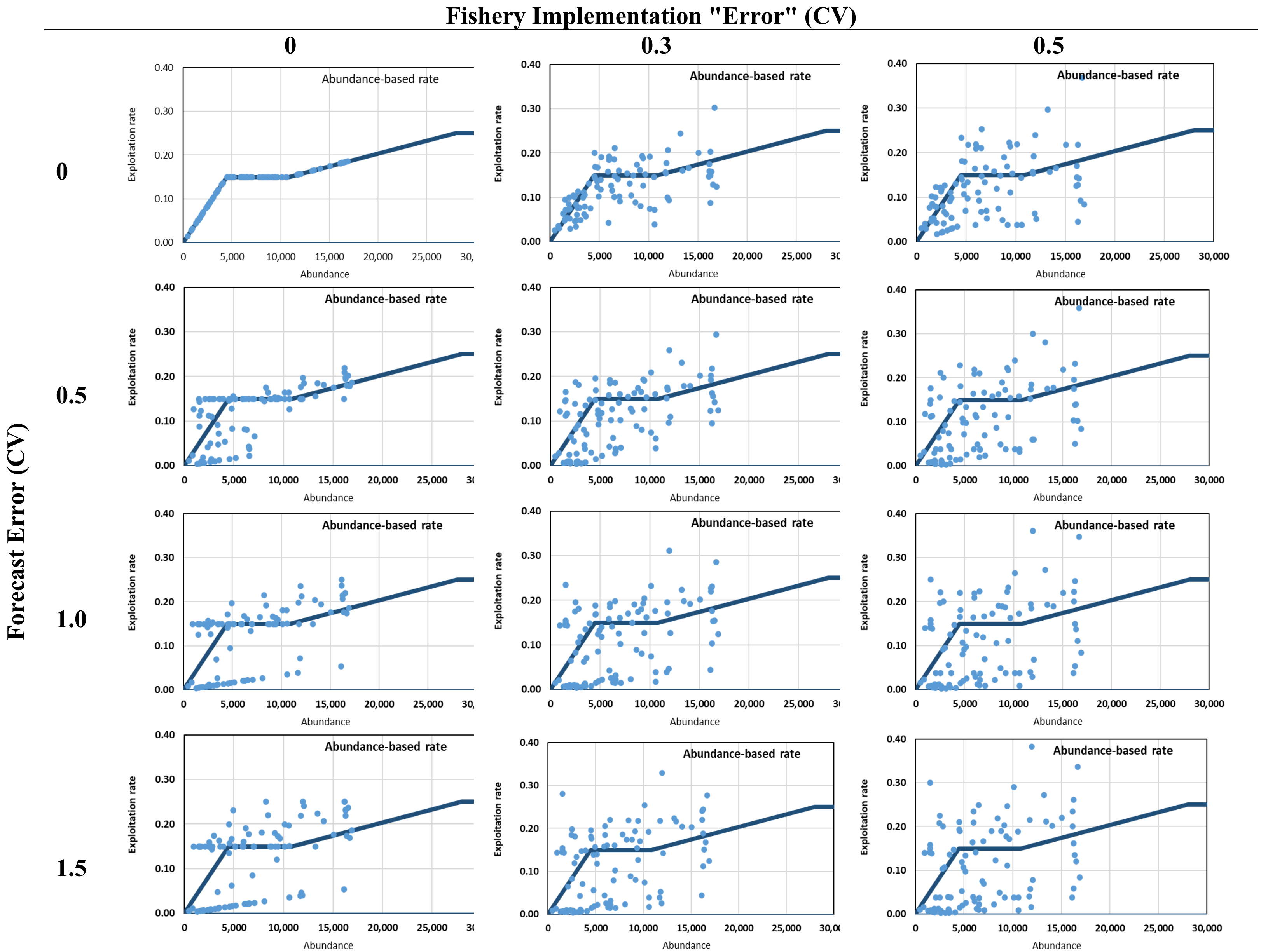

Figure 51. Effects of forecast error and fishery implementation error on distributions of ERs in an abundance-HCR (#8) for Rogue coho.

Effects of Alternative Stock-Recruitment Parameters
Effects of fixed exploitation rates on Trinity coho for productivity and capacity parameters estimated for this analysis and alternative values previously identified in a Hatchery Genetic Management Plan. We estimated productivity of 0.22 and capacity of 3,334. This compares to a productivity of 1.288 and an average abundance of 799.

Productivity and capacity parameters are jointly estimated in stock-recruitment analyses. Many combinations of pairs are similarly plausible but higher values of productivity correspond to lower values of capacity (Figure 52). Both sets of parameters produce generally similar risk assessment results (Figure 53). Therefore, the higher productivity parameter estimated by the HGMP comes at the cost of a lower equilibrium value and this tradeoff is a wash relative to risk level.

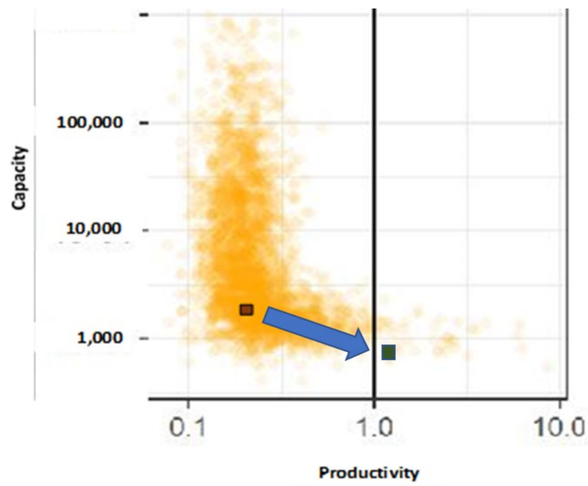

Figure 52. Likely values of productivity and capacity displayed on samples from the joint posterior distribution. The vertical line is at a productivity of 1 (replacement). The red square are the values in the analysis. The blue square is an alternative pair of parameters previously identified by a Hatchery Genetic Management Plan.

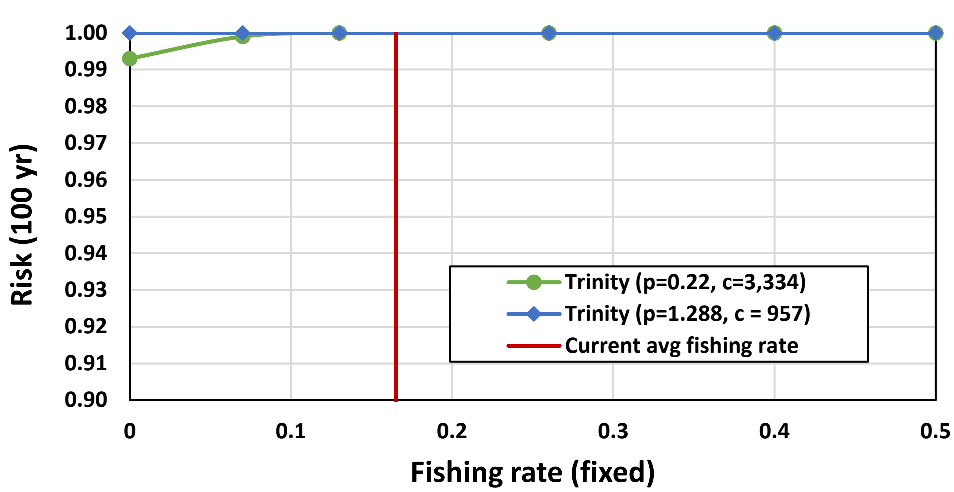

Figure 53. Sensitivity of low run size risk to alternative productivity and capacity parameters for the Trinity population of coho.

Discussion

This analysis provided a systematic quantitative means of evaluating conservation risks and fishery tradeoffs associated with alternative fishing levels and strategies defined by a series of harvest control rules. The stochastic population viability model used in this analysis estimated "quasi extinction" risks defined by the probabilities of falling below prescribed critical risk thresholds due to the combined effects of inherent productivity and capacity of a population, normal variability in productivity and survival, and fishing. A performance measures defined by low-run-size risk is intended by design to provide a conservative standard for fishery assessments of weak, listed stocks and populations of salmon.

Low run size risks generally increase with increasing exploitation rate but the response profile varies substantially depending on the inherent productivity and capacity of a population.

- Small and/or unproductive populations (e.g., Shasta, Bogus and Trinity) are at high risk regardless of exploitation rate. Whether or not these severely-depleted population can persist over the long term is largely independent of the impact of limited fishing rates.
- More productive populations, such as Freshwater Creek, are not particularly sensitive to low rates of exploitation (<20%). This is a classic example of a *de minimis* fishery situation where low exploitation rates do not impact enough fish to produce a significant influence on long term viability.
- Populations of intermediate size and/or productivity (Rogue and Scott) are somewhat sensitive to exploitation rates in the 0–20% range. These populations are the most sensitive indicators of the risk response of SONCC coho to the effects of alternative harvest control rules.

The analysis examined the effects of both fixed and abundance-based harvest control rules. Abundance-based management allows for greater exploitation rates in large run size years in exchange for lower exploitation rates in small run size years. The analysis confirmed that abundance-based rules can provide significant fishery benefits in years of large run sizes. Fishery benefits may provide increased management flexibility to access other salmon species and stocks in mixed stock fisheries, as well as some opportunity for direct harvest benefit. Fishery benefits for a given level of low run size risk were typically greater in ABM HCRs than for a fixed rate HCR with equivalent risk (but see Appendix C). This is because the fishery value of greater fishing on large runs far exceeds the foregone value of reduced fishing on small runs. This is only true where fishery value is measured primarily in harvest of SONCC coho. Further constraints to reduce exploitation rates of SONCC coho might potentially result in significant costs due to foregone fishing opportunity for other stocks in mixed species or stock fisheries.

Analyses of ABM HCRs in this report are examples which illustrate the potential value of these strategies if run size of SONCC can be reasonably forecast. At this time, it remains unclear whether run size of SONCC can be forecast with reasonable confidence. Limitations include a lack of robust indicators and uncertainty in whether indicator data such as brood year jack returns of natural-origin coho would be available in time to inform annual management decisions. A matrix-based HCR may provide some of the benefits of both the constant HCRs and the ABM HCRs with fewer challenges. However, the analysis of the matrix-based HCR is not yet complete.

The analysis considered harvest control rules defined by total and ocean-only exploitation rates. Risk calculations required estimates of total exploitation rates that included both ocean and freshwater fisheries. Therefore, simulations of ocean-only rules also assumed freshwater exploitation rates for each population based on recent annual averages documented from run reconstructions in this report. The analysis makes no assumption regarding any future allowances or allocation of exploitation among the various fisheries. It incorporates fishery-specific rates only to represent the net effect of fishing on low run size risks. Similarly, the analysis makes no judgement or assumption regarding an appropriate historical baseline for comparison of alternative harvest control rules. Analyses of fixed rate alternative include a broad range which encompasses both the recent average ocean exploitation rate (~6%) and the current consultation standard (13%).

Analyses of HCRs were based on six natural SONCC coho populations or population aggregates for which stock-recruitment data were available. Several of these are subject to substantial hatchery influence. Information is not available to assess how representative these SONCC populations are of the entire ESU. Therefore, the work group also examined population parameters for Oregon Coast Natural and Lower Columbia River Natural coho populations in order to provide some context for interpretation of the limited SONCC coho data. SONCC coho populations appear to be relatively small and unproductive relative to these other coho populations. For risk analysis purposes, SONCC coho populations exhibited a range of productivities and capacities, and produced a range in risk profiles to fishing suitable for use in the population viability analysis.

Risk profiles are highly sensitive to estimates of population productivity. Stock-recruitment relationships of SONCC coho are poorly described by the available data, likely due to inherent variability and the limitations of stock assessments for coho. Analyses were based on a Bayesian state space hierarchical model and a hockey-stick function. These methods have been observed to produce reasonable parameter values in other estimates of messy data. Uncertainty in parameter estimates is also quantified and propagated in the model's stochastic risk calculation structure.

The analysis explored the sensitivity of results to a concurrent vs. disaggregated-independent modeling approach (Appendix C) and included a variety of sensitivity analyses to input parameters to explore key uncertainties. These included effects of hatchery-origin spawners in natural populations, forecast and fishery implementation errors, and alternatively plausible combinations of productivity and capacity parameters. Analysis considered a range of values identified based on other Pacific Northwest coho fisheries.

Hatchery fish spawning in the wild provided a continuing demographic subsidy which reduced low run size risks for populations where the percentage of hatchery origin spawners was significant. Populations with substantial pHOS were also characterized by low productivity values. Wild population parameters are assumed to represent historical influences of hatchery fish on wild population productivity. Any changes in hatchery contributions or wild population productivity resulting from future changes in hatchery production or harvest strategy are not captured in the analysis. While it is computationally simple to simulate hatchery strays, assumptions regarding their effects on population productivity over time would be highly subjective.

Risk profiles were generally found to be relative insensitive to the magnitude of run size forecast or fishery implementation errors. Impacts of greater fishing rates in some years appear to be offset by the benefits of lower fishing rates in others within the relatively low range of exploitation rates considered by the harvest control rules.

While the risk analysis provides absolute estimates of low run size probability, the most robust application of this analysis will be in comparisons of the relative effects of alternative control rules. This is because the analysis includes a variety of explicit and implicit assumptions regarding population dynamics and parameters which can affect the absolute value of estimated risks. However, comparisons of the relative effects of fishing strategies will be hypothetically less sensitive to assumptions that affect all strategies in common.

8. SUMMARY

- This report represents a preliminary analysis of 11 HCRs for SONCC coho. The range of HCR forms include constant ER control rules and abundance-based ER control rules. The analytical work evaluating these HCRs will continue to be refined following guidance from the Council and its advisory bodies. The Workgroup has also begun an analysis of a matrix-based HCR (HCR 12).

- Information on natural production of SONCC coho is limited to six wild populations, population components, or population aggregates, some of which are subject to substantial hatchery influence. The Workgroup also examined population parameters for OCN and LCN coho populations in order to provide some context for interpretation of the limited SONCC coho data. SONCC coho stocks are generally at low levels of equilibrium abundance and moderate levels of productivity relative to OCN and LCN coho populations.

- A risk assessment modeling approach was applied to each control rule to evaluate their relative performance. The risk assessment approach is based on a quantitative population viability analysis which uses stock-recruitment data for Southern Oregon/Northern California Coast (SONCC) coho populations. The Council has implemented similar modeling approaches for other stocks, including Klamath Fall Chinook, Lower Columbia River Fall Chinook, LCN Coho, and Sacramento River Winter Chinook.

- The analysis considers performance measures for conservation (spawning escapement, and extinction risks) and fishery performance (exploitation rate and harvest of SONCC coho).

- The Shasta, Bogus and Trinity population units are all at high risk regardless of fishing rates due to their low productivity and/or capacity, critical risk threshold levels, and quasi-extinction threshold levels. Freshwater Creek is more resilient relative to the other population units. The Rogue and Scott rivers are intermediate between the Shasta, Bogus, Trinity group and Freshwater Creek with regard to sensitivity of extinction risk due to the effects of fishing.

- Risk assessment model results suggest that abundance-based strategies may produce greater fishery benefits than constant rate strategies at equivalent risk levels. However, a preliminary analysis using a modified risk assessment approach that models individual population units concurrently rather than individually was used to evaluate aggregate abundance-based HCRs. Results of this analysis suggest that quasi-extinction risk and experienced exploitation rates could be higher if population units are correlated and are modeled concurrently. The Workgroup plans to further discuss how the risk analysis results are sensitive to these variations in model structure.

- Abundance-based control rules require annual abundance forecasts for SONCC population components. An assessment of abundance forecasting potential indicated a limited number of moderate or strong statistical associations between ocean abundance and predictor variables. The assessment of abundance forecasting feasibility noted uncertainty about the future dependability and annual timing of data, particularly for the California populations.

The results of this evaluation is relevant to questions regarding whether abundance based control rules could be implemented in practice.

- The risk assessment requires information on total exploitation rates to assess conservation and fishery effects of the candidate control rules. In the evaluation of ocean-only ER control rules, recent year averages of freshwater exploitation rates were assumed. If these rates are not representative of future freshwater exploitation rates, the fishery and conservation outcomes could be quite different than expected. While this effect may be most pronounced for the ocean-only ER control rules, the assumptions about the extent and magnitude of freshwater fisheries affects all control rules considered here.

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10.APPENDICES

Appendix A: Workgroup Terms of Reference

Southern Oregon/Northern California Coast Coho Fishery
Ad Hoc Technical Workgroup
Terms of Reference and Timeline

(June 16, 2020)

1. Purpose

Develop a proposed harvest control rule for the Southern Oregon/Northern California Coast (SONCC) Coho Evolutionarily Significant Unit (ESU) for Pacific Fishery Management Council (Council, PFMC) consideration that would:

- allow fishing on abundant salmon stocks while not impeding the recovery of SONCC coho;
- establish harvest control rules in the form of fixed or tiered exploitation rates including consideration of control rules which reduce exploitation rates at low abundance levels, and which may include minimum or target spawner levels;
- assess a range of control rules including marine and freshwater fisheries combined, the marine and freshwater fisheries components, and marine fisheries only, affecting SONCC coho as appropriate, given potential data limitations, and what is feasible to accomplish within the timeline described below;
- evaluate the feasibility of considering the status of subcomponents of the ESU (e.g., Klamath and Trinity Rivers), marine and freshwater environmental conditions and other relevant factors as appropriate and as supported by the data available (similar to the Oregon Coast Natural coho salmon matrix).

2. Membership

- The Council will establish an Ad Hoc SONCC Coho Technical Work Group (Workgroup, WG).
- Membership will include technical representatives from:
    - Pacific Fisheries Management Council
    - NMFS West Coast Region (WCR)
    - NMFS Northwest Fisheries Science Center (NWFSC)
    - NMFS Southwest Fisheries Science Center (SWFSC)
    - U.S. Fish and Wildlife Service
    - Yurok Tribe
    - Hoopa Valley Tribe
    - California Department of Fish and Wildlife
    - Oregon Department of Fish and Wildlife
    - Contractors as deemed necessary or suggested by Workgroup participating entities

- The Workgroup will choose from among its members a Chair and a Vice-Chair. The Vice-Chair will act in instances where the Chair is unavailable. The Council will be responsible for administrative and logistical support.

3. Milestones

- Collect and summarize relevant information regarding the status of SONCC coho, biological characteristics, magnitude and distribution of fishing mortality, and marine and freshwater environmental indicators.
- Develop a range of alternative harvest control rules.
- Analyze the biological risks and fishing related benefits of the alternative control rules.
- Assist the Council with developing a preferred harvest control rule alternative that can be recommended for adoption by the Council and to NMFS for ESA review within 18 months from the Workgroup's initial meeting.
- Consult with the Council's Scientific and Statistical Committee (SSC) and Salmon Technical Team (STT) on the analytical methods used to evaluate draft alternatives. The Workgroup may consult with other Council Advisory Bodies and Technical Committees as necessary or as directed by the Council.

4. Timeline

- Pre-meet: Presentation of TORs and timeline at the April 2020 Council meeting
    - Council decides by May 31, 2020 whether to consider a process to develop the SONCC control rule and initiate Workgroup
- Pre-meet:
    - preseason abundance forecast feasibility meeting with WCR and SWFSC (Workgroup already in place);
    - invitations sent to participating parties;
    - NMFS (WCR, NWFSC & SWFSC) staff participants assigned and ready to engage (likely 4-6 technical staff [2-3 from the region and science center respectively, or potential contractors] successful implementation will require permanent staff to engage and carry through into the future);
    - FR notice of time/location of first Workgroup meeting finalized (Council staff); Workgroup meetings will be open to public.

- June 2020: initial first meeting (on-line)
    - introductions;
    - discussion/agreement on purpose of group (as defined by the Council);
    - establish ground rules and operating procedures;
    - develop proposed timeline;
    - group selection of Chair and Vice-Chair;
    - approve final Terms of Reference for Council endorsement
    - coordination/outline of tasks;
    - discussion/catalog of current control rules and status information available;

- establish criteria for alternative control rules (e.g., acceptable risk to ESU, distribution among populations or tributaries);
- discussion of potential methods to evaluate alternative control rules;
- discussion of potential development of abundance forecasts methods and a river harvest model; identify data gaps, estimate workload and timeline needed to complete.
- group assignment to address data gaps, and suggested alternate control rules, and investigate potential forecast/model development for discussion at next meeting;
  - define/assign specific tasks and products expected with due date
- date/location confirmed for next meeting, FR notice of time/location (Council staff).

- August 2020: second meeting (on-line)
  - updates/additional population information provided to address data gaps identified at June (first) Workgroup meeting;
  - group discussion of harvest control rule alternatives and the data necessary (e.g., forecast dependent, data used for environmental variables, stock subcomponents) for each are identified; potential alternatives are narrowed if possible,
  - group assignment to begin drafting analysis of each potential control rule, due prior to the November (third) Workgroup meeting;
  - date/location confirmed for next meeting, FR notice of time/location (Council staff).

- October 2020: third meeting
  - options for current forecasting/escapement methodology presented (if so – the following bullets are pushed to June 2021; if not – disregard this bullet);
  - draft analysis report (risk assessment) for proposals presented to Workgroup indicating relative risk of each potential harvest control rule (HCR) identified in second meeting to ESU (and other criteria, e.g., acceptable risk on the relative strength of the various contributing populations such as Trinity River Basin populations, environmental indicators);
  - discussion if suite of alternatives is adequate/possible revision of alternatives,
    - IF HCR alternatives are added based on initial draft report, these items will all repeat during next meeting;
  - discussion/questions of analysis for each HCR alternative;
  - Workgroup assignment to update draft risk assessment accordingly per discussions;
  - Workgroup assignment to present HCR alternatives and draft risk assessment report to each parties' respective constituency; schedule meeting to present to Council's Model Evaluation Workgroup (MEW), Salmon Technical Team (STT), and Council's Scientific and Statistical Committee (SSC) for methodology and analytical reviews as necessary; meetings to occur prior to, or during the November 2020 Council meeting;
  - Prepare document with range of alternatives, preliminary recommendation and draft report for Chair and Vice-Chair to present Workgroup report to the Council at the November 2020 Council meeting;
  - date/location confirmed for next meeting, FR notice of time/location (Council staff).

- January 2021: fourth meeting (on-line)
    - discuss input received from Council presentation and parties' constituencies
        - update alternatives per discussions and input from SAS, SSC, and other tribal or state input sources outside Workgroup;
    - group assignment to revise report for updated alternatives per external recommendations;
    - group assignment to present alternatives and revised report to each parties' respective constituency in time to present for March or April Council meeting

- April 2021: fifth meeting
    - Schedule meeting to present to Council's Salmon Advisory Subpanel (SAS) and other advisory bodies as necessary in preparation for April 2021 Council meeting;
    - Chair and Vice-Chair presents Workgroup recommendation to the Council for consideration in selection of a preliminary preferred alternative;
    - date/location confirmed for next meeting, FR notice of time/location (Council staff).

- June 2021 webinar : sixth meeting
    - Consider additional guidance provided at the April 2021 meeting
    - Group assignment to revise report for updated alternatives per external recommendations;
    - group assignment to present alternatives and revised report to each parties' respective constituency in time to present for September 2021 Council meeting.

- October 2021: seventh meeting
    - Discuss final alternatives for public review and comment (September if necessary);

Prepare for November 2021 Council meeting: draft Workgroup report for Chair and Vice-Chair to provide to the Council for adoption of final preferred alternative recommendation. Council transmits recommendation to NMFS via signed letters for Section 7 consultation.

Appendix B: Estimation of Natural-Origin SONCC Coho Ocean Recruits, Fishery Impacts, and Exploitation rates

Estimates of age-3 recruits for various components of the SONCC coho salmon ESU are needed for estimation of productivity and capacity as described in Section 7. Here, recruits (R) are defined as the abundance of age-3 fish prior to exposure to ocean fisheries in the year of river return. They represent the total number of age-3 fish, of a particular origin, that spawned in freshwater, died in freshwater fisheries, or died in ocean fisheries.

Estimates of ocean and freshwater fishery exploitation rates are needed for the estimation of recruits and to inform other aspects of the workgroup process, such as the design of control rules.

Methods used to estimate recruits, escapement, freshwater fishery impacts, and exploitation rates for natural-origin SONCC population units are described below.

Ocean age-3 recruits

Ocean age-3 recruits are estimated by expanding the river mouth return of age-3 coho (M, the sum of escapement and freshwater fishery impacts) by the ocean exploitation rate (F): $R = \frac{M}{(1-F)}$.

Escapement

For Klamath River natural population units (Bogus Creek, Shasta River, and Scott River) escapement is estimated by summing natural-origin escapement to their respective watersheds and the number of fish that originated in those watersheds that strayed into Iron Gate Hatchery (IGH). We estimated the number of fish that were likely to have strayed to IGH on the basis of the proportion of IGH-origin fish that strayed into the respective watersheds. This assumes, for example, that the high stray rate of IGH-origin fish to Bogus Creek would translate into the converse: a high stray rate of Bogus-origin fish into IGH. To account for natural-origin Trinity River coho that strayed into TRH, we assumed that all natural-origin coho that escaped to TRH were of Trinity River origin.

Freshwater fishery impacts

Natural-origin SONCC coho populations in the Klamath Basin can be exposed to tribal fisheries in the lower Klamath and Trinity rivers. There are also data on recreational harvest of coho in the Klamath and Trinity rivers that are the result of illegal catch (coho fisheries have been prohibited by the state of California since 1996). River harvest in Yurok tribal fisheries and Klamath River recreational fisheries is of mixed stock. Natural-origin fish caught in these fisheries likely include contributions from the Trinity natural population, Scott River, Shasta River, Bogus Creek, and other population units that are not regularly monitored. To estimate the composition of the natural-origin harvest in the Yurok tribal and lower Klamath River recreational fisheries, the harvest of natural-origin fish was apportioned to the Trinity, Scott, Shasta, and Bogus components on the basis of their relative escapement levels, after accounting for the portion of unmonitored stocks in the Basin (estimated to be 22 percent). Natural-origin fish caught in Hoopa tribal fisheries and Trinity River recreational fisheries were assumed to be of Trinity River origin. Dropoff mortality rates are applied to tribal and recreational harvests to provide estimates of impacts. Dropoff mortality rates are assumed to be 8.70 and 2.04 percent for tribal and recreational fisheries, respectively, following the convention used by the Klamath River Technical Team for fall Chinook salmon (e.g., see KRTT 2021). Total freshwater fishery impacts are the sum of impacts in all fisheries that each population unit encounters.

There are no fisheries in Freshwater Creek. For the Rogue River, direct estimates of freshwater sport fishery handling and impacts on natural coho are not available because retention is prohibited. Limited catch information is available from historical creel surveys and catch record cards which are voluntarily returned by anglers. Based on this limited information, we estimated that incidental mortality (hooking and dropoff) is likely less than five percent per year. This estimate is similar to numbers identified by ODFW for other Oregon coastal coho populations.

<u>Exploitation rates</u>

Ocean exploitation rates were estimated using the Fishery Regulation and Assessment Model (FRAM) as described in Section 4. Freshwater fishery exploitation rates for individual stock unit s are estimated by dividing stock-specific fishery impacts (from all pertinent freshwater fisheries) by the reconstructed age 3 abundance: $\mathrm{ER}_s = \frac{I_s}{R_s}$. Exploitation rates for individual fisheries can be estimated by substituting total impacts in the previous equation with fishery-specific impacts.

Reference

KRTT (Klamath River Technical Team). 2021. Klamath River Fall Chinook Salmon Age-Specific Escapement, River Harvest, and Run Size Estimates, 2020 Run. Available at https://www.pcouncil.org/

Appendix C: Assessment of Disaggregated-Independent vs. Concurrent Modeling of Aggregate Harvest Control Rules

In the real-world application of aggregate HCRs, forecasts are generated for each subcomponent, abundance values are summed to determine abundance for the aggregate, and the allowable harvest rate is determined and set for the forthcoming fishing season. In contrast, the Risk Assessment's (RA) population modeling framework presently allows for the simulation of only one population at a time (i.e., using a single set of stock-recruit parameters) and thus cannot replicate this scenario exactly. Assessments of HCRs 8-11 were therefore conducted using an approach that attempts to approximate the more realistic concurrent modeling situation. That is, the aggregate abundance *x*-axis for each HCR function was disaggregated into the fractional contribution attributable to each component population, and then applied in separate population simulations (hereafter, the 'disaggregated-independent' approach).

While this approach allowed the Workgroup to conduct an initial set of simulations for all abundance-based HCRs, some members of the workgroup were concerned that the disaggregated-independent approach may not accurately mimic the fishery and population dynamics of the more realistic concurrent modeling approach. To answer the question of 'does it matter?' a side-modeling exercise was undertaken using an adaptation of the RA modeling framework[7] that allowed for both concurrent and disaggregated-independent modeling of HCRs to understand the potential effect of disaggregated-independent simulation on quasi-extinction probabilities, as well as the mechanisms underlying any perceptible differences.

Using this adapted RA modeling framework, the HCR with the greatest level of aggregation (HCR 10) was evaluated in two separate runs, one using a disaggregated-independent and the other using a concurrent simulation approach. Additionally, to better address 'does it matter?', simulations using a fixed-rate HCR (HCR 3, 13% total ER) were also conducted to provide a reference point/context. Model parameters used in simulations were based on those presented in Chapter 6 (HCRs) and 7 (demographic parameters, stochastic components, etc.) and quasi-extinction risk [Prob(QE)] under each HCR was assessed for each population based on the outcome of n = 500 simulations of 100 years in length.

This analysis revealed the following important results:

(1) Applying HCR 10 independently for each population in separate simulations (i.e., disaggregated-independent) in effect allows harvest to respond to changes in abundance for individual populations in a manner that it does not for the more realistic, concurrent modeling application (Figure C1). Conversely, the realized aggregate-level exploitation rate responds to changes in aggregate abundance under the concurrent modeling approach, whereas it does not for the disaggregated-independent approach (Figure C2). Said another way, disaggregated-

[7] Note that while this adaptation of the RA model allowed the workgroup to explore the sensitivity of results to the concurrent vs. disaggregated-independent modeling approaches, it differs in some ways and thus provides estimates of Prob(QE) that differ for some populations relative to those presented in Chapter 7.

independent modeling of HCR 10 generates results that are more consistent with weak-stock management than aggregate management.

(2) It logically follows that a simulation approach (disaggregated-independent) that more closely approximates weak-stock management than true aggregate management will present lower levels of risk. The Prob(QE) levels generated under the two different approaches show this to be the case (Figure C3). Quasi-extinction risk levels (20, 100 year) generated using the disaggregated-independent approach were approximately 50-60% of the values produced by in concurrent simulations. Moreover, the difference quasi-extinction risk resulting from the concurrent vs. independent/disaggregated simulation of a given HCR were large enough to change the rank order of risk for HCR 10 relative to fixed-rate HCR 3. In other words, disaggregation may affect results sufficiently to support different conclusions about how HCRs rank in terms of risk relative to one another.

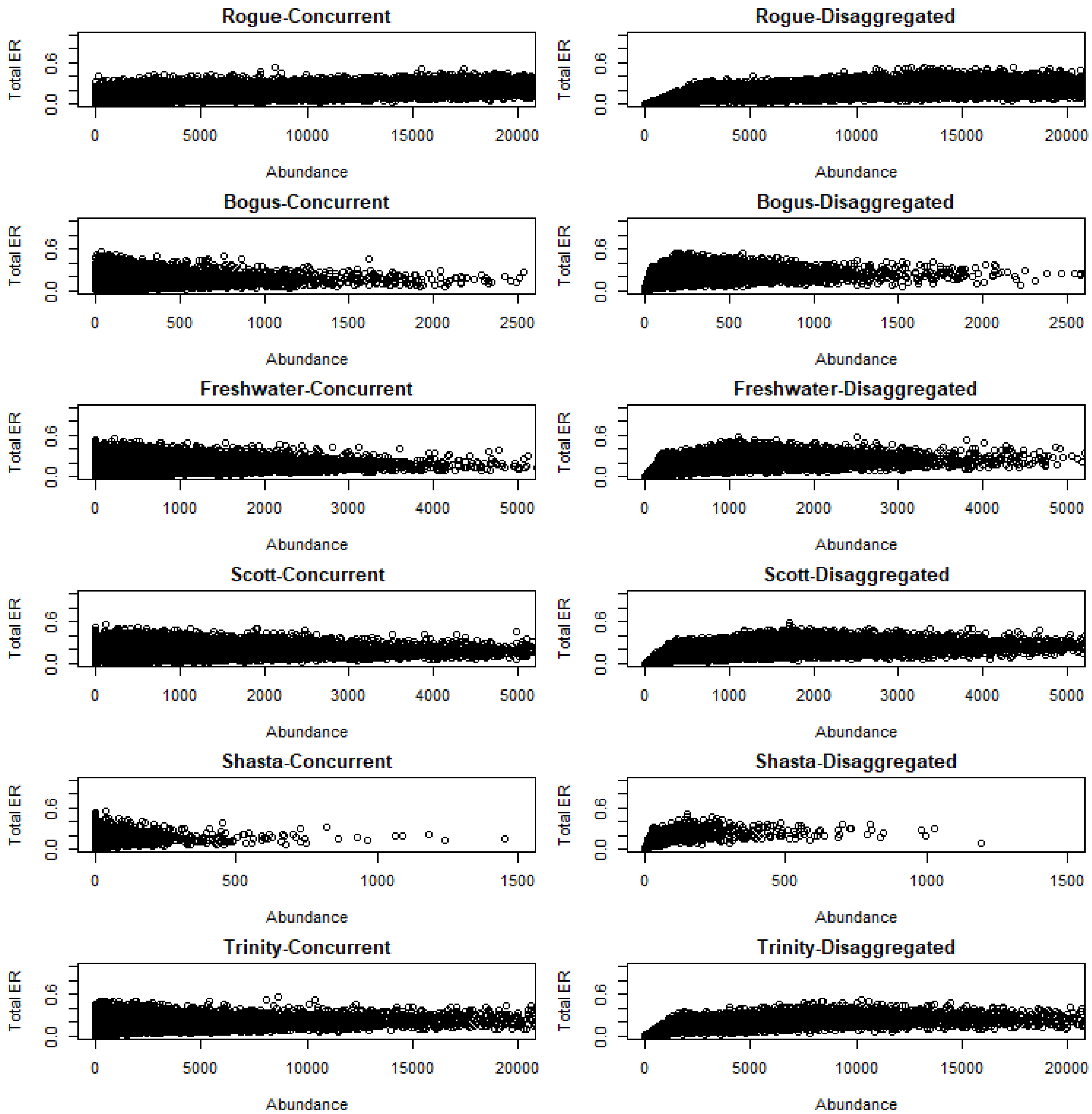

Figure C1. Plot of total exploitation rates (ER) applied to each population under a concurrent (left column) and disaggregated-independent (right column) modeling approach under HCR 10.

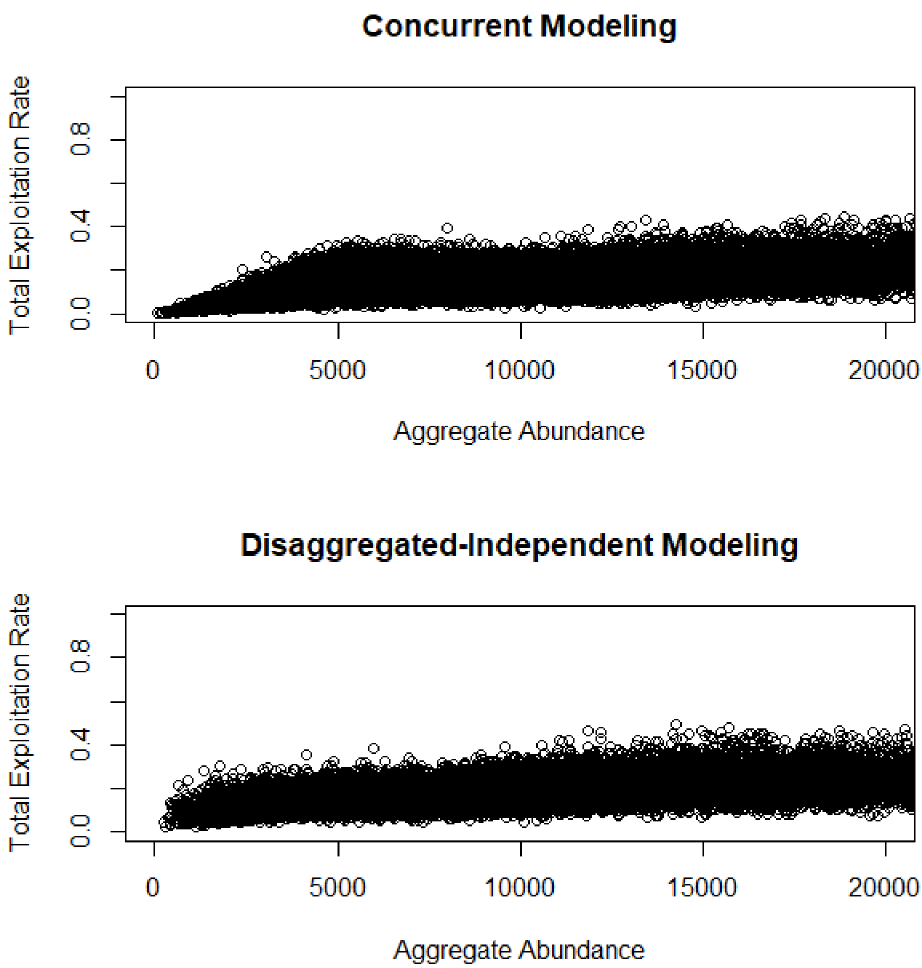

Figure C2. Plot of allowed/realized total exploitation rates relative to aggregate abundance for concurrent (top) and disaggregated-independent (bottom) modeling approaches under HCR 10.

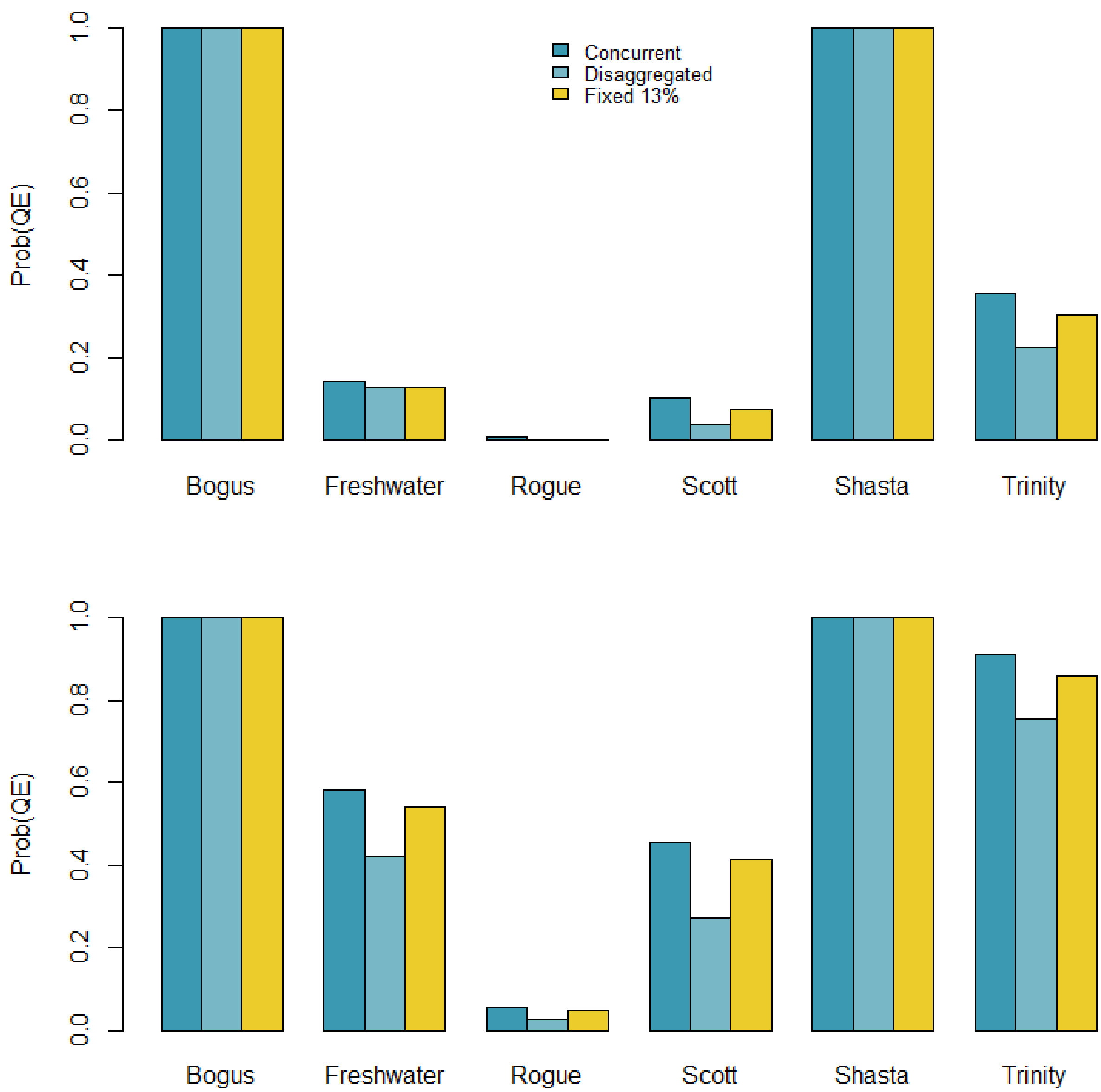

Figure C3. 20-year (upper panel) and 100-year (lower panel) quasi-extinction risk (Prob(QE)) for each population under a disaggregated-independent vs. concurrent modeling approach for HCR 10. The results for a fixed-rated HCR, 13% (HCR 3), are also provided as a reference.