CEDAR COAST
FIELD STATION

Stream-level Population Assessment of Salmon on the West Coast of Vancouver Island and Clayoquot Sound

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Chum, Coho, and Chinook salmon waiting to spawn. Photo: Shayne Stadnick

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Clayoquot Sound coastline. Photo: Mack Bartlett

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- Rowen Monks

Photos: Mack Bartlett & Shayne Stadnick
Salmon Illustrations: Rowen Monks

Foreword

Cedar Coast Field Station is an ecological monitoring research station based in Clayoquot Sound, BC. Cedar Coast monitors Pacific salmon at juvenile and adult stages through field research and data analysis. Cedar Coast began monitoring Pacific salmon in 2017 and has since provided annual reports of pathogens affecting juvenile Pacific salmon, in Clayoquot Sound. The following report expands the Cedar Coast assessments to the state of adult stages of Pacific salmon stocks in West Coast Vancouver Island (WCVI). The state of Pacific salmon in Clayoquot Sound was assessed in response to reports of declines in wild stocks and observations of high rates of parasitism on juvenile salmonids.

A Chum salmon post-spawn. Photo: Mack Bartlett

Summary

- According to the Wild Salmon Policy (DFO, 2005), the conservation of wild salmon stocks is the guiding principle for resource management. However, management is often informed and applied at a coarse scale which may be missing aspects of the overall status of salmon stocks. A finer scale assessment may offer a chance to better understand and address the stressors affecting diverse wild salmon stocks at the stream-level. However, finer scales are resource intensive and data are limited.

- To contribute effort to finer scale status assessments, we conducted status assessments on individual stocks, for each documented stream. The following status assessments use Fisheries and Oceans Canada (DFO) data, apply DFO status assessment methods using two kinds of spawner abundance indicators, and include a resilience indicator (Atkinson et al., 2020).

- We provided assessments of WCVI as a whole with a focus on Clayoquot Sound, where Cedar Coast Field Station is based. **Our stream-level assessments indicated that most stocks are Data Deficient and Data Limited; their status is unknown.**

- **Stream monitoring has declined to an all-time low. The main stocks with sufficient data are larger and often host hatchery stocks.** This pattern can introduce bias into assessments where regions may be largely based on these "indicator" stocks.

- The two spawner abundance indicator approaches - percentile and stock-recruit benchmarks had very different proportions of Red, Amber, and Green statuses. We deferred to the percentile approach as it had fewer data requirements, allowing assessment of more stocks and more recent status assignments.

- Using the percentile approach across WCVI, most stocks with sufficient data showed an Amber status, closely followed by Red. **Chum have the greatest number of stocks across WCVI and the greatest proportion of Red status stocks, followed by Amber.**

- In Clayoquot Sound, most stocks that had data available for a recent percentile status assignment were Red, followed by Amber. WSP defines Red status stocks as those at a higher risk of extirpation, needing immediate conservation measures and a high degree of management intervention.

- Across WCVI, most stocks with sufficient data had high intrinsic productivity, suggesting that resilience may be high enough that stocks could improve if released from stressors.

- **The status assignments given by this report suggest that immediate conservation measures are required for salmon stocks on WCVI and Clayoquot Sound.**

- Further investigation into the causes of the recent declining trends may support effective conservation and restoration of WCVI Pacific salmon. Increases in monitoring of smaller stocks and in accessibility of stock data (ex. harvest rates and age at maturity) may promote more responsive, holistic management.

Introduction

In British Columbia, wild salmon create foundations for life on the west coast of Canada. Pacific salmon offer food security (Nesbitt & Moore, 2016), nourish forests (Helfield & Naiman, 2002), feed numerous species, and contribute to commercial and recreational fisheries (Crutchfield & Pontecorvo, 2013). Pacific salmon are keystone species (Helfield & Naiman, 2006), meaning that the abundance of salmon populations has a disproportionately large effect on coastal species, communities, and ecosystems. Further, Pacific salmon are culturally significant to many coastal Indigenous nations in BC (Gerwing & McDaniels, 2006).

The Indigenous peoples of Western North America steward wild Pacific salmon and have done so since time immemorial. Productive salmon populations support First Nation communities and culture (Trosper, 2003). Because of this relationship, harvesting salmon is a critical right to Indigenous peoples in BC. Due to the importance of Pacific salmon to coastal communities, management of Pacific salmon involves input from many stakeholders. Assessments of the state of Pacific salmon populations inform stewards, stakeholders, and the resultant management decisions.

Numerous natural and human-induced stressors accumulate to contribute to low returns of wild salmon runs on the West Coast of Vancouver Island, WCVI (Crozier & Siegel, 2017; Daly & Brodeur, 2015; Grant et al., 2019; Macdonald et al., 1998; Malick & Cox, 2016; Peterman & Pyper, 2000; Withler et al., 2018). Relatively few recent Wild Salmon Policy (WSP) status assessments of WCVI Pacific salmon are available with reference to specific populations (DFO, 1999, 2002, 2016; PSC, 2021; Riddell & Beamish, 2003). Of these, stock assessments are often limited to a few, major, indicator populations. As with other WCVI management areas, the status of the different Pacific salmon populations in Clayoquot Sound have not been assessed for public review, at the stream-level. In this report, we refer to stream-level populations as stocks: groups of species-specific salmon whose majority return to the same stream or lake, at the same time, to spawn. A major goal of WSP is to protect the genetic diversity of wild salmon populations (DFO, 2005). This report was prepared to offer a review of the historical to present population trends, up to the stream-level for available data in Clayoquot Sound. At the stream-level view we offer a snapshot of the state of salmon in Clayoquot. The report and supplementary material include data and an analysis framework for the assessment of the seven management areas on the WCVI. Review of the other seven management areas may be found in future reports.

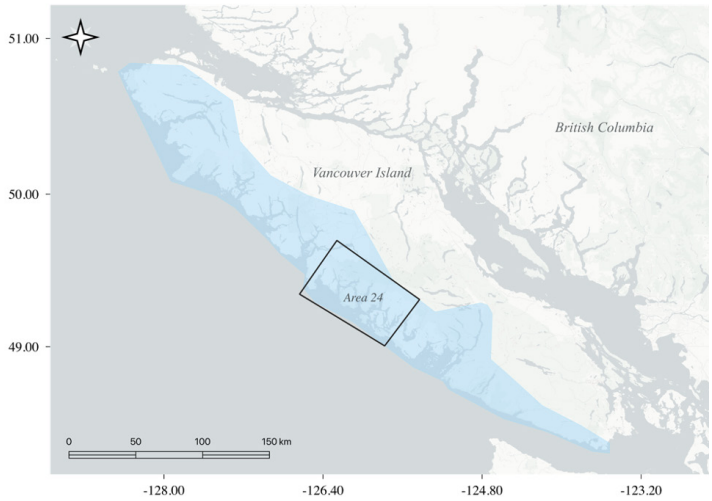
Assessment Location

The following study takes place in the territories of Kwakwaka'wakw, Nuu-chah-nulth, and Coast Salish First Nations, the sovereign managers of the lands and waters of WCVI and beyond. Within these nations are the territories of at least 21 First Nations which contain Fisheries and Oceans Canada (DFO) fisheries management areas over WCVI (Table 1, Map 1). Table 1 is an over-simplification of the complex boundaries and ongoing discussion of delineations of First Nations territories, meaning Table 1 is incomplete and likely incorrect. The communities and territories of these nations extend past the geographical or management boundaries imposed by the federal government.

The following study focuses on data associated with the boundaries of Area 24 which is contained within the Nuu-chah-nulth Hahoulthee (territory). The Nuu-chah-nulth First Nations include at least 14 nations. Aquatic resource management, research, and services are advanced by the Nuu-chah-nulth founded organization, Uu-a-thluk, and each Nation's fisheries programs.

Table 1. Indigenous territories and Pacific Fishery Management Areas that were included in this assessment range from Areas 20 – 27 on the WCVI.

First Nations	Area	Fisheries Management Area Boundaries
Kwakwaka'wakw : Quatsino	27	Solander Island, Cape Scott
Kyuquot/Checleseht	26	Union Island, Solander Island
Mowachaht/Muchalaht, Ehattesaht, Nuchatlaht	25	Nootka Sound, Esperanza Inlet
Tla-o-qui-aht, Ahousaht, Hesquiaht	24	Cox Point, Estevan Point
Huu-ay-at, Tse-shaht, and Uchucklesaht, Hupacasath, Toquaht, Yuu-cluth-aht	23	Cape Beale, Ucluelet
Ditidaht, Huu-ay-aht	22 and 21	Tzuquanah Point, Nitinat Lake
T'Sou-ke, Scia'new, Pacheedaht	20	Sooke, Bonilla Point Lighthouse



Map 1. The assessment of Pacific salmon populations covers the West Coast of Vancouver Island. The following report offers a more in-depth review of stream-level findings for Area 24.

Background

Life History of Pacific Salmon

To properly introduce assessments of salmon stocks, we start with an introduction on the life history of Pacific salmon. Pacific salmon are anadromous and semelparous, meaning they migrate between freshwater and saltwater, and end their life after reproduction. Pacific salmon begin and end their lives in freshwater streams and lakes where spawning occurs. Young salmon hatch from their redds dug by adult salmon (spawners) the previous fall and spend varying amounts of time in freshwater before migrating to the open ocean. Depending on the species and intra-species variation in life history, Pacific salmon may spend one to seven years in the marine environment. Once reaching sexual maturity, Pacific salmon return to the streams where they hatched, to spawn and die, completing the cycle. At each life stage, Pacific salmon are subjected to different stressors which affect their abundance and productivity.

Monitoring of Pacific Salmon Stocks

Some declines in salmon stocks began in parts of Southern BC before the development of DFO monitoring programs in the 1950s (Price et al., 2019). Readily available data on WCVI Pacific salmon, from before 1950 are relatively sparse, making it difficult to trace the state of WCVI stocks before the 1950s. One monitoring method is the enumeration of adult salmon returning to their natal streams (escapement). Enumeration methods include creek walks, counting fences, sonar devices, helicopter flyovers, drones, and snorkelling (DFO, 2020b). Escapement estimates are used as a metric of abundance. Abundance metrics convey trends in population stability over time. However, DFO typically provides large-scale assessments (Wade et al., 2019). Large-scale assessments cover Conservation Units (CU) which are defined as groups of stream-level stocks that are likely able to repopulate each other if one stock is extirpated. These CU assessments are less resource-intensive for management structures. Further, for salmonid species with higher straying rates like Pink salmon (Quinn, 1984), CU assessments may offer a more useful estimation of the health of the associated stream-level populations. To supplement large-scale assessments with a narrower focus, we will consider populations at the stream-level.

Long-term datasets on escapement in WCVI can show long-term trends. Although 1950 - 2020 is a short window relative to the history of our harvest and impacts on salmon, it offers a useful perspective. Long-term trends are useful for tracking, understanding, and isolating individual effects of human impacts on stocks. This greater understanding of human impacts yields useful recommendations for management of Pacific salmon populations. Further understanding can come from different scales of monitoring.

Human impacts exist on different scales. At the stream-level scale, the history of impacts on a stock from a given stream may be more easily correlated with the trends in abundance. However, DFO typically provides large-scale assessments (Wade et al., 2019). Large-scale assessments cover Conservation Units (CU) which are defined as groups of stream-level populations that are likely able to repopulate each other if one population is extirpated. These CU assessments are less resource-intensive for federal and provincial management structures. Further, for salmonid species with higher straying rates like Pink salmon (Quinn, 1984), CU assessments can offer a useful estimation of the health of the associated stream-level populations. To supplement large-scale assessments with a narrower focus, we will consider populations at the stream-level.

Assessments at larger scales may over-generalize our understanding of the state of

wild Pacific salmon. Smaller scale population assessments provide a closer look at trends in individual stocks. In the face of declines, the genetic diversity found in many stocks is important for the resilience of wild Pacific salmon.

Analysing historic trends at bigger and smaller spatial scales (area-level and stream-level) may provide more clues as to which specific stressors are affecting salmon returns. In turn, understanding human-caused stressors informs management for sound conservation, restoration, and harvest operations. The data used to find historic trends offer a common ground for discussion between Pacific salmon stewards, stakeholders, and impacting industries. All in all, analysis of long-term monitoring data can help address the sources of declines and find opportunities to support salmon populations.

For a more complete snapshot of the state of WCVI, we assessed all documented stocks by DFO, on WCVI. However, the number of possible analyses for all Pacific salmon species across each of the eight management areas of WCVI is too great for this preliminary report. As Cedar Coast Field Station is based in Clayoquot Sound, Area 24 will be the focal management area of this report.

Impacts to Pacific Salmon in Nuu-chah-nulth Territories : Clayoquot Sound

The diverse and abundant marine life in Clayoquot Sound has cultural ties to Nuu-chah-nulth Nations and has supported local livelihoods over many generations. Relative to the harvest of Pacific salmon in Clayoquot Sound by Nuu-chah-nulth Nations, the history of commercial extraction of terrestrial and marine resources has resulted in rapid changes to the Pacific salmon stocks in this area. Notably, periods of human-induced declines in Pacific salmon populations are seen across species (DFO, 1999, 2002, 2012, 2016; McHugh & King, 2018; PSC, 2021; Riddell & Beamish, 2003).

Some of the better known impacts to Pacific salmon stocks in Clayoquot Sound include overfishing, logging, and salmon farming. Commercial logging was introduced to Clayoquot Sound in 1955 (Grant, 2019). Erosion and sedimentation from logging have significantly deteriorated the spawning habitats of Pacific salmon stocks. The Atleo River was impacted by unregulated logging of the riparian zone, resulting in the local designation as a “dead” river. In contrast, the Moyeha River is one of the few major salmon-bearing rivers that remains unlogged (McHugh & King, 2018).

Fish farming was introduced to Clayoquot Sound in the early 1970s (Environmental Assessment Office, 1997; K. Sandberg, pers. comm., 2021). Rigorous monitoring and targeted research studies have found that salmon farms in BC are a source of pathogen transmission that can affect out-migrating juvenile salmon and survival (Bateman et al., 2021; Krkošek et al., 2005; Krkosek, 2011; Morton & Routledge, 2003; Shea et al., 2020). Between 2004 - 2020, 23 salmon farms have been active throughout Clayoquot Sound - the highest farm density on WCVI. (K. Sandberg, pers. comm., 2021).

Focal Stocks

To further focus the analysis, we report on stream-level assessments for focal stocks in Clayoquot Sound. Focal stocks include: Cypre River, Megin River, Moyeha River, and Tranquil Creek for Chum, Coho, and Chinook; and the Kennedy and Clayoquot systems for Sockeye. Time series and the status of other stocks with available data are provided in Appendix A of this report.

Pink salmon were not included in this report. Where total escapement of the monitored WCVI Pink stocks (~85) was around 100,000 fish between 1950 - 1980, the total escapement dropped to around 100 in 2001 (Riddell & Beamish, 2003). Coupled with declines in escapement was a decline in already inconsistent monitoring for many Pink stocks. The available escapement estimates were too low and inconsistent for the reasonable application of modelling techniques required for analysis. Further, an assessment of WCVI Pink salmon would not provide new information on their status. The loss of WCVI Pink salmon is a reminder of the risk confronting other Pacific salmon species and the communities they benefit.

Salmon Stock Assessment

This analysis aims to highlight patterns, trends, and statuses of Pacific salmon populations on

three scales: WCVI, Clayoquot Sound, and focal streams. Assessment at different spatial scales provides a clearer picture of the state of salmon populations on WCVI. The historical time series analyses may be used to understand the current state of Pacific salmon populations within the context of historical impacts.

To relay the state of salmon, we provide recent statuses for each stock that had sufficient data for analysis. We used three approaches to designate statuses for stocks from a given stream, based on stream-level abundance and productivity. Each approach offers a different stream-level view into the status of stocks. For application to relevant DFO policy on salmon population management, two of our approaches for assigning status follow criteria outlined in the WSP (DFO, 2020a). The WSP statuses we assign may identify stocks that require immediate management intervention to reduce the risk of extinction.

With our third, productivity-based status assignment, we attempt to understand the resilience of WCVI salmon (Atkinson et al., 2020). All together, we provide stream-level status assignments of Pacific salmon in Clayoquot Sound, based on abundance and productivity. This in-depth look at the state of salmon stocks in Clayoquot Sound is an opportunity to address potential risks to stocks that may have been overlooked by bigger scale assessments. Finally, this assessment attempts to convey the quality of the available monitoring data.

Working in the field. Photo: Mack Bartlett

Methods

We used publicly available data supplied by DFO and the status framework defined by WSP to provide stream-level assessments for WCVI Pacific salmon stocks. Under WSP, the status of a population is given by one of three status zones: Green (good), Amber (fair), Red (poor), or Data Deficient. Benchmarks are the boundaries between these WSP zones (Figure 1). An informative status zone, specific to this assessment, is the Data Limited zone which denotes less than 10 years of escapement data. To determine the status zone of stocks, the stock-specific benchmarks must be determined first.

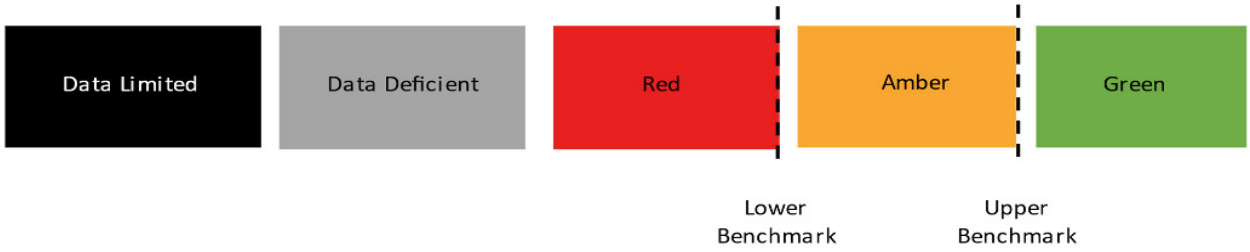
Under the WSP framework, benchmarks that delineate status zones directly or indirectly use abundance to determine the appropriate management approach for a population (DFO, 2018). Management approaches often consider harvest levels, conservation, and provide an alternative benchmark - the resilience benchmark (Atkinson et al., 2020) - that uses intrinsic productivity to infer the status of a stock. Intrinsic productivity is defined as the number of potential returning offspring per spawner, if the stock was released from stressors. We use intrinsic productivity of a stock to infer the resilience of that stock.

The lower benchmark separates the Amber and Red zones. The Red zone indicates that a

stock is at risk of extinction if it is not released from the current stressors (e.g. fishing, habitat degradation, impacts of industry). A precautionary buffer to account for uncertainty in assessments is incorporated into the lower benchmarks that are suggested by DFO.

The upper benchmark delineates Green and Amber zones. WSP defines the upper benchmark as being dependent on maximum yield and a further decreased probability of extinction. Maximum yield or Maximum Sustainable Yield (MSY) is a fisheries management term denoting the maximum number of fish that can be caught while maintaining the maximum growth rate of the population. Therefore, basing the status of populations on MSY may be a human-centric approach instead of reflecting the true health of the population. The certainty of status

Status	Definition
Data Limited	Less than 10 years of escapement data are available over the whole study period.
Data Deficient	Less than 10 years of escapement data are available in the last 10 years of the study period.
Red	The population is at risk of extinction and cannot sustain mortality from the current stressors. Red status assignment will "initiate an immediate consideration of ways to protect the fish" (DFO 2018)
Amber	The population may become at risk of extinction and is unlikely to produce maximum sustainable yield
Green	The population is unlikely to be at risk of extinction



Benchmarks	Definition	Determinant
Percentile : $S_{25} - S_{75}$	The lower and upper benchmarks represent the 25th and 75th percentile of all available spawner abundance, respectively.	These benchmarks are compared to the mean spawner abundance from the latest generation there is data for.
Spawner-Recruit : S_{GEN} - S_{MSY}	The upper benchmark S_{MSY} represents the spawner abundance required to achieve Maximum Sustainable Yield.The lower benchmarks represents the number of spawners required to achieve S_{MSY} in one generation.	These benchmarks are compared to the mean spawner abundance from the latest generation there is data for.
Productivity : e^a	The one benchmark is intrinsic productivity at replacement : $e^a = 1$.	The benchmark is compared to two values : the mean and the lower confidence interval of e^a for the latest generation.

Figure 1. The WSP status zones, Green, Amber, and Red are delineated by benchmarks and refer to the potential a population has for survival. The status zones correspond to different management requirements and to the degree of intervention needed for a given stock. The three different approaches to defining upper and lower benchmarks - percentile, spawner-recruit, and productivity - give their own type of status assignment, but with similar conclusions regarding management suggestions. The potential for survival cannot be estimated for Data Deficient and Data Limited populations due to high uncertainty or an absence of data.

designations for all populations is dependent on the quality, consistency, and quantity of the data. All data used in this assessment were sourced from DFO for three reasons. One reason being ease of access, as much of the required data is available from online databases in a versatile format. Second, the DFO database provides one of the oldest, most extensive, and most consistent public datasets that can be readily used for statistical analysis. Lastly, using data from DFO ensures consistency with DFO methods. Consistency with DFO methods is important as the status assignments in this report are meant to be relevant to WSP designations which invoke DFO support for assessing populations at risk.

Determining Status Zone

The publicly available data (DFO, personal communication, 2019) used for the assessments included: estimated number of spawning adults, escapement (DFO, 2020b); the percent of total returning adults that were harvested (harvest rates, Hr); and proportions of each age class of spawning adults (age at return, AAR). We tailored the stock assessment methodologies from the State of the Salmon Report for the Broughton Archipelago by Salmon Coast Field Station (Atkinson et al., 2020) to the Fishery Management Areas 20 – 27 for WCVI (Table 1).

We used three different benchmarks. For the two sets of abundance-based benchmarks, we determined status by comparing the geometric average escapement from the most recent generation to the upper and lower benchmarks. The geometric average was used because escapement values are assumed to be serially correlated.

The values of the two kinds of abundance-based benchmarks are specific to each stock. Whereas the resilience benchmark is a growth rate at replacement. The growth rate at replacement is one spawning adult yielding one offspring returning to spawn. The replacement rate is the same for all populations, as it is a basic principle for determining population growth. For the resilience benchmark, we compared the intrinsic productivity estimate from the most recent year in the last decade to intrinsic productivity at replacement.

The first set of abundance benchmarks is based on percentiles of historic abundance. Percentile benchmarks shift with the most recent addition to historical abundance but may become more stable over time. The lower percentile benchmark is set at the 25th percentile and the upper percentile benchmark is set at the 75th percentile of all escapement estimates.

The second set of abundance benchmarks is derived from the standard Ricker equation (Equation 1) which describes the "spawner-recruit" relationship between escapement (spawners or stock) and the resulting progeny (recruits) that return at different age classes (Ricker, 1975). This second set of benchmarks are referred to as the spawner-recruit benchmarks. Spawner-recruit benchmarks provide annual benchmarks based on desirable fisheries management outcomes. The upper spawner-recruit benchmark is 80% of the spawner abundance that produces the maximum sustainable yield (S_{MSY}) and the lower benchmark which is the spawner abundance required to achieve S_{MSY} in one generation (S_{GEN}).

The last set of benchmarks used for status assignment are based on estimates of annual intrinsic productivity (Atkinson et al., 2020). Intrinsic productivity (e^{α}) gives the ratio of recruits per spawner ($\frac{R}{S}$) when the density of the returning spawners is low enough that the density dependence factor (β) is zero. The intrinsic productivity or "resilience" benchmarks compare the latest estimate of productivity to the replacement value ($e^{\alpha} = 1$).

Equation 1. The standard Ricker equation where $R_{i,t}$ is the number of returning spawners (recruits) from the same brood year (t) – including returning adults that were caught by fisheries – for a given population (i), and $S_{i,t}$ is the number of spawning adults that produced these recruits on brood year, t. For each stock, intrinsic productivity ($\alpha_{i,t}$) is calculated annually, but density dependence (β_i) is static.

$$R_{i,t} = S_{i,t}e^{(\alpha_{i,t}-\beta_i S_{i,t})}$$

Using a combination of benchmark approaches to inform a stock assessment offers a fuller depiction of stock dynamics. Spawner-recruit benchmarks are often less volatile than percentile benchmarks. The resilience benchmark is static and thus provides the least volatile assessment. However, percentile benchmarks offer more coverage over a time series, as they require less contiguous data, than either of the more biologically informed benchmarks.

Omissions from Assessment

The three sets of benchmarks were applied in assessments of WCVI Chum, Coho, Chinook, and Sockeye stocks. Due to the dramatic declines of WCVI Pink salmon stocks since the 1980s, Pink salmon stocks were omitted from the assessment. All Chinook and Sockeye stocks with less than 100 individuals for all the years of the available escapement data were omitted from the assessment. Annual escapement for some stocks may consist of 100 or fewer individuals, especially during declines. However, if there is no evidence of a once stable stock above 100 individuals, from escapement data between 1953 and present, we assume the enumerated individuals strayed from neighbouring stocks.

Data Compilation

Publicly available escapement, Hr, and AAR data from DFO were used for our assessments. The escapement data were used to determine status using all three sets of benchmarks.

The scale of the data depended on the category. Escapement was stream-level while Hr and AAR were fisheries management area-level. Where some area-level Hr or AAR estimates were unavailable, data from indicator streams in neighbouring areas were used. These indicator streams often have a higher degree of consistency in monitoring and so had more years with data over the study period.

Escapement

Annual, stream-level escapement data were used to calculate benchmarks and determine stock status. The escapement estimates were taken from the maximum annual estimates provided by the NuSEDs database (DFO, 1999). Differentiation between hatchery escapement estimates and wild origin escapement was inconsistent in available data. The maximum escapement estimate was used from the available dataset. Therefore, this assessment includes both hatchery and wild salmon escapement. Major hatcheries in the region are: Nitinat Hatchery (Area 22) and Conuma Hatchery (Area 25) which both produce Chinook, Chum, and Coho; and Robertson Creek (Area 23) which produces Chinook and Chum.

Uncertainty in the escapement data can come from the varying consistency with which streams are enumerated for escapement estimates. Indicator streams are used by DFO to estimate the escapement of nearby, unmonitored stocks. Enumeration for escapement of a stream will sometimes cease if escapement declines to very low numbers.

Harvest Rates

Annual, area-level harvest rates (Hr), within the period 1953 – 2019, were obtained from DFO. Raw catch data may include stocks from other management areas and US origin. Therefore, we used the annual, area-level Hr provided by DFO that are adjusted to account for the mixed stock origin using mainly commercial fisheries data. For this assessment, we assume Hr data are representative of both wild and hatchery fish. The Hr data were used to calculate recruits associated with a given brood year (Equation 2 then Equation 3).

Whereas Hr for WCVI Chum were based on commercial catch of wild stocks, Hr for Coho were based on the Robertson Creek Hatchery escapement between 1975 and 1998. Between 1999 and 2019, Coho Hr were based on escapement to Stamp Falls. The Hr for all WCVI Chinook were based on CWT catch from and returns to Robertson Creek Hatchery. The catch data used to estimate Chinook Hr include Individual Stock Based Management (ISBM) and Aggregate Abundance-Based Management (AABM) Chinook fisheries. The Hr and catch data were sourced from the Joint Chinook Technical Committee Report (PSC, 2021b).

From 1974 to 2011, the Hr for all WCVI Sockeye were based on the conglomerate catch of Somass River stocks (Great Central Lake and Sproat Lake) and the smaller Henderson Lake stock. After 2012, the catch used in WCVI Sockeye calculations removed Henderson Lake contributions using DNA differentiation, making the Somass River stocks the only Hr indicator for WCVI Sockeye.

Age at Return

Data on AAR were used to calculate the sum of the different age classes of recruits from a specific brood year. The area-level AAR data are based on biological samples taken by DFO, from catch and escapement. The assumptions made in using this data are first, that age composition data from a mix of hatchery and wild salmon gives a single age composition estimate that can be applied over both hatchery and wild salmon in this assessment. The second

assumption is that age composition of specific neighbouring WCVI areas can substitute for missing estimates in other areas. The third assumption is that age compositions of catch and of escapement are the same.

For years between 1990 - 2018, if annual AAR data were not available for Chum in Areas 20 to 24, the annual AAR composition from the Nitinat Hatchery (Area 22) was used. Conuma Hatchery (Area 25) was used to represent Chum in Areas 25 and 26 for the years 1990 - 2018. The WCVI Sockeye AAR data is based on the Somass River stocks of area 23. The WCVI Chinook AAR data are based on the wild and hatchery samples from the Stamp River system. Whereas WCVI Chum, Chinook, and Sockeye had variation in AAR, Coho was assumed to have a set four-year generation (K. Mathias, pers. comm., 2019). Chum were assumed to return at ages three through five, Chinook at ages two through five, and Sockeye at ages three through six (K. Mathias, pers. comm., 2019).

Ricker Modelling

Using spawner-recruit estimates, the Ricker model allows estimation of intrinsic productivity (e^{α}) and density dependence (e^{β}). With model estimates of these two variables, we solved for the components of the resilience benchmark (intrinsic productivity, e^{α}) and the spawner-recruit benchmarks (S_{GEN} and 80% S_{MSY}). The percentile benchmarks simply use historical abundance. Therefore, we did not require values from the Ricker model.

Spawner-Recruit Ratio

To determine the spawner-recruit ratio depicted by the standard Ricker equation we first estimated the total returns ($Ret_{i,t}$). We defined total returns as the sum of catch and escapement for a given year and stock. We solved for returns (Equation 2) using annual, area-level Hr_i and annual stream-level escapement ($S_{i,t}$). We then solved for Recruits ($R_{i,t}$) that were associated with a given brood year and $S_{i,t}$.

To solve for $R_{i,t}$, we applied the annual proportions of age classes from area-level AAR data to the annual returns (Equation 3). Iterations of this calculation were conducted for each stock (i) and each brood year when the spawners produced the recruits (t). The resultant ratio of $R_{i,t}$ and $S_{i,t}$ were then used in a linearized, standard Ricker model (Equation 4) to estimate ($\alpha_{i,t}$) and β_i.

Equation 2. For each stock, Annual returns ($R_{i,t}$) are calculated as the escapement ($S_{i,t}$) expanded by the remainder of the area-level, annual percent of returns harvested (hr_t). This defines annual returns as the sum of escapement and catch.

$$Ret_{i,t} = \frac{S_{i,t}}{1 - hr_{a,t}}$$

Equation 3. This stock recruit equation shows the calculation for Chum Salmon which return between the ages of 3 and 5. Each brood year (y) yields 3, 4, and 5 year-old recruits depending on the size of the return and the age composition (z) associated with the population (i).

$$R_{i,t} = z_{3,t=y+3}Ret_{i,t=y+3} + z_{4,t=y+4}Ret_{i,t=y+4} + z_{5,t=y+5}Ret_{i,t=y+5}$$

Equation 4. We provided $R_{i,t}$ and $S_{i,t}$ to the linearized Standard Ricker model, for each population (i) and brood year (t). From the model, we obtained intrinsic productivity ($e^{i,t}$), a static density dependence factor (β_i), and observer and precision error ($\epsilon_{i,t}$).

$$ln\left(\frac{R_{i,t}}{S_{i,t}}\right) = \alpha_{i,t} + \beta_i S_{i,t} + \epsilon_{i,t}$$

Modelling Approach for Estimating Benchmark Components

To obtain values for calculating the spawner-recruit and resilience benchmarks, we used a Bayesian framework when fitting a standard Ricker model, in R Studio (R Core Team, 2021). The model fit provided estimates of annual $\alpha_{i,t}$, static β_i, and precision error ($\epsilon_{i,t}$). Precision error is assumed to increase with gaps in data for the time series due to the increased variance associated with the random walk during model fitting. We applied a linearized, standard Ricker model to each stock using a Markov Chain Monte Carlo (MCMC) iterative sampling algorithm using the rjags package (Plummer, 2019). The priors assume a uniform distribution, and initial values of 3.0, 0.1, and 1.0 for $\alpha_{i,t}$, β_i, and $\epsilon_{i,t}$, respectively. Uniform distribution is assumed when there are limited data to inform predictions of the probability distribution (Holt

et al., 2018).

We assumed convergence of the spawner-recruit model was successful if the Gelman-Rubin diagnostics were < 1.1 (Gelman & Rubin, 1992; Holt et al., 2018; Plummer et al., 2006). A second diagnostic consisted of visually checking for model fit using residual plots. Once convergence was determined, status based on the $e^{\alpha_{i,tmax}}$ benchmark or the S_{GEN} and 80% S_{MSY} benchmark pairs could be assigned for each stock with sufficient data for model fitting. We solved for the S_{GEN} benchmark numerically by using the optimize function from the stats package (R Core Team, 2021) in R. The S_{MSY} benchmark was solved for using methods from Scheuerell (2016) using the gsl package (Hankin, 2006).

In the final status assignment, we used e^{α} to infer stock status and resilience. Here, we compared the most recent annual estimate of e^{α} to the replacement benchmark. From our model outputs, we took the mean e^{α} and the lower 95% confidence intervals of e^{α}. If the most recent year had a lower confidence interval and a mean e^{α} below 1, we assigned the stock a Red resilience status. If the lower confidence interval was below 1, but the mean e^{α} was above 1, we assigned the stock an Amber resilience status. If both lower confidence interval (LCI) and mean e^{α} were above 1, we assigned the stock a Green resilience status.

Data Requirements

Availability of abundance data used to estimate these benchmarks varied over the study period. To balance data availability with meaningful assessments using model fitting, we required that a stock have at least 10 years where both escapement and recruit data were present to estimate 80% S_{MSY} and S_{GEN}, or e^{α} (Holt et al., 2018; Atkinson et al., 2020). We considered a stock Data Deficient if there was no escapement estimate within 10 years of the latest escapement estimates used for the assessment. Whereas a Data-Limited stock – one that we could not perform any of the assessment methods on - was defined as a stock with less than 10 years of escapement data over the whole study period.

Chum salmon in Tranquil Creek. Photo: Mack Bartlett

Results

Enumeration

Salmon spawning enumeration efforts have declined on WCVI since the 1980s, with less stocks being monitored now than ever before (Figure 2). Monitoring efforts had a sharp decline in the number of stocks assessed in the 1980s and continued to decline into the 2000s. By 2019, only 43 stocks were monitored - marking the fewest number of streams being enumerated in monitoring history, on WCVI.

Chum and Coho stocks make up the majority of monitored stocks on WCVI, followed by Chinook, then Sockeye. The number of monitored Chinook, Sockeye, and Pink salmon stocks were similar until the decline of Pink stock monitoring in the late 1970s. Pink salmon stock monitoring then became relatively stable at these lower numbers. The number of monitored Chinook stocks has remained relatively stable, while Sockeye monitoring has increased slightly. Although Chum and Coho stocks are the most widely assessed, their monitoring efforts have decreased the most. As a result, in 2019, the number of Chum and Coho stocks being monitored across all five species is only around 20 more than that of Pink. Whereas in the 1950s, around 100 more Chum and Coho stocks were monitored than Pink.

Status Assignment - WCVI Overview

The majority of stocks in our assessment were Data Limited and Data Deficient, having insufficient data to provide a Red, Amber, or Green status from any benchmark approach (Table 2, Figure 3). By definition, Data Limited stocks have insufficient data for all three of the benchmark approaches. Most stocks with insufficient data for percentile benchmarks were in the Data Limited category, while most stocks with insufficient data for spawner-recruit and resilience benchmarks were Data Deficient. All stocks with insufficient data for our analysis made up nearly three quarters of all status assignments. Percentile benchmarks had the greatest instance of sufficient data for status assignment.

The three benchmark approaches showed different proportions of Red, Amber, and Green status assignments. Spawner-recruit and resilience benchmarks showed more Green stocks than percentile statuses. The resilience benchmarks had a larger component of Amber status assignments than spawner-recruit benchmark assignments. The majority of percentile statuses were Amber, closely followed by Red.

A misty hillside. Photo: Mack Bartlett

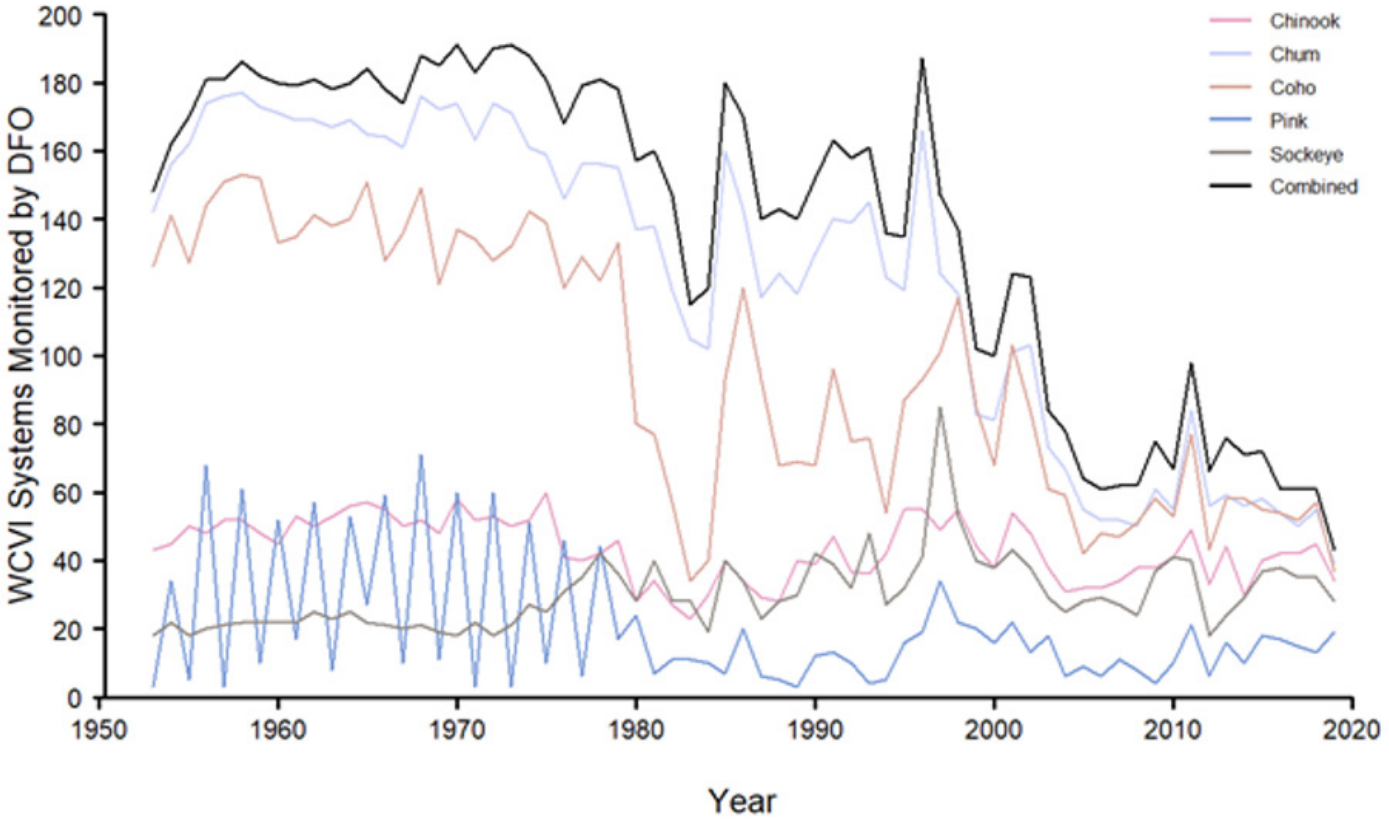


Figure 2. Observed spawner escapement of WCVI waterbodies between 1953 - 2019 show a reduction in the number of streams monitored by DFO. A reduction in monitoring can be seen for waterbodies bearing salmon ("Combined") and for waterbodies that are specific to each Pacific salmon species.

Table 2. Status assignments for all populations that were documented in the DFO escapement database, across species and across WCVI. The spawner-recruit, percentile, and resilience benchmark approaches showed different proportions of WSP and resilience status assignments, but the majority of WCVI populations had insufficient data for status assignments. Percentile status assignments had the most status assignments with sufficient data and was the only benchmark approach with an Amber and then Red majority.

Status	Percentile Count	Percentile %	Resilience Count	Resilience %	Spawner-Recruit Count	Spawner-Recruit %
Green	38	5%	53	8%	68	10%
Amber	129	17%	33	5%	10	1%
Red	109	14%	2	0%	10	1%
Data Deficient	236	30%	327	48%	327	48%
Data Limited	269	34%	269	39%	269	39%

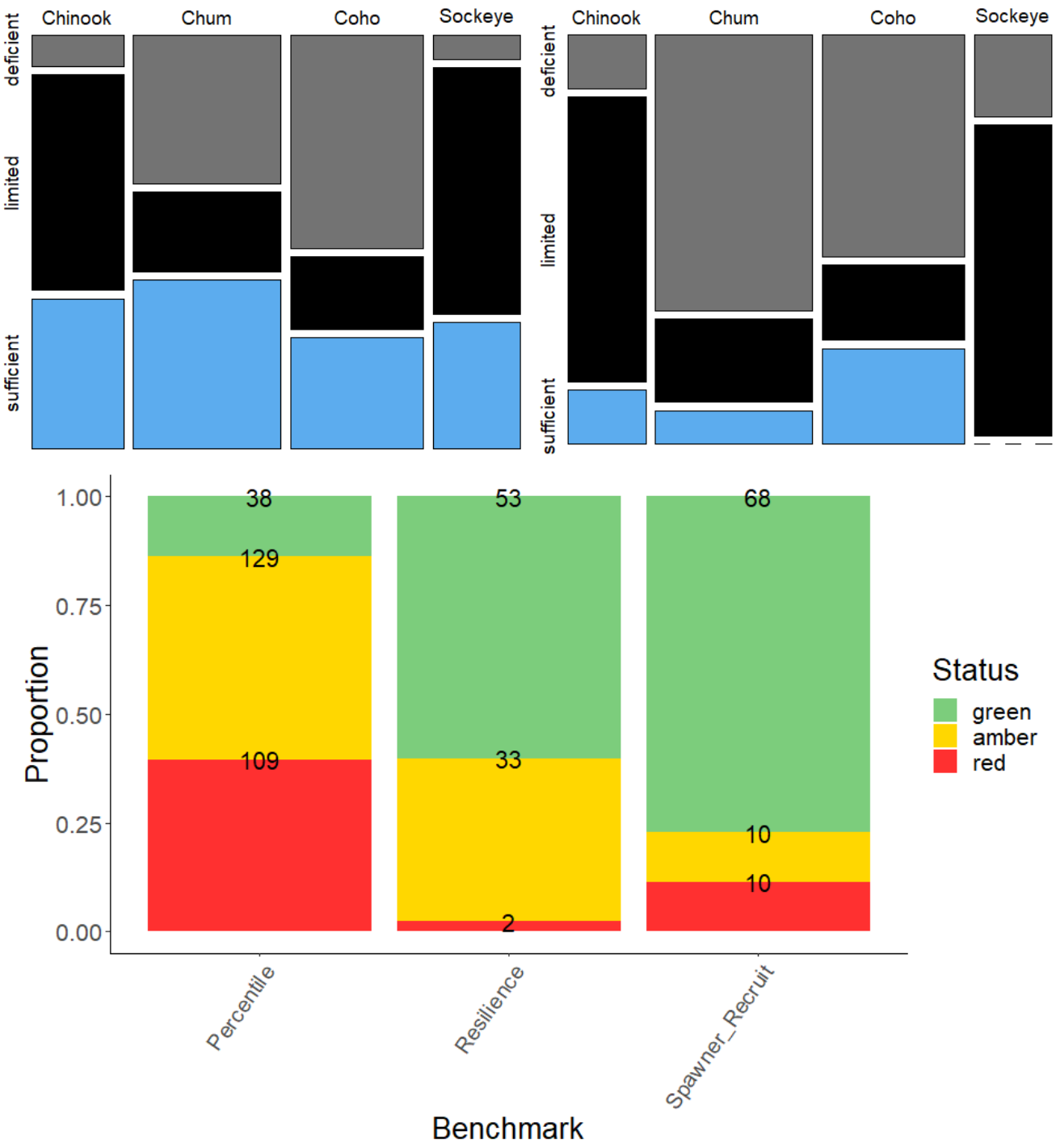


Figure 3. Proportions of status assignments for all species, across WCVI, from data sufficiency (A and B) to WSP assignments (C). (A) Using a percentile benchmark approach, the proportions of WCVI-wide populations with data that was sufficient (at least 10 yrs of escapement data with at least one data point in the last decade since analysis, blue), deficient (at least 10 yrs of escapement data, but without any data points in the last decade since analysis, grey), or limited (less than 10 years of escapement data, black). (B) Using resilience or spawner-recruit benchmark approaches, the proportions of WCVI-wide populations with escapement data that was sufficient, deficient, or limited for status assignment. (C) For populations with sufficient data to be assessed, the proportion of WSP status assignments (Red, Amber, and Green), for each benchmark approach.

WCVI Overview - Species Specific

On WCVI, Chum and Coho salmon had a greater number of stocks with sufficient data for status assignments than Chinook and Sockeye (Figure 4). The majority of WCVI Chinook and Sockeye stocks were Data Limited while the majority of Chum and Coho stocks were Data Deficient. Proportions of Chum and Coho status assignments were more varied than those of Chinook and Sockeye. Chinook and Sockeye had similar, relatively low counts of assessed stocks but with different proportions of status assignments. Chinook primarily had Green assignments while Sockeye primarily had Amber and Red assignments. Sockeye did not have enough consistency in recent data to provide spawner-recruit or resilience statuses in the last 10 years of the study. All species showed different proportions of Green, Amber, and Red status assignments, depending on the benchmark. All stocks had more percentile status assignments than assignments using other benchmarks.

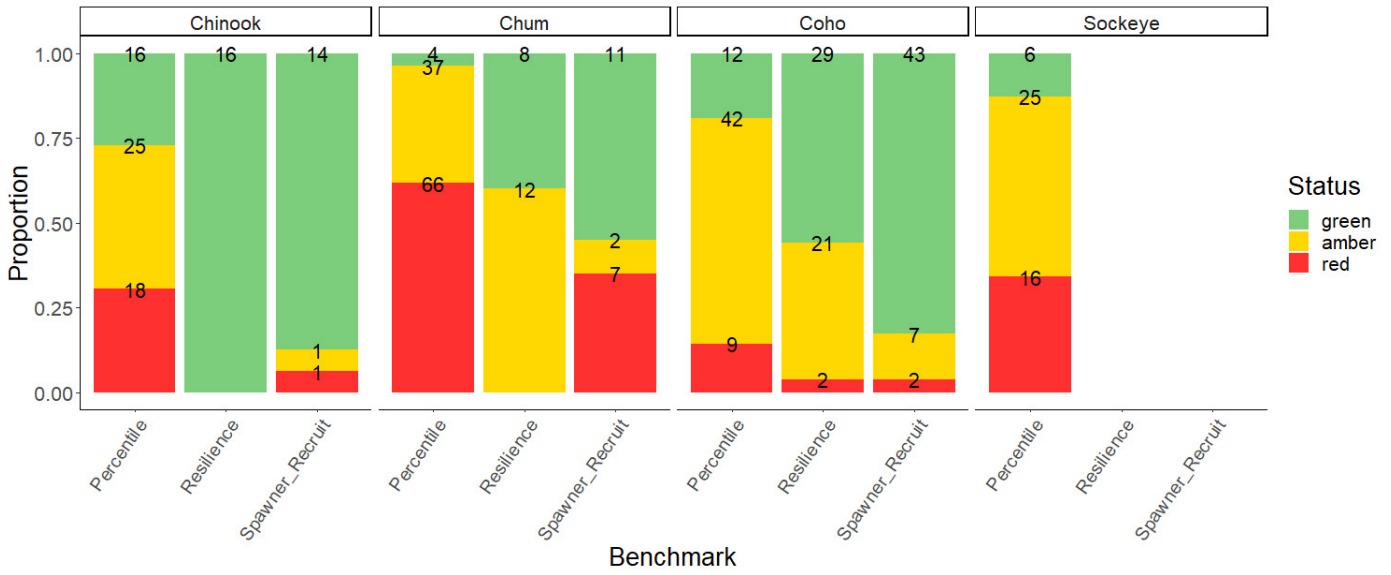


Figure 4. Proportions of Green, Amber, and Red WSP status assignments for the populations of each species on WCVI, with sufficient data. Chinook, Chum, and Coho showed different proportions of status assignments for each benchmark approach, but generally reflected more Amber and Red status assignments for the percentile approach. Sockeye populations in this assessment had the fewest assessed populations and had insufficient data for spawner-recruit or resilience statuses.

Chum

Of all the assessed species, Chum stocks had the highest proportion of Red statuses for both percentile and spawner-recruit assignments. Chum stocks also had the highest proportion of Amber resilience statuses, but a relatively lower number of stocks with resilience and spawner-recruit status assignments. For Chum stocks, percentile status assignments showed a higher proportion of Red statuses (n = 66), followed by Amber statuses (n = 37), and Red (n = 4). Resilience statuses were mostly Amber (n = 12), with the remainder being Green (n = 8). The spawner-recruit status assignments were mostly Green (n = 11), followed by Red (n = 7).

Coho

Coho stocks across WCVI showed the greatest proportion and number of Amber statuses for percentile benchmarks (n = 42). Coho stocks had mainly Green assignments for resilience (n = 29) and spawner-recruit benchmarks (n = 43). Resilience statuses had similar proportions of Green and Amber (n = 21) status assignments than the other benchmarks. Only Coho stocks had Red resilience statuses (Jansen Lake and Kauwinch River Coho).

Chinook

Chinook stocks across WCVI had the highest proportions of Green statuses, across benchmarks. Chinook showed greater Amber statuses for percentile benchmarks (n = 25) and greater Green statuses for resilience (n = 16) and

spawner-recruit benchmarks (n = 14). Chinook had a relatively balanced number of Green, Amber, and Red percentile statuses. Chinook had the highest proportion of Green resilience statuses (100%). Spawner-recruit benchmarks were nearly all Green.

Sockeye

Sockeye stocks across WCVI only had sufficient data for percentile benchmarks. The highest proportion of Sockeye stocks were assigned Amber statuses (n = 25). Stocks with a Red status (n = 16) held the second highest proportion for Sockeye stocks. Of all species in this assessment, Sockeye had the lowest number of stocks with sufficient data for status assignment.

Clayoquot Sound Overview

Overall, wild salmon stocks in Clayoquot Sound are declining. The paths of these declines are varied - some stocks steadily decreasing since the 1950s, others showed steep declines in the 1960s. However, around the 1990s, some stocks experienced periods of increased escapement ("the bump") that exceeds the earliest documented escapement.

Stretches of escapement estimates at 0 or near 0 were relatively common for many focal stocks. Longer stretches of 0 or near 0 escapement were typical for stocks with smaller abundance at the beginning of monitoring on WCVI (typically Chinook stocks). Unlike the Atleo River (Figure 5), some of these stocks with 0 or near 0 estimates later showed a period of increasing escapement. The increasing escapement typically corresponded with the 1990s bump. Many of the stocks that showed a 1990s bump have since declined to levels similar to the 1960s decline. Others may currently be declining from these bumps or may be showing a decline to a stable trough.

When intrinsic productivity was displayed in a time series it showed a clearer trend for the overall state of the stocks than other metrics. In addition, intrinsic productivity data showed that despite declining trends in escapement, many stocks maintained relatively high intrinsic productivity. Most focal stocks showed a majority of Green statuses for available, annual intrinsic productivity estimates, followed by Amber, with few instances of Red. However, many of these resilience trends are Data Deficient which limits our understanding of the state of salmon in Clayoquot Sound.

Mapped statuses and time series showed that the percentile benchmark provided the most statuses with sufficient data, over time and the most recent estimates of status. Many spawner-recruit statuses are Data Deficient. Maps of spawner-recruit statuses showed the Data Deficient status for most or all stocks in Clayoquot Sound, for all species. Time series and maps of spawner-recruit statuses are provided in Appendix B.

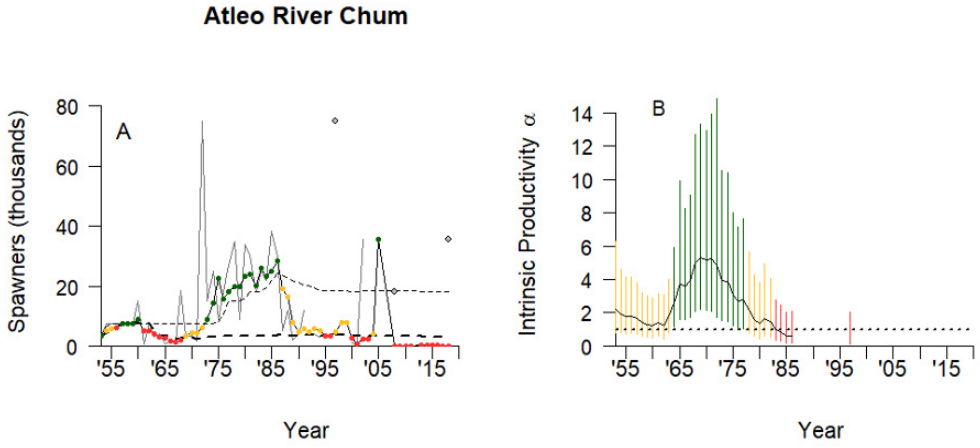
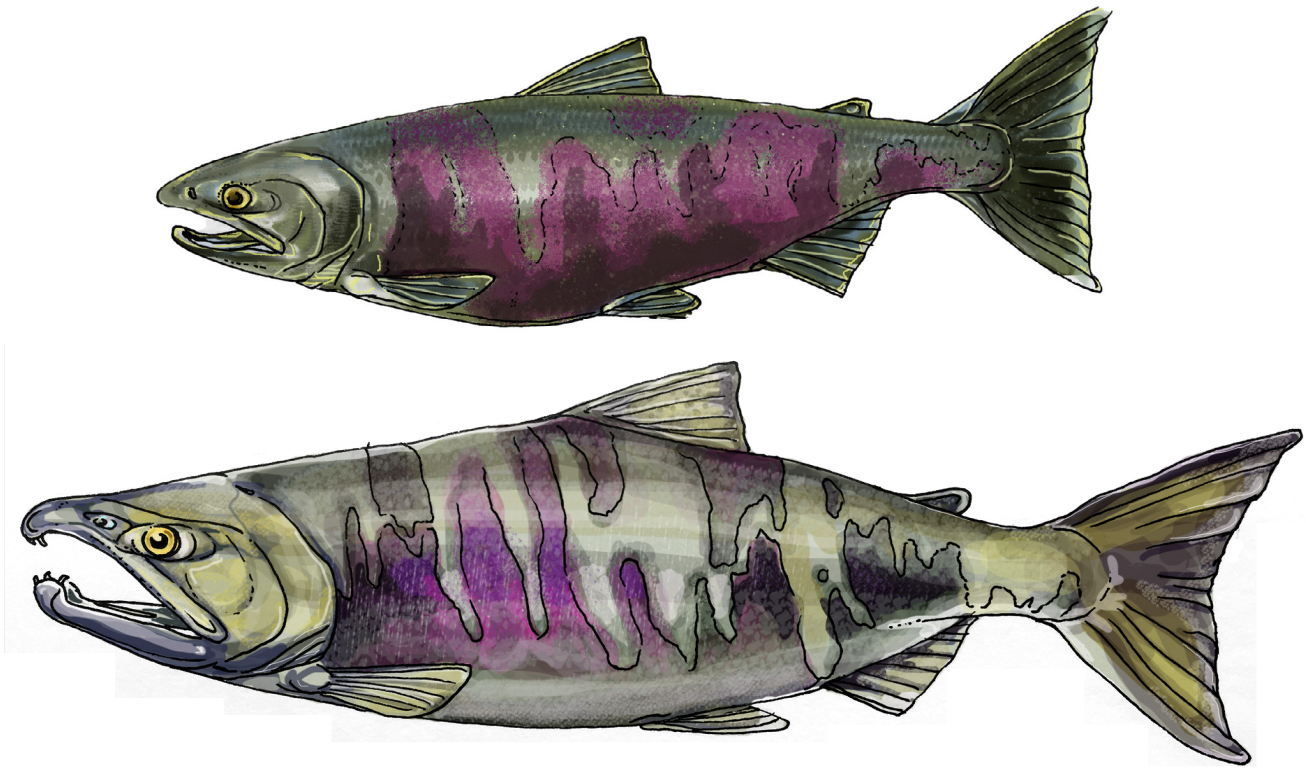


Figure 5. The Atleo River Chum stock offers an example of the escapement and productivity crashes associated with a "dead" stock, as it is locally referred to. (A) Percentile benchmarks for escapement (upper 75th percentile = light dash, lower 25th percentile = bold dash) show that Atleo Chum have gone from having one of the greatest returns in Clayoquot Sound to stretches of 0 individuals for recent escapement estimates (grey line). (B) Productivity for Atleo Chum is below the replacement line of one recruit per spawner (black dotted line) giving Atleo Chum a Red resilience status (red vertical line), matching the Red percentile status (solid red circle, Panel A).



Clayoquot Sound - Species Specific

Chum

Chum in Clayoquot Sound showed the highest proportions and numbers of recent Red and Amber percentile status assignments (Map 2) out of all other assessed species. Most of the spawner-recruit and resilience status assignments were Data Deficient (Table 3). Area 24 Chum showed high resilience and the capacity for relatively high escapement. Overall, Chum typically had higher escapement than Coho and Chinook. As with all species, the focal Chum stocks of Clayoquot Sound declined around 1950-1960 and showed downward trends for recent years. Variation between the focal Chum stocks was seen in the peaks of recovery and in productivity trends. Cypre, Moyeha, and Tranquil showed a bump in mean escapement starting around the 1990s or 2000s. Megin River Chum showed an earlier bump around the 1970s. The status of Cypre River Chum was Red for both percentile assignments and Amber for resilience assignments (Figure 7). Cypre River Chum declined from the bump in escapement in the 1990s. The drop in escapement since the 1960s led to stretches of percentile statuses being assigned as Amber and Red.

Megin River Chum were assigned a Red percentile status and an Amber resilience status (Figure 8). Megin River Chum steadily declined since the early 2000s, reaching record lows in 2018 and 2019. The resilience trends showed declines since the 1980s.

Moyeha River Chum had a Red percentile status and a Data Deficient resilience status (Figure 9). Moyeha River Chum had a near two-fold increase in escapement around the late 1990s bump. The Red percentile status points to the dramatic decline after the 1990s bump to nearly 0 returning adults. Annual estimates of intrinsic productivity increased since the early 2000s and were mostly Green.

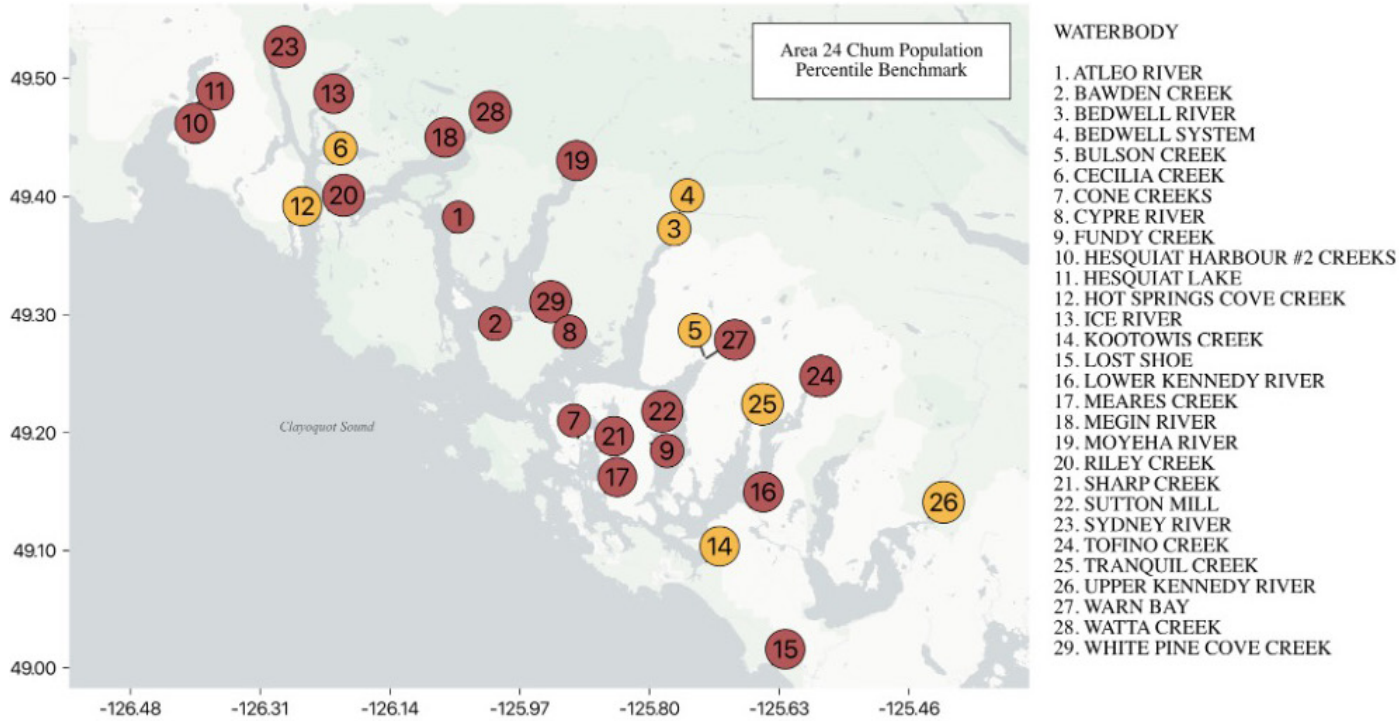
Tranquil Creek Chum were assigned an Amber percentile status and a Green resilience status (Figure 10). Tranquil Creek Chum had Red and Amber percentile statuses for the majority of the study period except after the 1990s bump. Since the 1990s bump, Tranquil Creek Chum had consistent Green productivity where α could be calculated.

Table 3. Stock status assignments for Chum salmon populations in Area 24, Clayoquot Sound. Percentile, spawner-recruit, and resilience benchmark approaches are used to assign a status of either Green, Amber, Red, or Data Deficient (Grey). Data Limited populations (with less than 10 years of escapement data) are not included in this table.

Stock	Spawner-Recruit Abundance	Percentile Abundance	Resilience
Atleo River	Data Deficient	Red	Data Deficient
Bawden Creek	Data Deficient	Red	Data Deficient
Bedwell River	Data Deficient	Amber	Data Deficient
Bedwell System	Data Deficient	Amber	Data Deficient
Bulson Creek	Data Deficient	Amber	Data Deficient
Cecilia Creek	Data Deficient	Amber	Data Deficient
Cone Creek	Data Deficient	Red	Data Deficient
Cypre River	Green	Red	Amber
Fundy Creek	Data Deficient	Red	Data Deficient
Hesquiat Harbour #2 Creeks	Data Deficient	Red	Data Deficient
Hesquiat Lake	Data Deficient	Red	Data Deficient
Hootla Kootla	Data Deficient	Green	Data Deficient
Hot Springs Cove Creek	Data Deficient	Amber	Data Deficient
Ice River	Data Deficient	Red	Data Deficient
Kootowis Creek	Data Deficient	Amber	Data Deficient
Lost Shoe	Data Deficient	Red	Data Deficient
Lower Kennedy River	Data Deficient	Red	Data Deficient
Meares Creek	Data Deficient	Red	Data Deficient
Megin River	Red	Red	Amber
Moyeha River	Data Deficient	Red	Data Deficient
Riley Creek	Data Deficient	Red	Data Deficient
Sharp Creek	Data Deficient	Red	Data Deficient
Sutton Mill	Data Deficient	Red	Data Deficient
Sydney River	Data Deficient	Red	Data Deficient

Table 3. Chum salmon statuses for Area 42 continued.

Tofino Creek	Data Deficient	Red	Data Deficient
Tranquil Creek	Green	Amber	Green
Upper Kennedy River	Data Deficient	Amber	Data Deficient
Warn Bay	Red	Red	Amber
Watta Creek	Data Deficient	Red	Data Deficient
White Pine Cove Creek	Data Deficient	Red	Data Deficient



Map 2. The latest available Red, Amber, Green, and Data Deficient percentile status assignments for Chum salmon populations of Clayoquot Sound. The majority of populations had a Red percentile status while the rest were Amber. Not including Data Limited populations

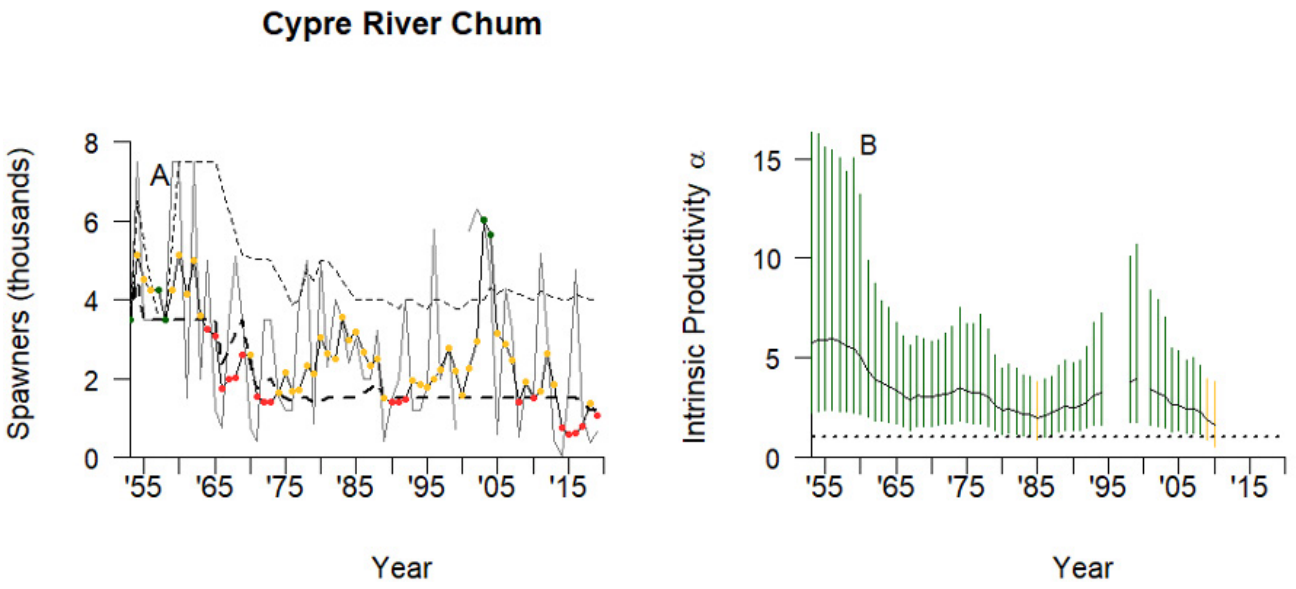


Figure 6. The time series for Cypre River Chum showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points and black line) showed recent declines, below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash), resulting in a Red percentile status. (B) For the entire resilience time series, the mean intrinsic productivity (black solid line) was above the benchmark of one recruit per spawner (black dotted line), but steadily declined over time. The 95% intervals (vertical lines) showed that annual resilience status went from largely Green to Amber in recent years.

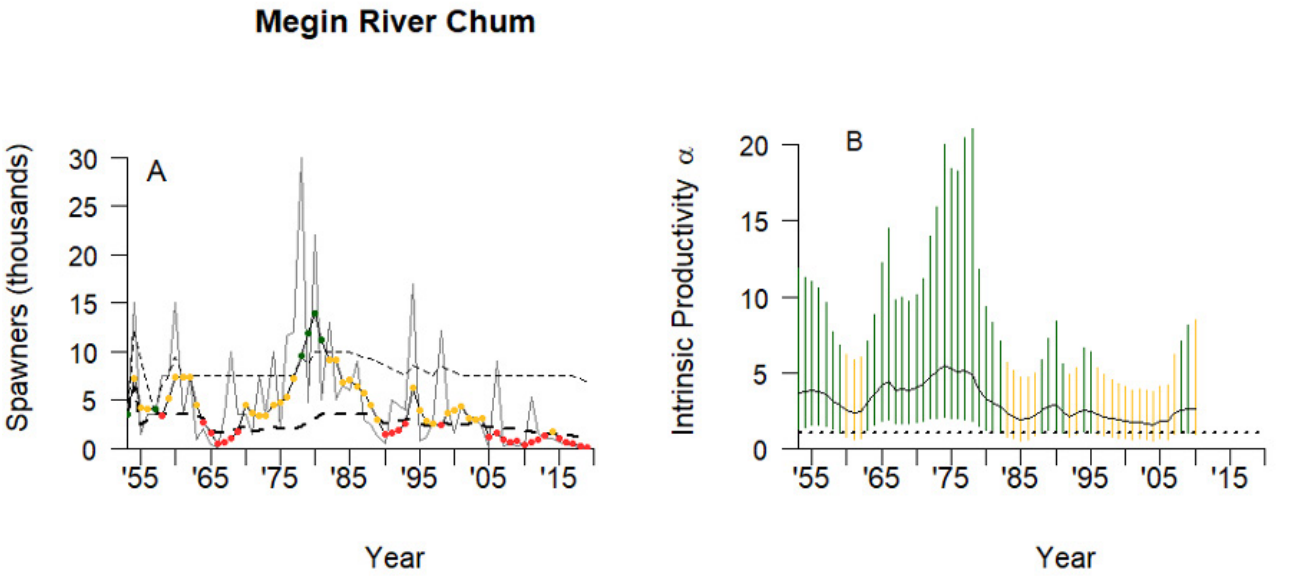


Figure 7. The time series for Megin River Chum showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points) for Megin River Chum showed recent declines, below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) to 0, resulting in a Red percentile status. (B) For the entire resilience time series, the mean intrinsic productivity (black solid line) was above the benchmark of one recruit per spawner (black dotted line), but the 95% intervals (vertical lines) declined over time, going from largely Green to Amber after the 1980s, and ending in an Amber resilience status.

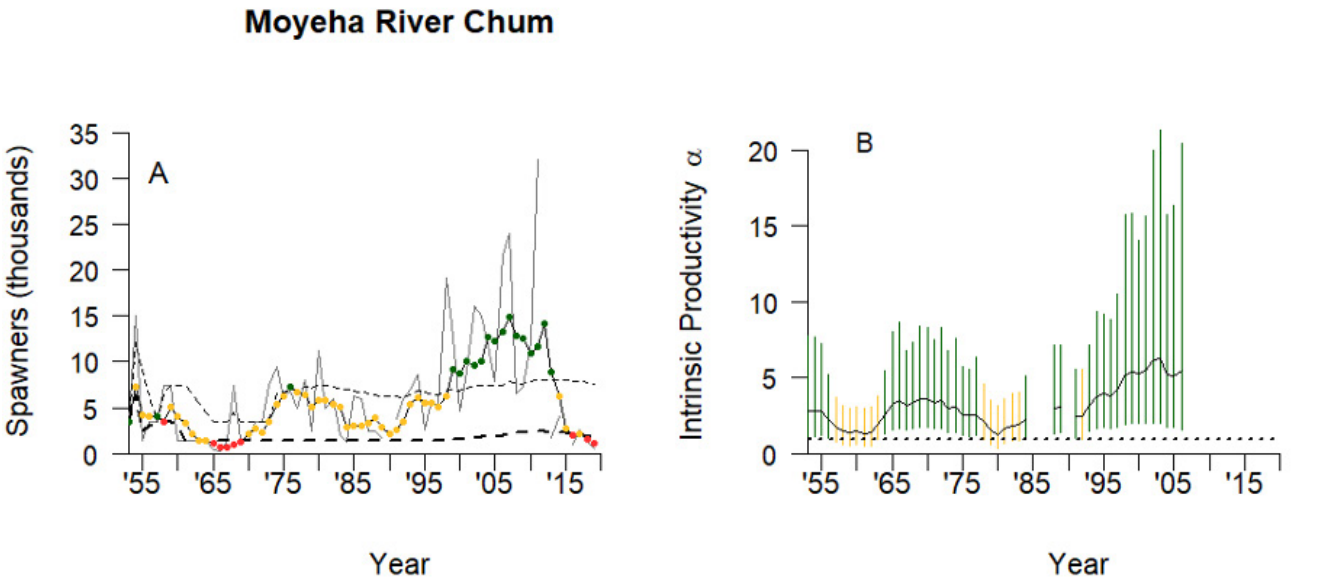


Figure 8. The time series for Moyeha River Chum showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points) for Moyeha River Chum showed a recent decline below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) to near 0, resulting in a Red percentile status. (B) For all of the resilience time series, the mean intrinsic productivity (black solid line) and 95% intervals (vertical lines) were above the benchmark of one recruit per spawner (black dotted line), giving a Green resilience status.

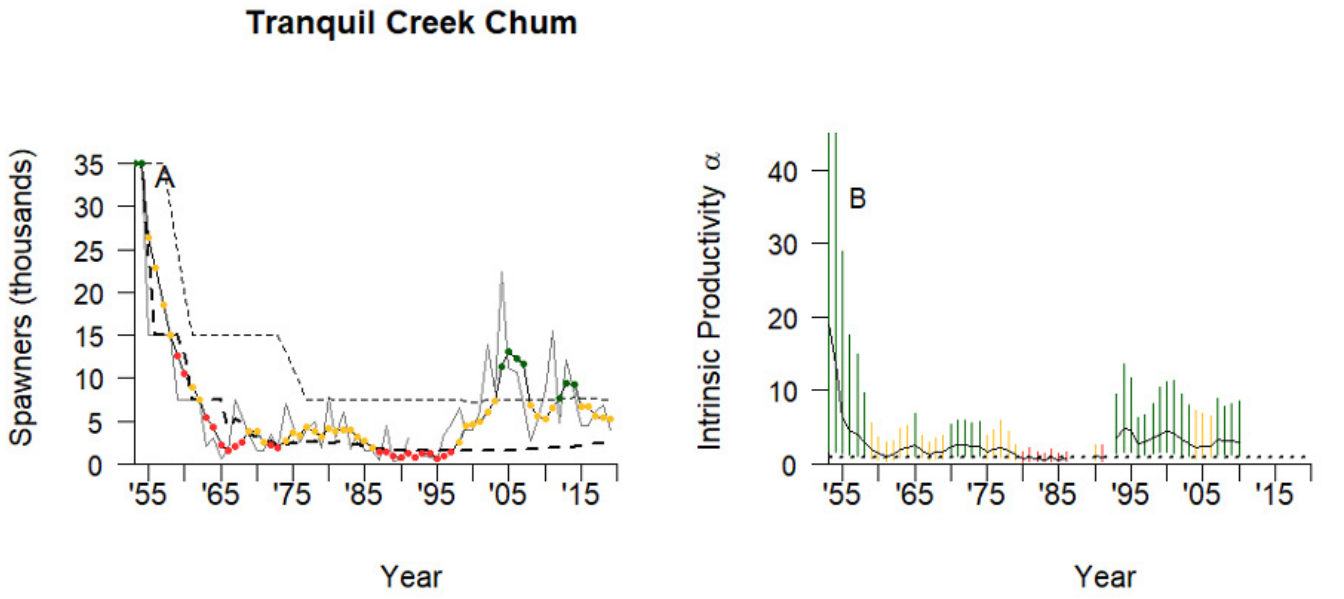
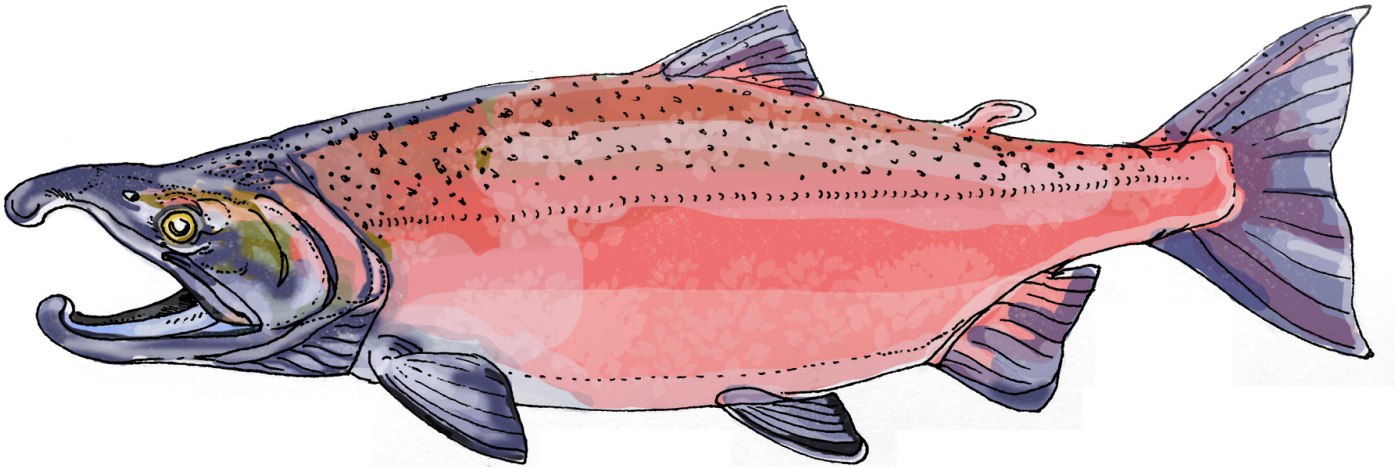


Figure 9. The time series for Tranquil Creek Chum showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points) showed dramatic declines below the lower benchmark (25th percentile = bold dash) at the beginning of monitoring that rebounded after the 2000s to around the upper benchmark (75th percentile = light dash) yielding an Amber percentile status. (B) The mean intrinsic productivity (black solid line) was below the benchmark of one recruit per spawner (black dotted line) during the 1980s but the latest 95% intervals (vertical lines) show a Green resilience status.



Coho

Coho stocks that were not Data Deficient or Data Limited, had healthier status assignments than Chum stocks. The majority of spawner-recruit and resilience status assignments for Coho stocks in Clayoquot Sound were Data Deficient (Table 4). While the majority of percentile status assignments were Amber, followed by Red, then Green (Map 3). All of the focal Coho stocks had a percentile status of Amber while resilience statuses were mostly Green. Coho stocks in the Megin (Figure 12) and Moyeha (Figure 13) were undergoing a recent decline. However, recent escapement did not decline to the extent of the trough, before the 1990s bump. Before the bump, these Coho stocks were often assigned a Red percentile status. The resilience trends for Megin and Moyeha Coho showed a steadily declining productivity, since the 1990s bump.

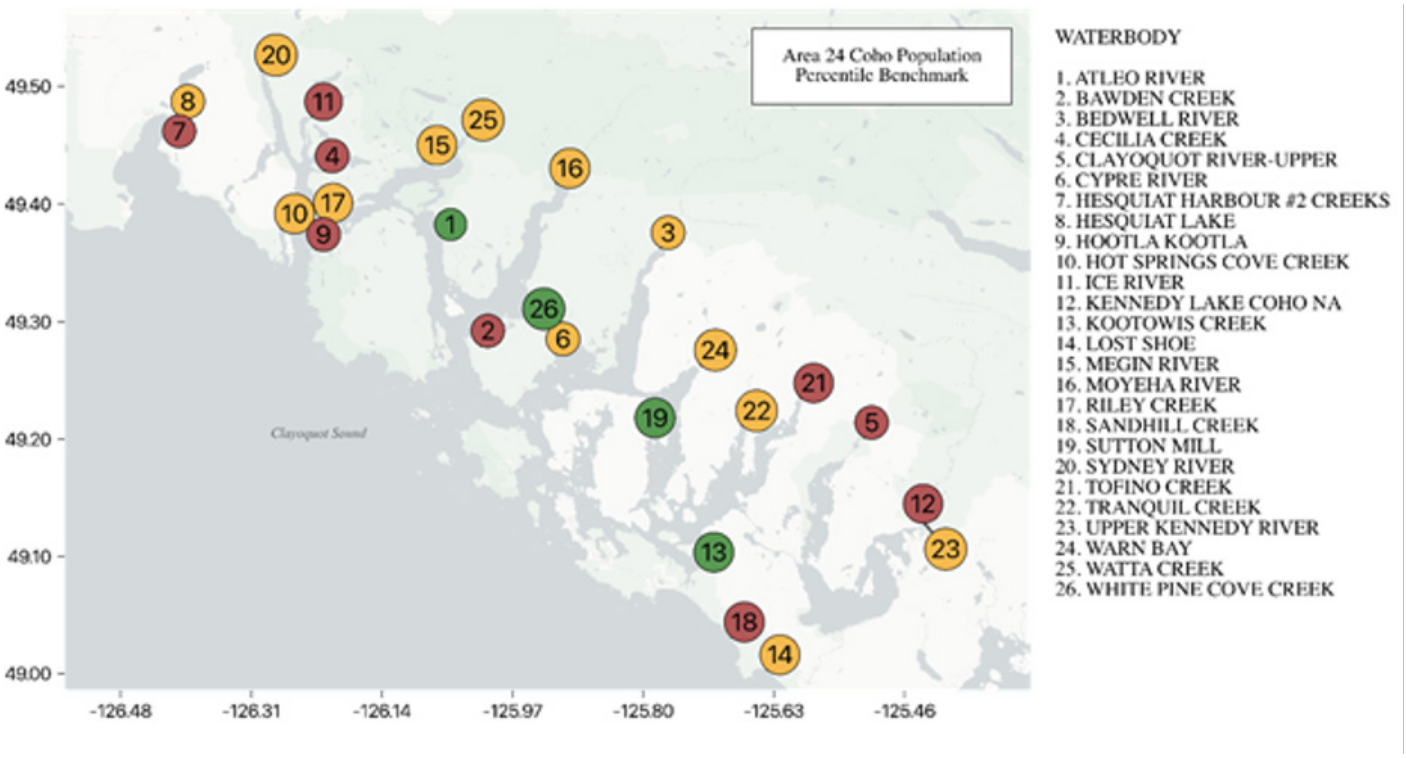
Between 1960 and 1990, Cypre River (Figure 14) and Tranquil Creek Coho (Figure 15) seemed to have experienced similar declines in abundance as other Clayoquot Sound Coho stocks. Cypre River Coho had a relatively stable bump in escapement and resilience since the 1990s that led to an Amber percentile and Green resilience status. The 1990s bump in escapement for Tranquil Creek Coho seemed relatively stable, giving the stock an Amber percentile and Green resilience status.

Table 4. Stock status assignments for Coho salmon populations in Area 24, Clayoquot Sound. Percentile, spawner-recruit, and resilience benchmark approaches are used to assign a status of either Green, Amber, Red, or Data Deficient (Grey). Data Limited populations (with less than 10 years of escapement data) are not included in this table.

Stock	Spawner-Recruit Abundance	Percentile Abundance	Resilience
Atleo River	Green	Green	Amber
Bawden Creek	Data Deficient	Red	Data Deficient
Bedwell River	Green	Amber	Green
Bedwell System	Data Deficient	Amber	Data Deficient
Cecilia Creek	Data Deficient	Red	Data Deficient
Clayoquot River-Upper	Data Deficient	Red	Data Deficient
Cold Creek	Data Deficient	Amber	Data Deficient

Table 4. Coho salmon statuses for Area 42 continued.

Cypre River	Green	Amber	Green
Hesquiat Harbour #2 Creeks	Data Deficient	Red	Data Deficient
Hesquiat Lake	Green	Amber	Amber
Hootla Kootla	Data Deficient	Red	Data Deficient
Hot Springs Cove Creek	Data Deficient	Amber	Data Deficient
Ice River	Data Deficient	Red	Data Deficient
Kennedy Lake	Data Deficient	Red	Data Deficient
Kennedy Lake Feeder Streams	Data Deficient	Red	Data Deficient
Kootowis Creek	Data Deficient	Green	Data Deficient
Lost Shoe	Data Deficient	Amber	Data Deficient
Megin River	Green	Amber	Amber
Moyeha River	Green	Amber	Green
Riley Creek	Data Deficient	Amber	Data Deficient
Sandhill Creek	Data Deficient	Red	Data Deficient
Sutton Mill	Data Deficient	Green	Data Deficient
Sydney River	Green	Amber	Green
Tofino Creek	Data Deficient	Red	Data Deficient
Tranquil Creek	Green	Amber	Green
Upper Kennedy River	Green	Amber	Green
Warn Bay	Green	Amber	Amber
Watta Creek	Data Deficient	Amber	Data Deficient
White Pine Cove Creek	Data Deficient	Green	Data Deficient



Map 3. The latest available Red, Amber, Green, and Data Deficient percentile status assignments for Coho salmon populations of Clayoquot Sound. The majority of populations had an Amber percentile status, followed by Red, then Green.

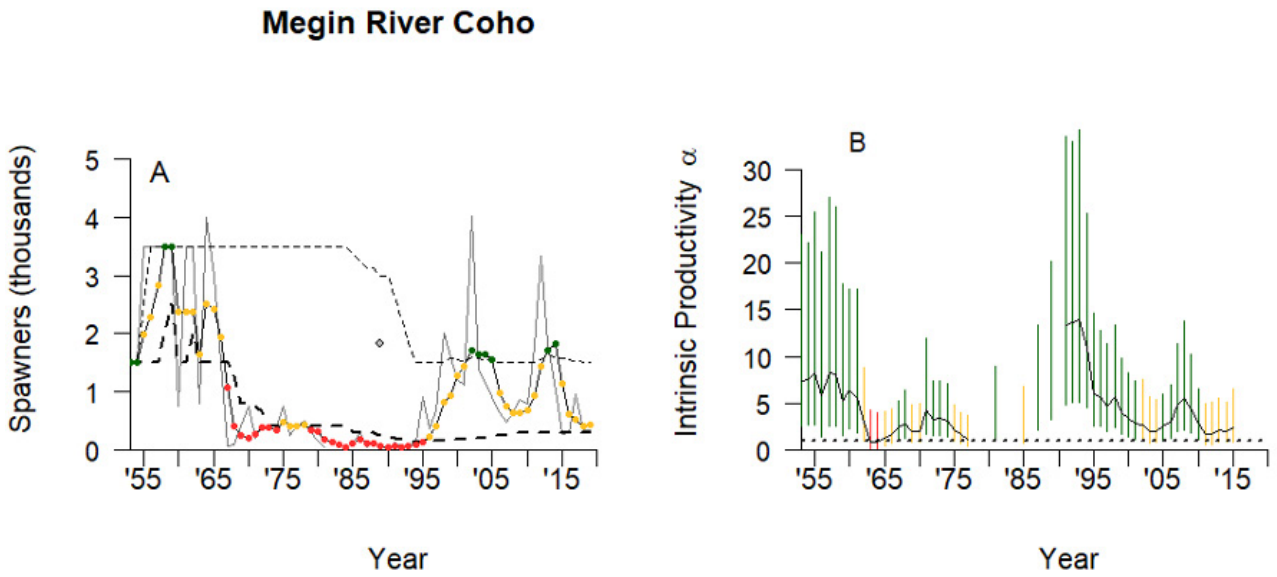


Figure 10. The time series for Megin River Coho showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) showed steep declines in the 1960s where escapement hovered below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) with an improvement in the 1990s, yielding an Amber percentile status. (B) The mean intrinsic productivity (black solid line) was below the benchmark of one recruit per spawner (black dotted line) during the 1960s but increased as the 95% intervals (vertical lines) showed a mix of Green and Amber resilience statuses again, with the latest resilience status being Amber.

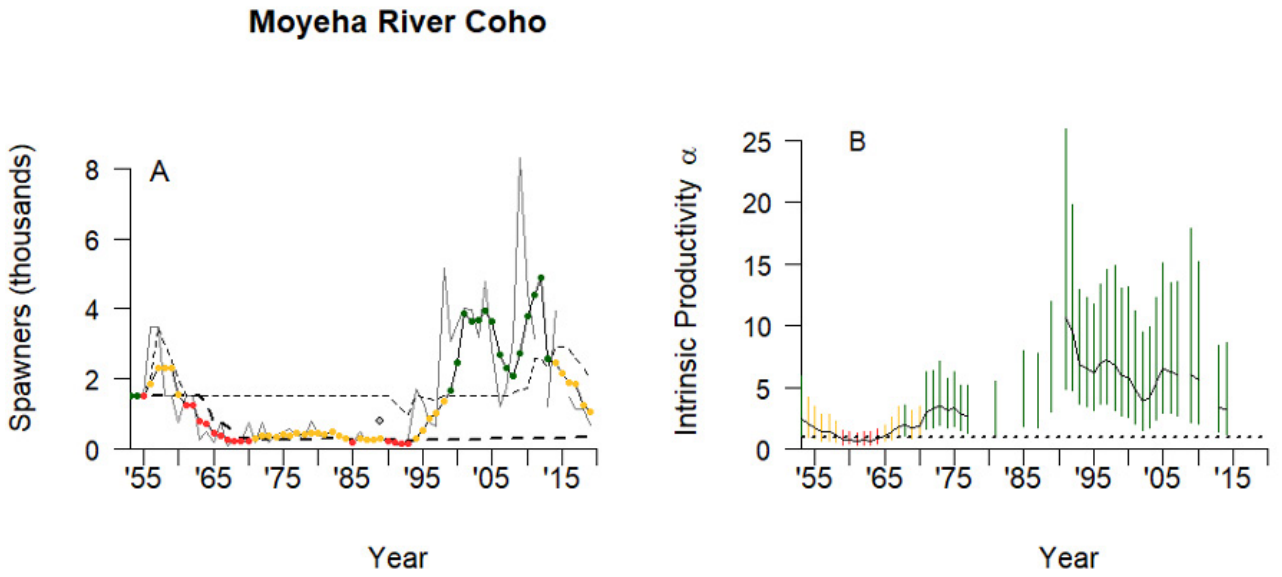


Figure 11. The time series for Moyeha River Coho showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) showed declines below the upper benchmark (75th percentile = light dash), to hover around the lower benchmark (25th percentile = bold dash) until increasing in the 1990s, ending with an Amber percentile status. (B) In the resilience time series, the mean intrinsic productivity (black solid line) was below the benchmark of one recruit per spawner (black dotted line) around the 1960s until the 95% intervals (vertical lines) went from Amber and Red to Green in the 1970s. The latest resilience status for Moyeha River Coho was Green.

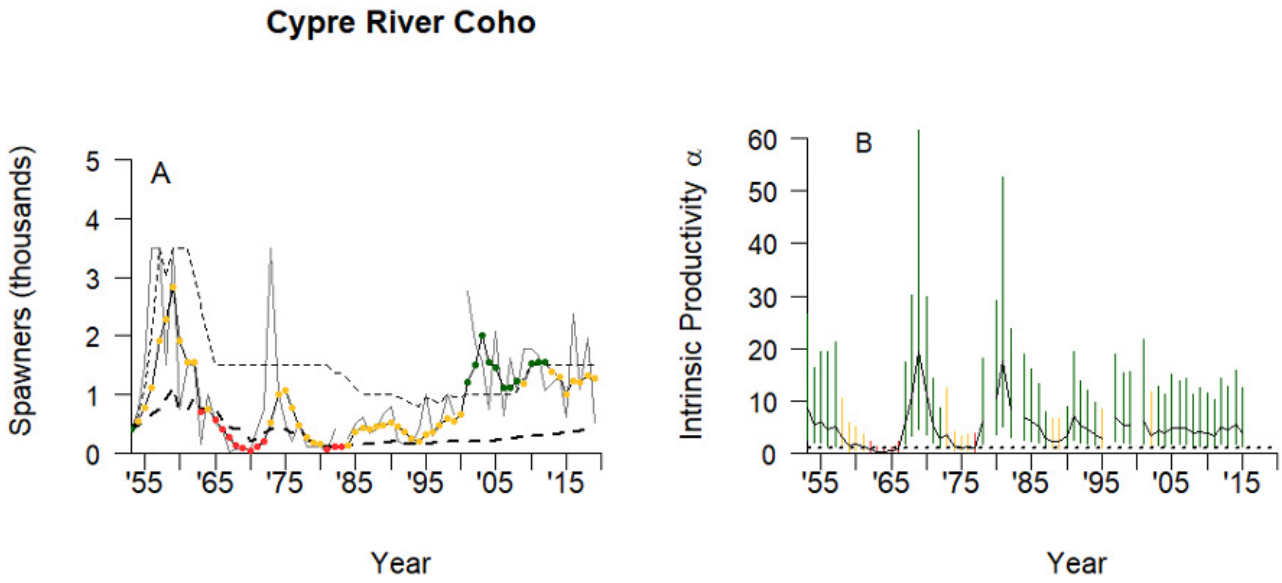


Figure 12. The time series for Cypre River Coho showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) declined below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) in the 1960s with a slow increase that resulted in an Amber percentile status. (B) In the resilience time series, the mean intrinsic productivity (black solid line) was below the benchmark of one recruit per spawner (black dotted line) in the 1960s until the 1980s when the 95% intervals (vertical lines increased to a mix of Green and Amber and ending in a Green annual resilience status.

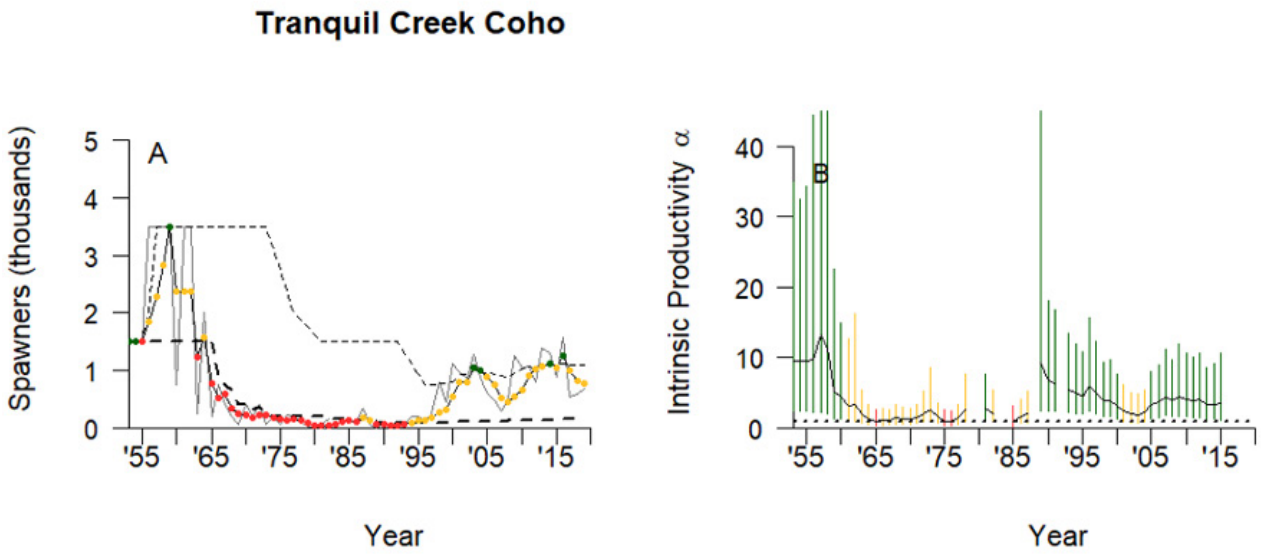


Figure 13. The time series for Tranquil Creek Coho showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) declined in the 1960s below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) yielding mainly Red percentile statuses with a smaller increase in the 1990s ending with an Amber percentile status. (B) In the resilience time series, the mean intrinsic productivity (black solid line) hovered below the benchmark of one recruit per spawner (black dotted line) between 1960-1990 but otherwise the 95% intervals (vertical lines) showed that annual resilience status was primarily Green and the latest resilience status being Green.

Chinook

Chinook stocks in Clayoquot Sound with sufficient data, were generally doing poorly (Table 5). However, Chinook stocks show higher resilience statuses and relatively high productivity. The majority of Chinook in Clayoquot Sound with sufficient data for status assignment were assigned Red percentile statuses (Map 4). Clayoquot Sound Chinook had fewer stocks with sufficient data for percentile status assignments than Chum and Coho. Resilience statuses were Data Deficient for all Clayoquot Sound Chinook. The 1990s bump in escapement was seen for all focal Chinook stocks. The 1990s bump was typically followed by an increase in productivity.

Megin River (Figure 17), Moyeha River (Figure 18), and Tranquil Creek Chinook (Figure 19) showed similar trends in escapement throughout the time series. Since the 1960s, Moyeha River Chinook dipped from under 1000 fish to under 100 fish. A slight increase occurred in the 1990s, but had since declined, resting at an Amber percentile status. Tranquil Creek Chinook declined below 100 between the 1960s and 1990s, but increased in abundance and productivity in the 1990s, resting at an Amber percentile status. Megin River Chinook went from nearly 1000 fish to near 0 for the rest of the time series, outside of the 1990s bump. Megin River Chinook rested at a Red percentile status.

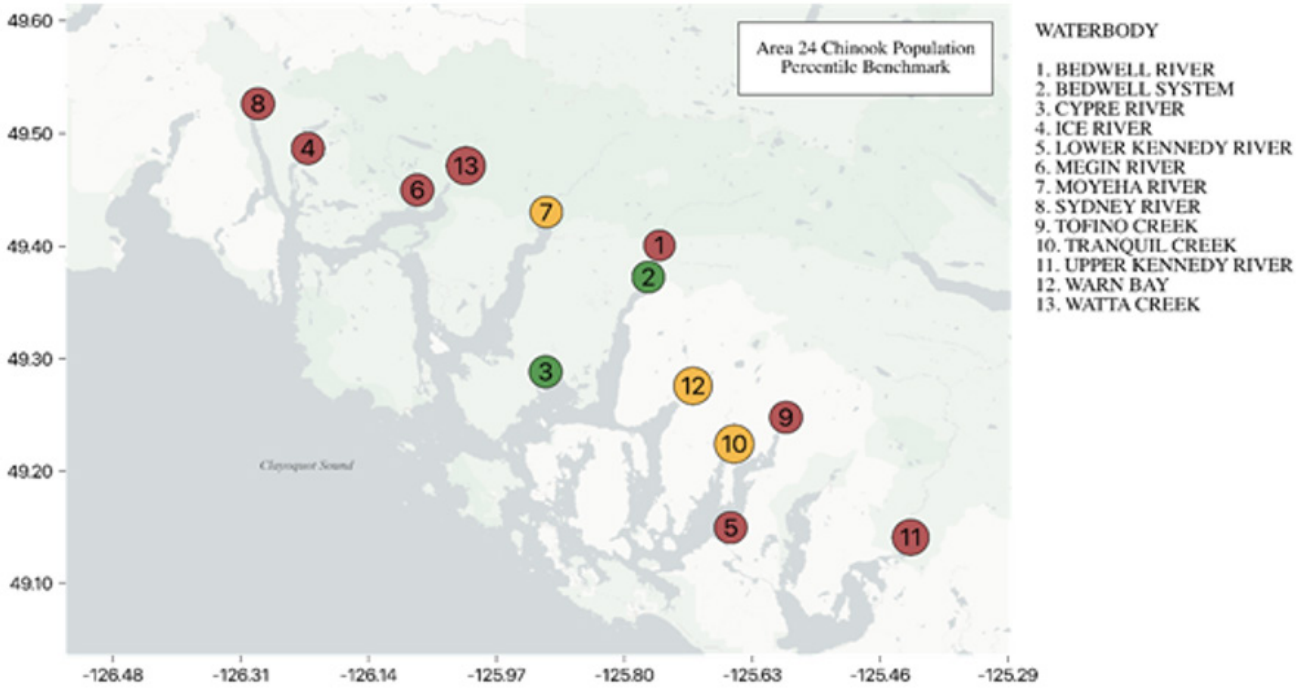
Cypre River Chinook (Figure 20) stock trends varied from the other focal stocks. Cypre River Chinook had a later bump, in the 2000s with a more sustained increase in escapement. Cypre River Chinook maintained a Green percentile status after the 2000s bump. The most recent escapement estimate was above the escapement before the 2000s bump. Cypre River Chinook had a minimum of one observed individual in 1994 before beginning to increase.

Table 5. Stock status assignments for Chinook salmon populations in Area 24, Clayoquot Sound. Percentile, spawner-recruit, and resilience benchmark approaches are used to assign a status of either Green, Amber, Red, or Data Deficient (Grey). Data Limited populations (with less than 10 years of escapement data) are not included in this table.

Stock	Spawner-Recruit Abundance	Percentile Abundance	Resilience
Bedwell River	Data Deficient	Green	Data Deficient
Bedwell System	Data Deficient	Red	Data Deficient
Cypre River	Green	Green	Green
Ice River	Data Deficient	Red	Data Deficient
Lower Kennedy River	Data Deficient	Red	Data Deficient

Table 4. Chinook salmon statuses for Area 42 continued.

Megin River	Amber	Red	Green
Moyeha River	Data Deficient	Amber	Data Deficient
Sydney River	Data Deficient	Red	Data Deficient
Tofino Creek	Data Deficient	Red	Data Deficient
Tranquil Creek	Red	Amber	Green
Upper Kennedy River	Data Deficient	Red	Data Deficient
Warn Bay	Data Deficient	Amber	Data Deficient
Watta Creek	Data Deficient	Red	Data Deficient



Map 4. The latest available Red, Amber, Green, and Data Deficient percentile status assignments for Chinook salmon populations of Clayoquot Sound. The majority of populations had a Red percentile status. Not including Data Limited populations.

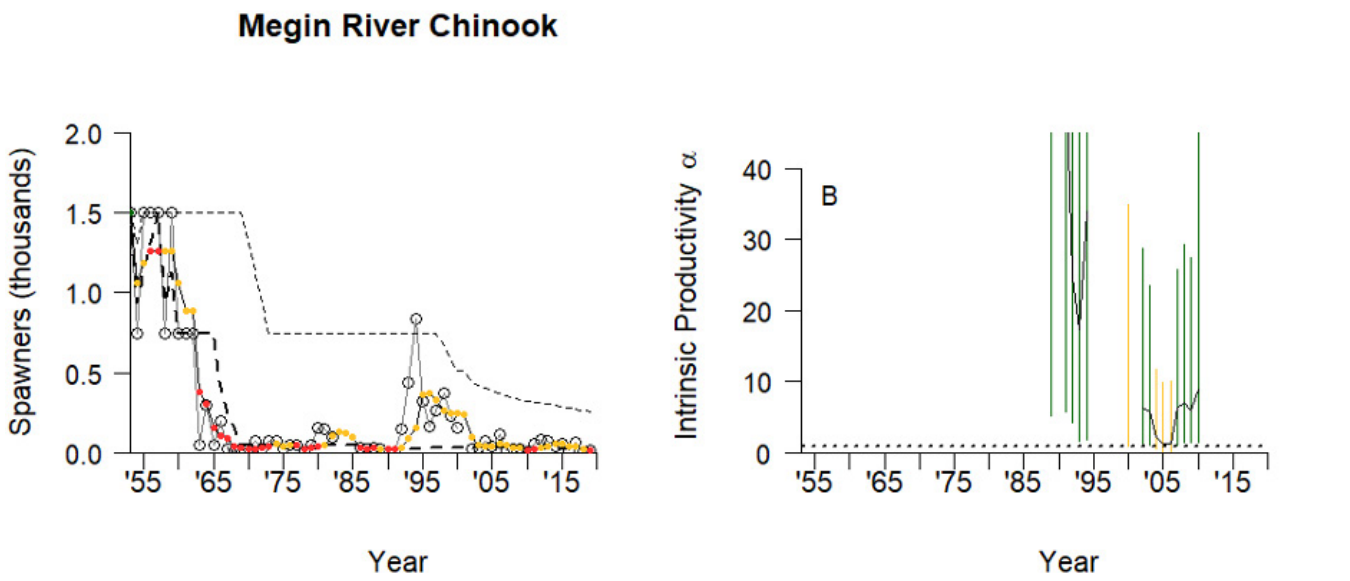


Figure 14. The time series for Megin River Chinook showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) declined in the 1960s below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) with a smaller increase in the 1990s, eventually declining to a recent Red percentile status. (B) In the resilience time series, the mean intrinsic productivity (black solid line) and the 95% intervals (vertical lines) was largely above the benchmark of one recruit per spawner (black dotted line) resulting in Green for the latest resilience status. Relatively few years were available where data was consistent enough to calculate intrinsic productivity.

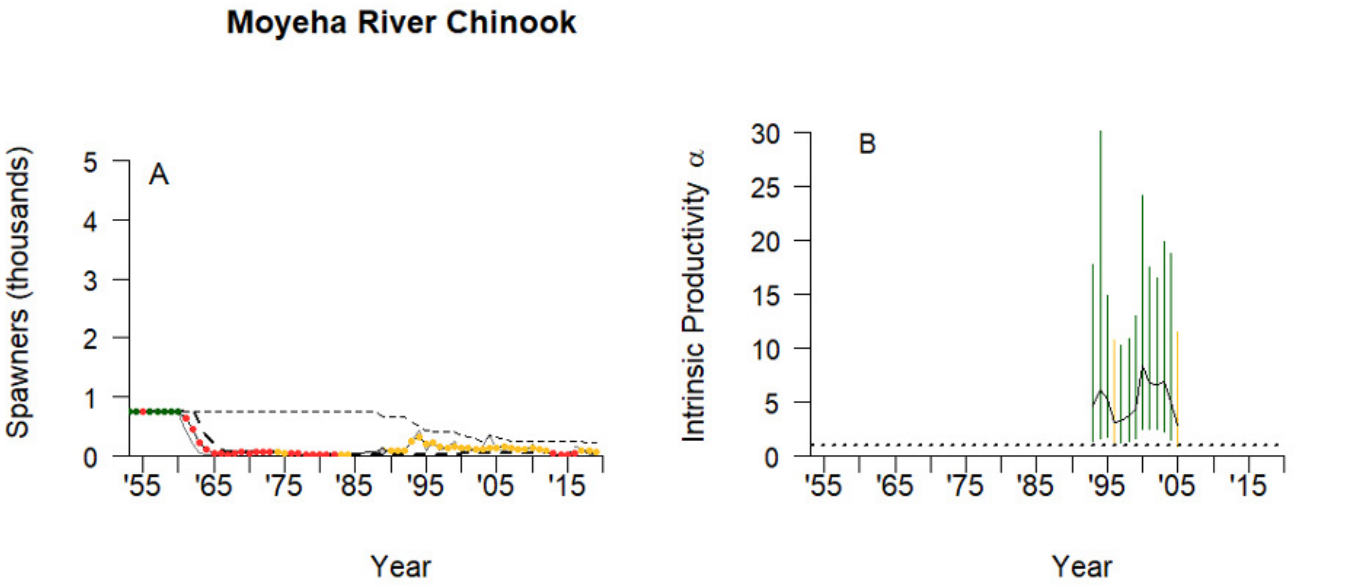


Figure 15. The time series for Moyeha River Chinook showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) declined below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) in the 1960s with a smaller increase in the 1990s, eventually declining but maintaining an Amber percentile status. (B) For the relatively few years where data was consistent enough to calculate intrinsic productivity in the resilience time series, the mean intrinsic productivity (black solid line) and the 95% intervals (vertical lines) were mostly above the benchmark of one recruit per spawner (black dotted line) but decreased, ending in an Amber annual resilience status.

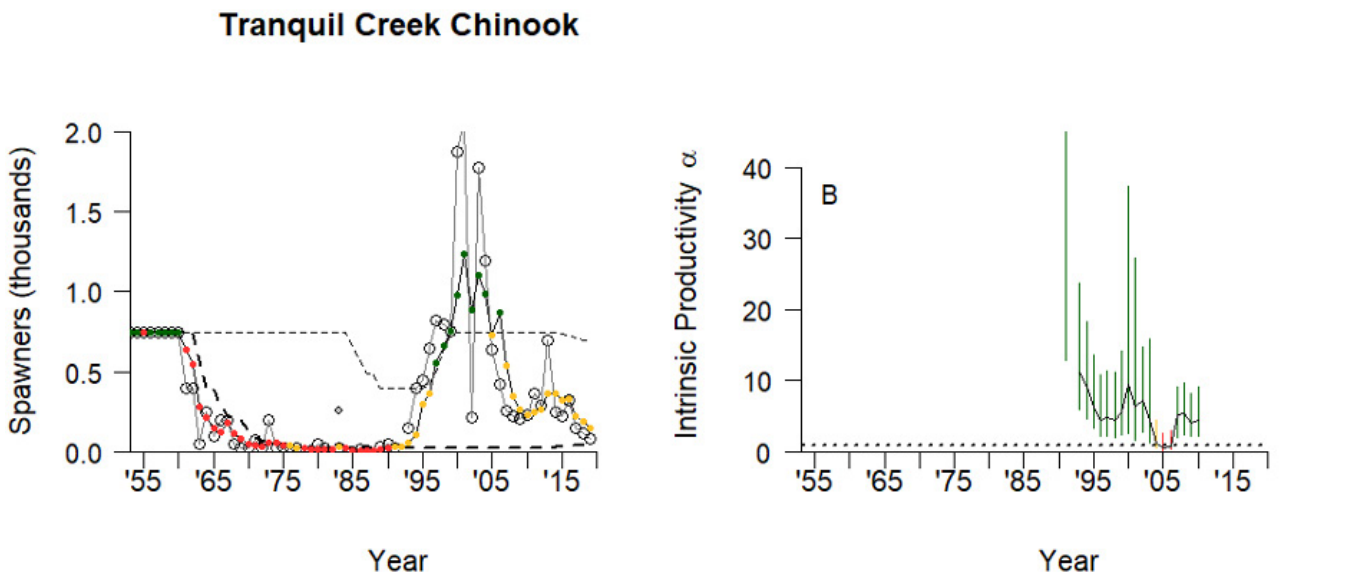


Figure 16. The time series for Tranquil Creek Chinook showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) declined below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) in the 1960s with an increase in the 1990s, but eventually declining to a recent Amber percentile status. (B) For the relatively few years where data was consistent enough to calculate intrinsic productivity in the resilience time series, the mean intrinsic productivity (black solid line) and the 95% intervals (vertical lines) declined over time, but were mostly above the benchmark of one recruit per spawner (black dotted line), ending in a Green annual resilience status.

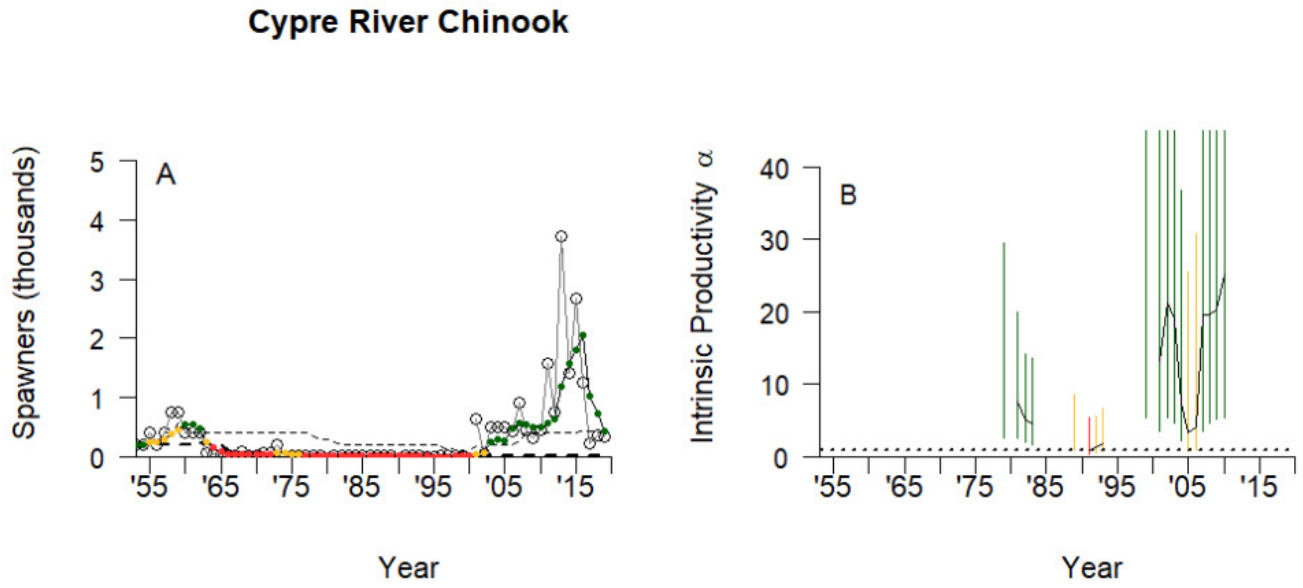
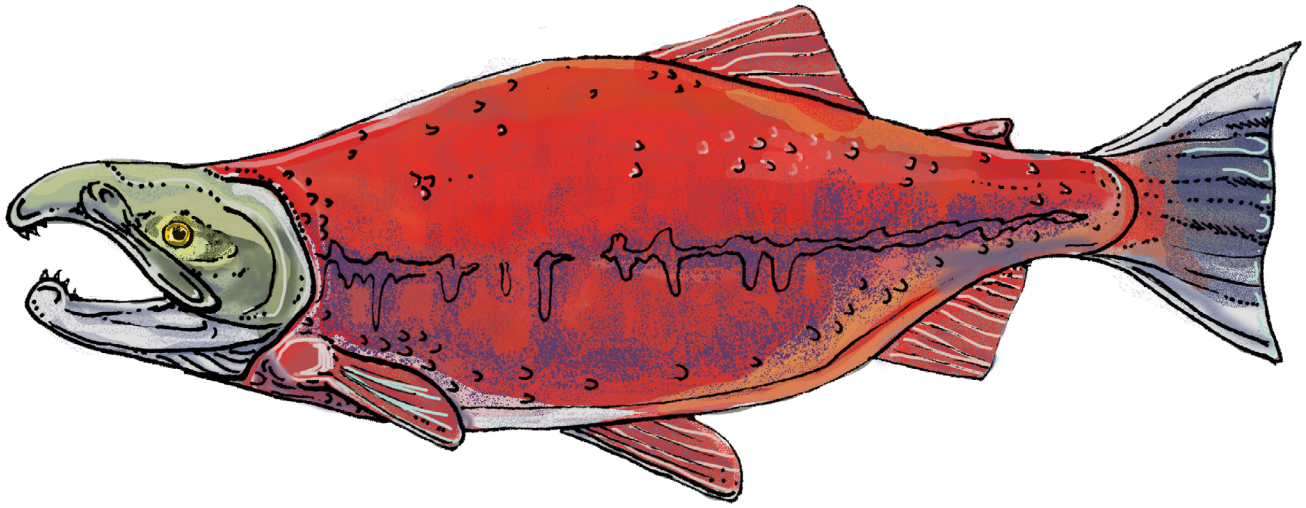


Figure 17. The time series for Cypre River Chinook showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The mean generational escapement (coloured points) declined below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) in the 1960s with an increase in the 2000s that has persisted as a Green percentile status. (B) In the resilience time series, the mean intrinsic productivity (black solid line) was below the benchmark of one recruit per spawner (black dotted line) around 1990, but the 95% intervals (vertical lines) were primarily Green for the relatively few years where data was consistent enough to calculate intrinsic productivity. The latest resilience status for Cypre River Chinook was Green.



Sockeye

Of the assessed stocks, Sockeye stocks were the most Data Deficient (Table 6). For Clayoquot Sound Sockeye stocks with a percentile status assignment, the majority were Amber (Map 5). The focal Sockeye stocks in Clayoquot Sound all show declines during the 1950s-60s and again in recent years. However, focal Sockeye stocks show variation in peaks or increases in escapement.

Sockeye stocks for Cypre River, Moyeha River, and Tranquil Creek, had below 10 individuals for the most recent escapement estimates. In 2019, Tranquil Creek Sockeye had an escapement of 0. Some of the highest historical escapement of major Sockeye stocks in Clayoquot Sound occurred in Kennedy Lake (Figure 22) and the Clayoquot System (Figure 23). Recent percentile statuses for these Sockeye stocks ranged from Red to Amber.

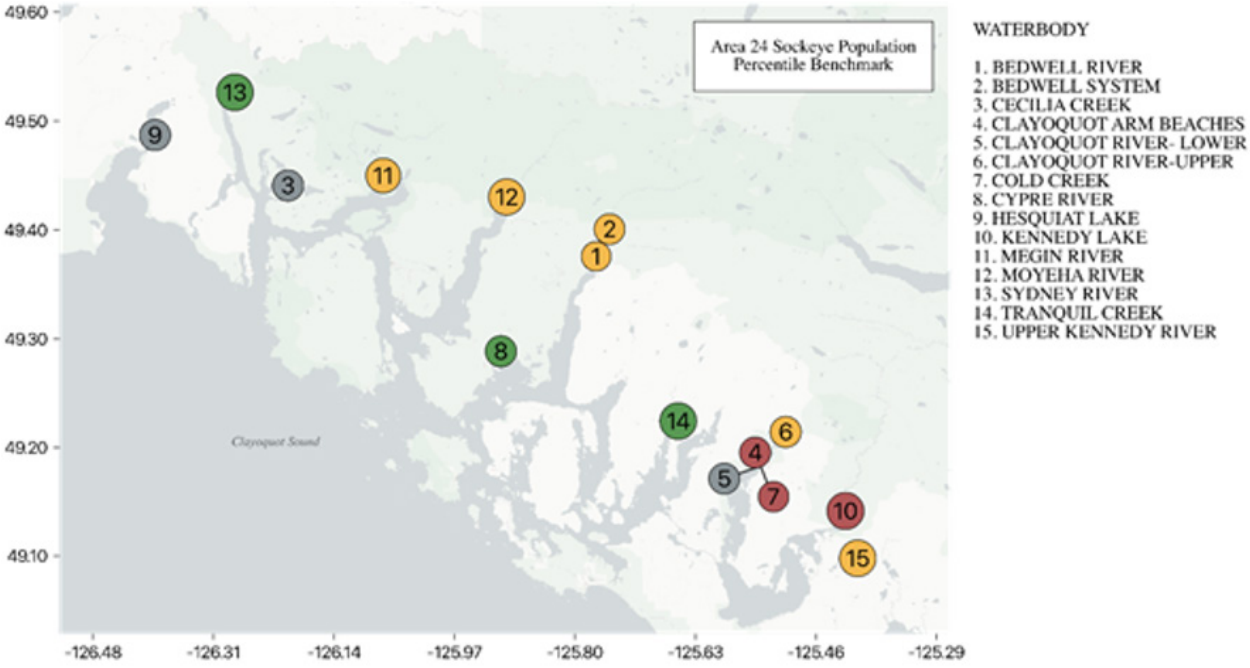
Megin River Sockeye (Figure 24) were assigned an Amber percentile status and Data Deficient resilience status. Megin River Sockeye decreased from the escapement abundance at the beginning of monitoring on WCVI and maintained a lower abundance into the present. Available estimates showed that intrinsic productivity was relatively high.

Table 6. Stock status assignments for Sockeye salmon populations in Area 24, Clayoquot Sound. Percentile, spawner-recruit, and resilience benchmark approaches are used to assign a status of either Green, Amber, Red, or Data Deficient (Grey). Data Limited populations (with less than 10 years of escapement data) are not included in this table.

Stock	Spawner-Recruit Abundance	Percentile Abundance	Resilience
Bedwell River	Data Deficient	Amber	Data Deficient
Bedwell System	Data Deficient	Amber	Data Deficient
Cecilia Creek	Data Deficient	Red	Data Deficient
Clayoquot Arm Beaches	Data Deficient	Red	Data Deficient
Clayoquot River-Upper	Data Deficient	Amber	Data Deficient
Clayoquot River-Lower	Data Deficient	Amber	Data Deficient
Cold Creek	Data Deficient	Red	Data Deficient
Cypre River	Data Deficient	Green	Data Deficient

Table 6. Sockeye salmon statuses for Area 42 continued.

Hesquiat Lake	Data Deficient	Amber	Data Deficient
Kennedy Lake	Data Deficient	Red	Data Deficient
Megin River	Data Deficient	Amber	Data Deficient
Moyeha River	Data Deficient	Amber	Data Deficient
Sydney River	Data Deficient	Green	Data Deficient
Tranquil Creek	Data Deficient	Green	Data Deficient
Upper Kennedy River	Data Deficient	Amber	Data Deficient



Map 5. The latest available Red, Amber, Green, and Data Deficient percentile status assignments for Sockeye salmon populations of Clayoquot Sound. The majority of populations had an Amber percentile status. Not including Data Limited populations.

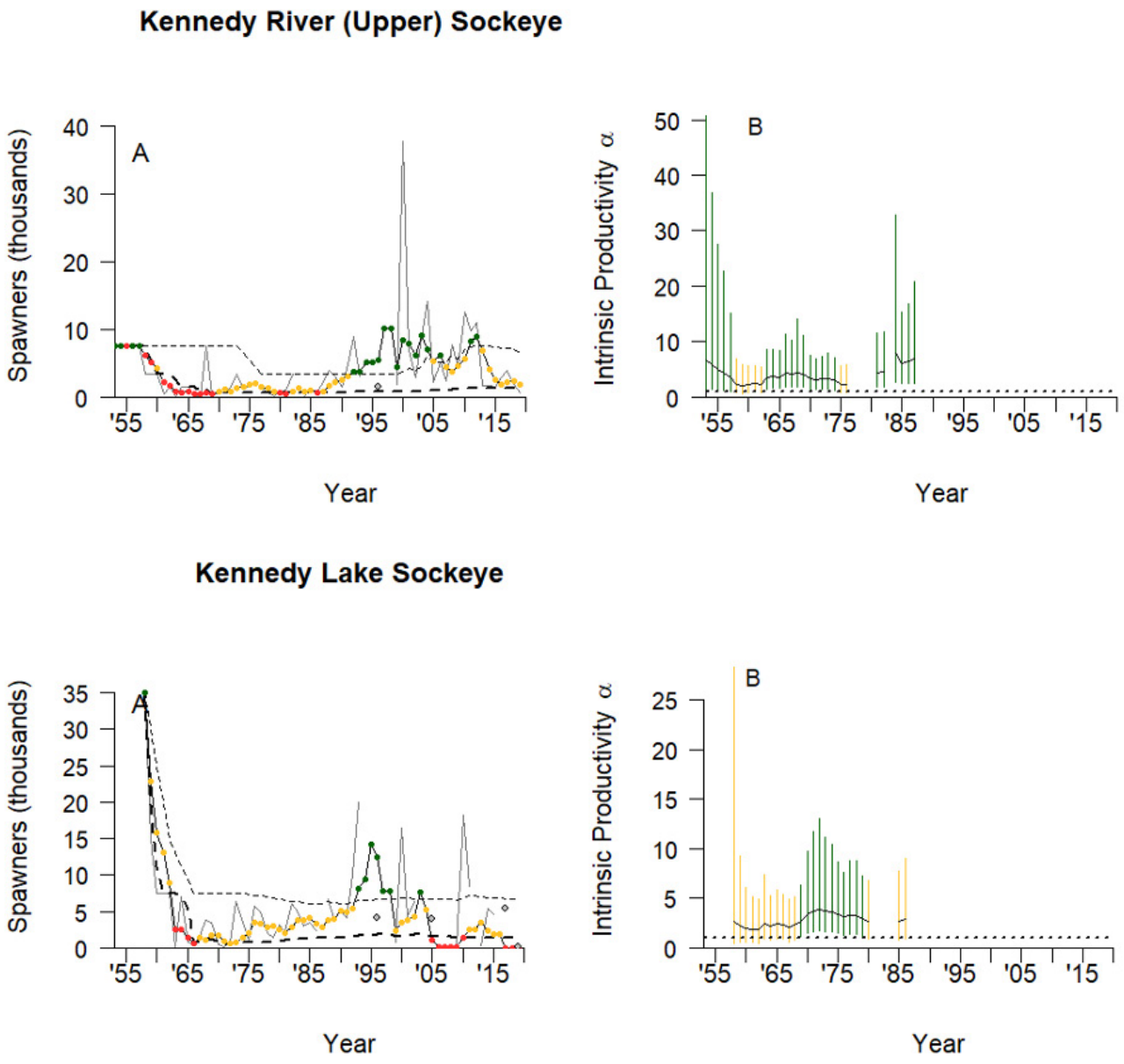


Figure 18. The time series for Kennedy System Sockeye showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points) for Clayoquot System Sockeye showed a decline in the 1960s that increased over the 1990s before declining to an Amber status for Kennedy River Sockeye and a Red status for Kennedy Lake Sockeye. (B) In the resilience time series, the mean intrinsic productivity (black solid line) and the Data Deficient 95% intervals (coloured vertical lines) were mostly above the benchmark of one recruit per spawner (black dotted line), ending in a Green resilience status for Kennedy River Sockeye and an Amber resilience status for Kennedy Lake Sockeye.

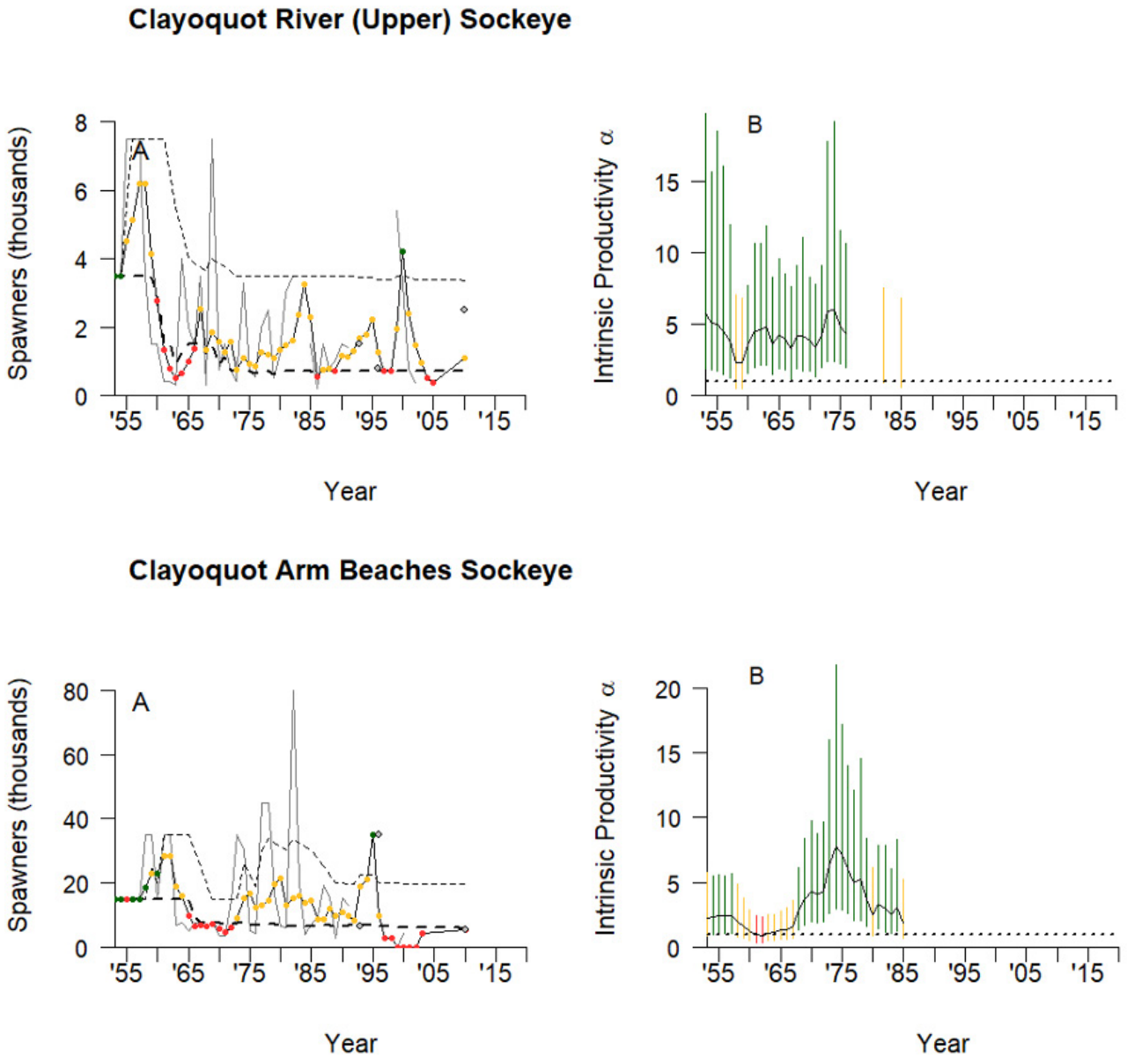


Figure 19. The time series for Clayoquot System Sockeye showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points) for Clayoquot System Sockeye showed a decline in the 1960s below the upper (75th percentile = light dash) and lower benchmark (25th percentile = bold dash) and in recent years, yielding a Red percentile status for Clayoquot Arm Beaches Sockeye, and an Amber percentile status for Upper Clayoquot River Sockeye. (B) In the resilience time series, the mean intrinsic productivity (black solid line) and the Data Deficient 95% intervals (coloured vertical lines) were mostly above the benchmark of one recruit per spawner (black dotted line) for Upper Clayoquot River Sockeye more than for Clayoquot Arm Beach Sockeye.

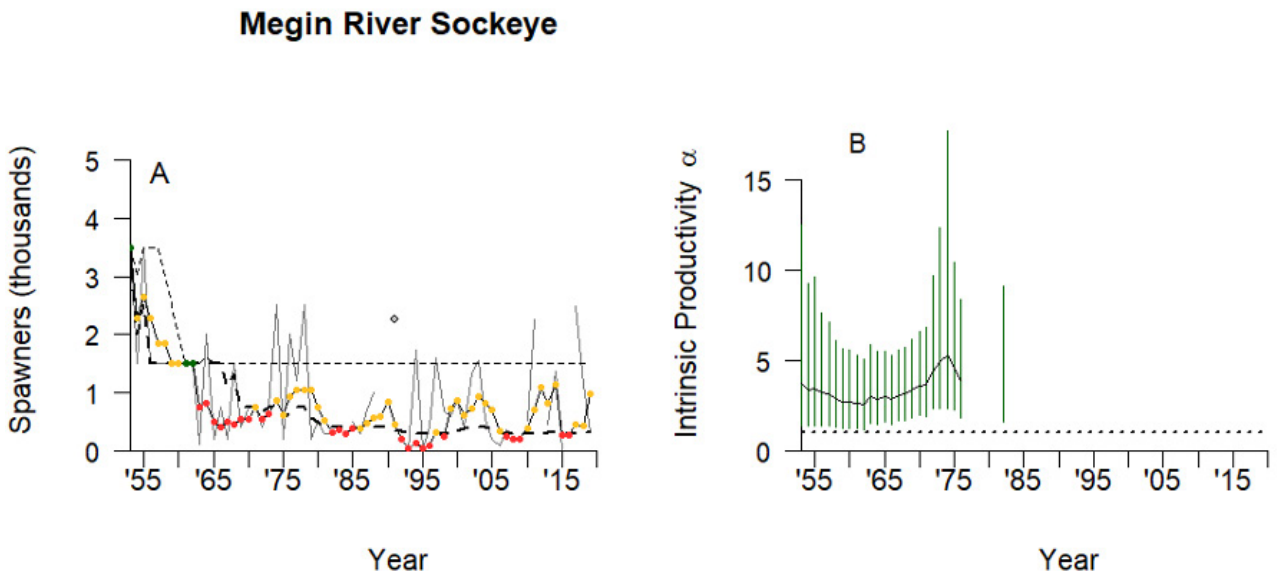


Figure 20. The time series for Megin River Sockeye showing the escapement (grey line) with percentile status assignment (A) and productivity with resilience status assignment (B). (A) The time series showing mean generational escapement (coloured points) for Megin River Sockeye showed a decline in the 1960s and in recent years, yielding an Amber percentile status. (B) In the resilience time series, the mean intrinsic productivity (black solid line) and the Data Deficient 95% intervals (coloured vertical lines) were above the benchmark of one recruit per spawner (black dotted line).

A Chum salmon swimming upriver. Photo: Mack Bartlett

Discussion

We conducted this assessment to understand the state of Pacific salmon stocks on WCVI, with a focus on Clayoquot Sound. We found similar general results to stock assessments from a decade prior; many stocks are doing poorly (DFO 1999, 2002, 2012). Our updated assessment revealed a recent decline across species in Clayoquot Sound. Despite fisheries closures and restrictions in Clayoquot Sound, the majority of focal stocks have declined within the last few years; some major stocks reached a return of zero or near zero in the last couple of years. Many stocks seem to be at greater risk of extinction (Red status) and require immediate protection according to the WSP. Our assessment showed that for the salmon stocks with enough consistent data, intrinsic productivity was often high. High intrinsic productivity could facilitate an increase for some stocks, if released from stressors.

Status assignment and an understanding of the state of salmon on the WCVI and Clayoquot Sound was limited due to limited data. The majority of stocks - especially smaller stocks without hatchery production - had an unknown status. Focusing on major hatchery stocks as indicators of the state of the many wild stocks may bias the available data. These potential biases could veil the true state of Pacific salmon on WCVI and Clayoquot Sound. Small stocks' status are important to understand as they can be genetically diverse and genetic diversity adds resilience within species' CUs (Carlson & Satterthwaite, 2011; Schindler et al., 2010).

Status Assignments

Together, the three benchmarks provided a clearer picture of the current state of WCVI wild salmon stocks. For stocks in WCVI and Clayoquot with sufficient data, the different benchmarks indicated different proportions of Green, Amber, and Red status assignments. The percentile benchmarks for stocks at the Clayoquot and WCVI level indicated a greater proportion of Amber status assignments, closely followed by Red. While both the majority of spawner-recruit and resilience status assignments for stocks at the Clayoquot and WCVI level were Green.

An interpretation of these seemingly contradictory status assignments comes in three points. The first point is that the spawner-recruit status assignment seemed to have

squeezed S_{MSY} and S_{GEN} benchmarks for stocks with low productivity. In our analysis, squeezed benchmarks occurred when the upper benchmark was drawn down toward the lower benchmark. The squeezed benchmarks reduced the range of abundance where Amber status could be assigned while increasing the range where Green status can be assigned. When the productivity is low enough for benchmark squeeze, the application of spawner-recruit benchmarks should be called into question; any yield on a depressed stock may not be appropriate, let alone MSY.

The second point is to note the difference in timing between status assignments from different benchmark approaches. Spawner-recruit and resilience status assignments lag behind by at least one generation from the latest data point. The percentile status assignment does not lag behind by a generation, meaning it can include the recent decline in stocks. Within the span of a generation, some stocks have experienced a decline. For example, Chum stocks from Moyeha River, Cypre River, Atleo River, and Tranquil Creek experienced a recent decline since the 1990s bump. For some stocks, the spawner-recruit and resilience benchmark approaches consider returns that were still steady from the 1990s bump.

Lastly, the spawner-recruit and resilience benchmarks are also more sensitive to inconsistent observations of returns because productivity calculations require data for all recruits, for a given brood year. To have consecutive spawner-recruit and resilience status assignments, uninterrupted, annual monitoring is needed. The source of bias is that more consistent monitoring occurs when a stock has higher returns (Price et al., 2008; Van Will et al., 2009). Thus, the available spawner-recruit and resilience status assignments are more often possible during periods of higher returns or for stocks with high returns. It is the greater representation stocks with high abundance that can make inference on the overall state of WCVI appear healthier. Data availability that favours stocks with a higher abundance affects all three benchmark approaches for all areas of WCVI. It may be worth repeating that the majority of WCVI stocks have insufficient data for any status assignment.

Stocks with Insufficient Data

Both Data Deficient and Data Limited stocks make up about three quarters of the documented stocks across WCVI. The data deficiency across WCVI may give more credibility to the percentile benchmark approach, which has fewer data requirements. Calculating percentile benchmarks does not require consecutive data points. Despite the more biologically informed approach of resilience and spawner-recruit benchmarks, percentile benchmarks provided more coverage of stocks and more recent statuses. Recent status assignments promote responsive and holistic management, especially for stocks with high interannual variability. As the status of the majority of stocks are unknown, the state of salmon in Clayoquot Sound relies heavily on inference from major stocks, such as the focal systems of this report.

Exploring Stock Stressors

Stressors Correlated with Stock Trends in Focal Systems

Stock trends in Clayoquot Sound were similar between and within species rather than within systems (Appendix C). For example, across all the focal systems, Chinook and Coho shared similar stock trends that neither Chum nor Sockeye shared. All focal stocks for Chinook and Coho in Clayoquot showed similar troughs around the time of destructive logging practices and high Hr, in the 1970s-80s (DFO 2002, 2011, 2016; McHugh & King, 2018; Peterman & Pyper, 2000). Focal Chinook and Coho stocks in Clayoquot also shared a trend of increased escapement around the 1990s after enhancement began in earnest and strict fisheries closures were introduced. Hatchery stocking for Chinook and Coho is done for Cypre and Tranquil, but the other focal systems showed the same stock trends (DFO 1999, 2002, 2016; PSC, 2021). For the 1990s increase of the focal Chinook and Coho stocks, it is possible that the release from high Hr was a more significant factor than hatchery input. Straying could be another speculative explanation.

Chum and Sockeye stocks in Clayoquot Sound showed higher variation in stock trends across

systems than Chinook and Coho. Chum stocks in Clayoquot Sound experience low Hr. Sockeye in Clayoquot Sound have relatively low hatchery output in Area 24 (DFO, 1999; PSC, 2021a). With a reduction in the major influences of harvest and hatchery production, system-specific variation may be seen more clearly. System-specific influences include factors such as productivity, volume, flow rate, erosion rates, coarse woody debris, and microclimates (Rajala, 1999).

Stressors Correlated with Stock Trends Across Species

Despite having some of the highest escapement, WCVI Chum stocks showed the greatest number and proportion of stocks with a Red percentile status, relative to other WCVI salmon species. WCVI Chinook have the greatest proportion of Green stocks relative to other WCVI salmon species despite often having smaller stocks relative to Chum. The reason for the difference in stock status between Chum and Chinook may be due in part to differences in hatchery outputs and Hr. Chinook have a greater hatchery output than Chum (DFO 2002, 2016; McHugh & King, 2018; PSC, 2021). For some stocks, the peaks that follow hatchery production are sometimes greater than any previous peaks documented by enumeration. Meaning that hatchery production may be inflating the escapement while overfishing in previous years may have drawn down the benchmarks for WCVI Chinook stocks. Lower benchmarks make it more likely that inflated WCVI Chinook abundance will be assigned a Green status. Despite high hatchery production (DFO, 2012) and fishery restrictions (DFO, 2016), Chinook stocks in Clayoquot Sound are experiencing a further decline.

In the focal area of Clayoquot Sound, the majority of Chinook stocks had Red status assignments. Clayoquot Sound has no major hatcheries but still contributes millions of juvenile Chinook salmon per year (DFO, 2012). Chinook in Clayoquot Sound have experienced high Hr throughout the time series (DFO, 2012). Although recent Hr for Chinook in Clayoquot Sound has been reduced, Chinook continue to decline. A similar decline is seen for other species in Clayoquot Sound. For example, Chum stocks in Clayoquot Sound also have a majority of Red percentile status assignments. The majority of Coho and Sockeye stocks in Clayoquot had an Amber percentile status assignment. The contribution of individual stressors to the status assignments of Clayoquot salmon stocks is unclear. Differing combinations of stressors are likely at play for each of the species and focal systems.

Stressors Correlated with Stock Trends Across Clayoquot Sound

The sources of the declines in Clayoquot salmon may be present in all life stages, from both natural and human-caused stressors. Natural stressors include competition, predation, and variation in climate due to the Pacific Decadal Oscillation (Price et al., 2008; Waples et al., 2009). In Area 24, the present and historical human impact on salmon stocks include overfishing (DFO, 1999, 2002, 2012; PSC, 2021), hatchery competition (Price et al., 2008; Waples, 1991; Weber & Fausch, 2003), homogenization of wild with hatchery stocks (Carlson & Satterthwaite, 2011; Withler et al., 2018), habitat degradation from logging practices (DFO, 1999, 2002; Price et al., 2008; PSC, 2012; Rajala, 1999), pathogen transmission from fish farming (Bateman et al., 2021; DFO, 2002; Price et al., 2008c; Shea et al., 2020), and climate change. Recent local reports describe the interrupted access between river and sea caused by heat waves and drought which affects juvenile outmigration. Other symptoms of climate change have a negative effect on freshwater and marine survival of salmon stocks (Barange et al., 2018). Coho and Sockeye have especially poor marine survival and documented sensitivity to years with high average SST (DFO, 1999, 2002).

In Clayoquot Sound, declines occurred across species in the 1960s and 1970s. Poor logging practices are known to have degraded riparian areas in Clayoquot Sound in the 1970s - 1980s (McHugh & King, 2018). The contributions of poor logging practices and overfishing to the initial declines of salmon stocks is unclear. However, the troughs in escapement across species seemed to correlate with the timing of poor logging practices and high Hr. Focal streams that incurred degradation from logging have since stabilized and Hr continues to be largely restricted across species (McHugh & King, 2018). However, recent years show declines across species. Proposed sources of recent declines in Clayoquot Sound include pathogen transmission from fish farms (DFO, 2012) and

heat waves (Cai et al., 2014; DFO 1999, 2002; Eliason et al., 2011; Smale et al., 2019).

Proposed sources of recent declines in Clayoquot Sound seem to be primarily associated with marine survival. Climate change is a large-scale stressor that presents a number of specific stressors at different life stages in salmon, including increased SST, reduced oxygen levels, reduced prey, and reduced habitat availability (Barange et al., 2018). Marine survival can also be affected by human activity such as fish farms. Juvenile and adult salmon incur mortality from pathogens that are transmitted by fish farms such as sea lice infestations, Piscine Orthoreovirus (PRV), and Tenacibaculum maritimum infections (Bateman et al., 2021; CCFS, 2020; EAO, 1997; Krkosek et al., 2005; Mordecai et al., 2021; Peacock et al., 2013; Shea et al., 2020).

Consideration for Sources of Uncertainty

What the State of the Data Means for the State of the Salmon

The accuracy of status assignments is dependent on the quality, uncertainties, and biases of the data used. All data came from DFO. Throughout the assessment, we tried to align our methods with that of DFO stock assessment and WSP. The number of systems monitored has declined over the years and the methods used to enumerate the documented systems change. Another source of uncertainty and potential bias is found in the use of indicator stocks. If uncertainty and bias result in healthier status assessments or unassigned status, management may miss critical windows of opportunity for conservation and restoration of important salmon stocks. Lastly, the framework itself may focus on a narrow definition of stock status. For example, the spawner-recruit approach assigns status using MSY which can miss out on aspects of a stock that are integral to productivity, such as female to male ratios or age distributions (Frid & Atlas, 2020; Ohlberger et al., 2020).

Declining Enumeration Effort

In further exploring sources of inaccuracy, first we return to the declining enumeration effort and two important aspects of status assessment that may be missed as a result. Enumeration efforts typically focus on stocks with consistently higher abundance (Price et al., 2008; Van Will et al,. 2009). The focus on major stocks created a data gap in escapement for naturally smaller stocks (Appendix A) and stocks that have collapsed (ex. Atleo, Meares, and Bedwell River Chum). The data gap is seen in the high proportion of Data Deficient and Data Limited stocks which make up the majority of status assignments. Assessments of the state of salmon that can include the depressed stocks may offer a more realistic assessment and would likely increase the degree of urgency for conservation measures. Having status assignments for more salmon stocks - including smaller stocks with fewer data - may also offer a look at the state of genetic diversity along WCVI, giving a clearer picture of overall resilience. Resilience is increasingly important for salmon stocks confronted with the rapidly changing stressors presented by climate change. Management considerations that include smaller stocks may increase the chances of successful adaptation to these mounting pressures.

Changing Enumeration Methods

Second, we consider the uncertainty around changing enumeration methods over the course of the time series. Escapement data throughout 1953 – present have been collected using multiple methods within and between years, each with their respective accuracy and precision. An example of low accuracy methods include enumeration using rough visual estimates to the thousandth which was done in the early monitoring years. These rough estimates are seen in the step-like escapement of time series (ex. Tranquil Creek Chum). In general, early enumeration likely has low accuracy. The uncertainty in enumeration is also specific to systems or annual climate trends. For example, “flashy” systems with abruptly high levels of rainfall can flush out the carcasses used for mark recapture studies (McHugh & King, 2018). If marked individuals are flushed before being surveyed, the system may have inflated escapement estimates. Although some error in productivity is integrated into our stock assessments, we have not accounted for error specific to systems nor error caused by combining estimates from different enumeration methods.

Indicator Stocks

Finally, we consider the uncertainty around the use of indicator stocks. The data from one larger,

more consistent indicator stock in an area is sometimes used in the calculation of returns for stocks across multiple areas. The use of indicator stocks may result in assessments that miss out on important aspects of the state of the salmon. Indicator stocks are typically more consistently abundant. If indicator stocks are used to reflect the state of a region, the assessment may be inflated.

Indicator stocks are also often associated with high hatchery production (ex. Nitinat River Hatchery, Stamp River Hatchery, Conuma River Hatchery). Using data from hatchery returns may introduce bias in the age at return and catch data. Hatchery fish may return earlier (Thorpe, 2004) which could skew the calculation of returns for other stocks. Hatchery fish may also be easier to catch (Nelson et al., 2005) making the harvest rate inflated if applied to other stocks. An inflated harvest rate may inflate the estimated return. The potential biases associated with indicator stocks result in an inflated assessment that could assume a healthier state than is true.

Hatchery Stocks

Hatchery stocks have a relatively large presence on WCVI and can be difficult to distinguish from wild stocks without confirmation in the lab. Wild stocks are important contributors to the genetic resilience of WCVI salmon and their management needs are distinct from hatchery stocks. By including hatchery spawners in escapement estimates, the resultant abundance and productivity estimates may be inflated. Systems with major hatcheries like the Conuma, Nitinat and Somass can distinguish hatchery spawners as those that return to the hatchery proper. A high homing rate back to the hatchery reduces the risk of inflating estimates of productivity or abundance for wild stocks. However, hatchery-reared spawners stray into other systems (Withler et al., 2018). It is unclear whether stray hatchery spawners veil the status of wild stocks by inflating the escapement.

Harvest Rates

Uncertainties in Hr depend partially on matching the origin of the catch to the fishery management area. Matching catch with the area of origin can be based on Coded Wire Tags (CWT) from hatchery fish or genetic information with catch location. The accuracy of these catch estimates may also depend on the communication of catch origin between American and Canadian fisheries. Catch reporting becomes more difficult to coordinate internationally. Consistency in reporting of mixed origin catch between American and Canadian fisheries can be unreliable (PSC, 2021a, 2021b). Hr may appear lower than reality if harvest of salmon from a WCVI area goes undeclared. Other uncertainties include the validity of the assumption that hatchery and wild fish or different age classes experience the same levels of exploitation. A lower Hr can lower the estimates of returns (Equation 2) which can then lower estimates of recruits (Equation 3), which lower the productivity and affect status assessment.

Shifting Baselines

Shifting baselines can also adjust the position of the benchmarks used to assess stocks. For many WCVI stocks, the highest escapement estimates were recorded when monitoring began at which point large scale harvest may have already affected salmon abundance (Price et al., 2019). As the assessment may start at a lower point than the true baseline abundance, calculated benchmarks assume a lower natural abundance. Lower baselines may lead to status assignments that overestimate the stability of these stocks (Pauly, 1995).

Implications for Management

Low escapement may make some WCVI stocks more sensitive to stressors. Stretches of consistently low escapement - at times 0 or 1 individuals detected - in some stocks suggests that any mortality on returning spawners may have a high impact on the long-term survival of those stocks. Stocks with recent stretches of low escapement include but are not limited to those returning to Kennedy Lake, the Megin River Chum/Chinook, the Moyeha River Chum/Chinook, and the Atleo River.

Despite low escapement, the time series showed that many WCVI stocks have high intrinsic productivity and resilience. High intrinsic productivity estimates suggest that WCVI salmon could improve if released from stressors. Although some stressors such as climate change are less immediately manageable, management of certain known stressors are more within reach. Such as

fisheries restrictions and pathogen transmission.

Fisheries restrictions are used for Clayoquot Sound salmon and seemed to have a big effect on the returns. Further restrictions to commercial and sport fisheries may support the rebuilding of stocks. However, climate change may present a greater obstacle than fisheries restrictions can help overcome. Other avenues to support marine survival, such as salmon farm management, may be worth pursuing. Salmon farms are another known stressor in Clayoquot Sound (CCFS, 2018, 2019, 2020). Releasing salmon stocks from these known local stressors may be lower-hanging fruit than climate-driven stressors and compensate for unknown stressors.

Increased protection may serve as a precautionary measure appropriate for matching the high uncertainty and limitations of stock data. The number of monitored streams is the lowest it has been since monitoring began on WCVI. To address some uncertainty and orient protective measures, we recommend reinstating enumeration programs for the unmonitored stocks of Clayoquot Sound. Supporting unmonitored stocks with greater monitoring effort and ensuant management may support the genetic resilience and subsequent survival of Clayoquot salmon faced with the mounting stress of climate change.

Glossary

Amber A status assignment indicating that a population may become at risk of extinction and is unlikely to produce maximum sustainable yield.

B.C. British Columbia

CWT Coded Wire Tag used for identifying which stock and brood an individual is from.

Data Limited A population with less than 10 years of escapement data available

Data Deficient A population with no escapement data for the last 10 years since the start of the study.

Density Dependence A factor that conveys the role of freshwater competition in reducing the productivity of a stock, e^{β}.

Fishery Management Area A division of Canadian waters, including the portion of streams within the division boundaries.

Green A status assignment indicating that a population is unlikely to be at risk of extinction.

Intrinsic Productivity The number of potential returning offspring per spawner, if the population was released from stressors. Used to infer the resilience of a population, e^{α}.

MSY Maximum Sustainable Yield

Productivity The number of returning offspring per spawner.

Recruit The successful offspring of an adult salmon that has returned to spawn.

Red A status assignment indicating that a population is at greater risk of extinction and cannot sustain the current stressors. Red status assignments initiate an immediate consideration for protection.

Resilience The capacity for a population to withstand, adapt, and recover from stressors.

S_{GEN} The number of spawners required to reach S_{MSY} in one generation. S_{GEN} is used as the lower spawner-recruit benchmark.

S_{MSY} The number of spawners required to produce the maximum sustainable yield. The upper spawner-recruit benchmark is 80% of S_{MSY}.

Spawner Adult salmon returning to freshwater to spawn.

Stock Used to refer to a group of species-specific Pacific salmon whose majority return to the same stream or lake and can spawn together during a particular season. It is used interchangeably with stream-level population.

Stressor An environmental or human-caused factor that reduces the productivity and or abundance of a population

WCVI West Coast Vancouver Island

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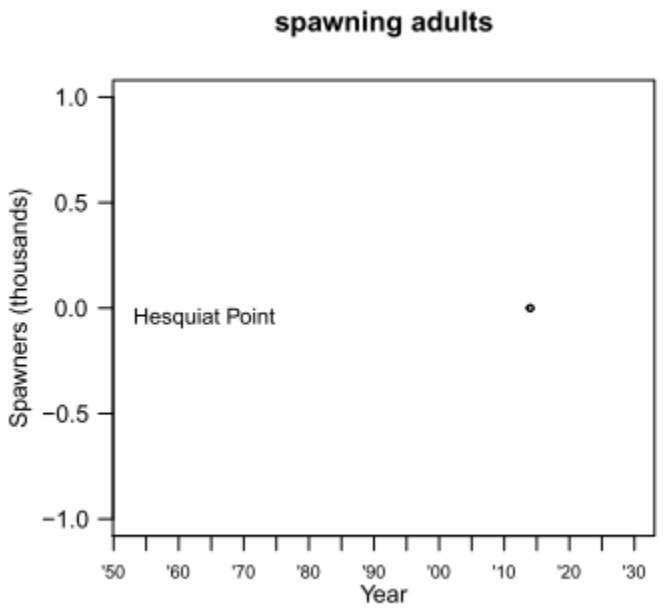
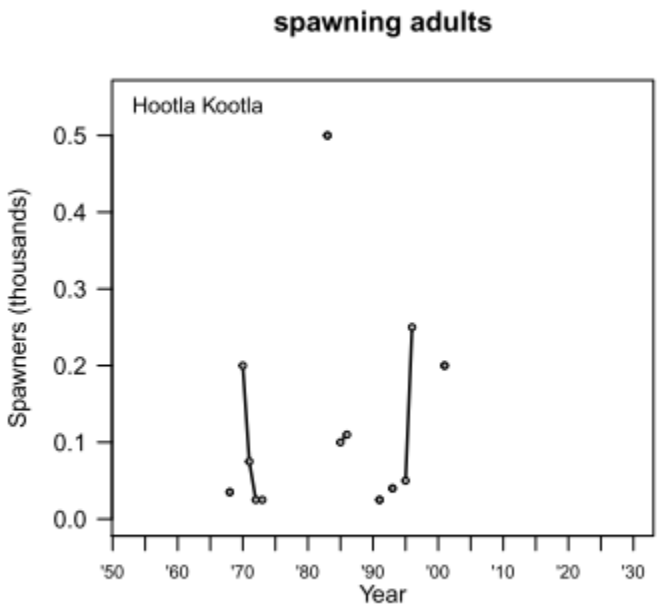
Appendices

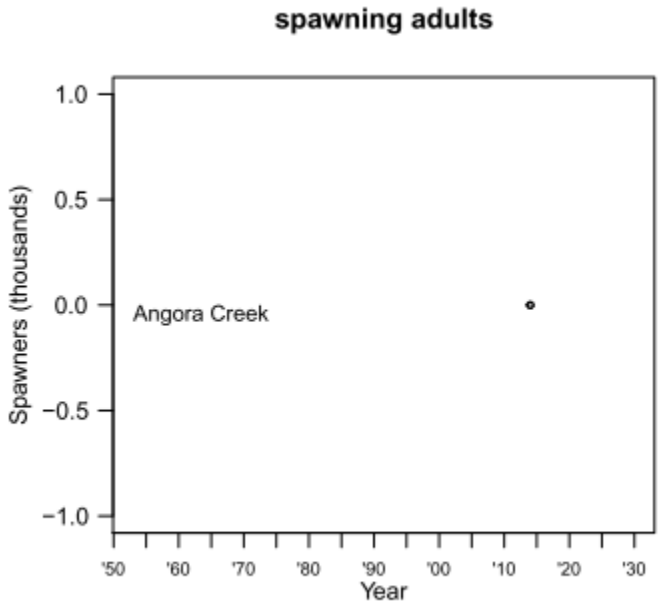
Appendix A

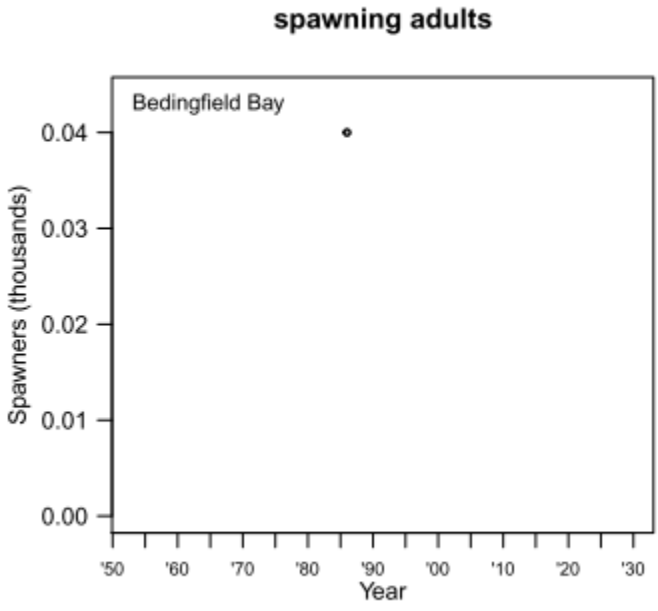
Escapement time series (1953 - 2020) for all Clayoquot Sound Populations of Chum, Coho, Chinook, and Sockeye with at least one escapement data point. Escapement is given in the thousands. Populations with at least 10 data points are presented with percentile benchmarks (S25 - S75), percentile status assignment, and productivity status assignments throughout time. Panel B shows productivity status assignments throughout time, relative to the productivity benchmark (dotted line): intrinsic productivity (S/R when density dependence is 0) at replacement (intrinsic productivity = 1). Mean intrinsic productivity is given as the solid black line while the 95% confidence interval and subsequent productivity status assignment is given by coloured bars.

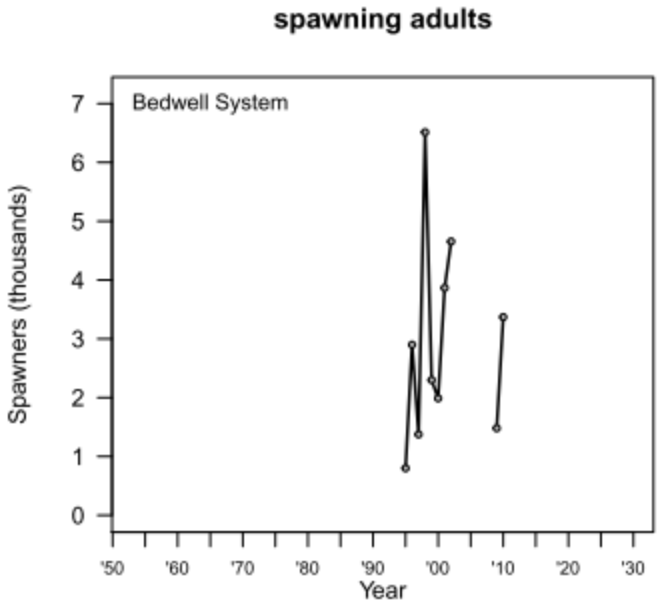
Chum

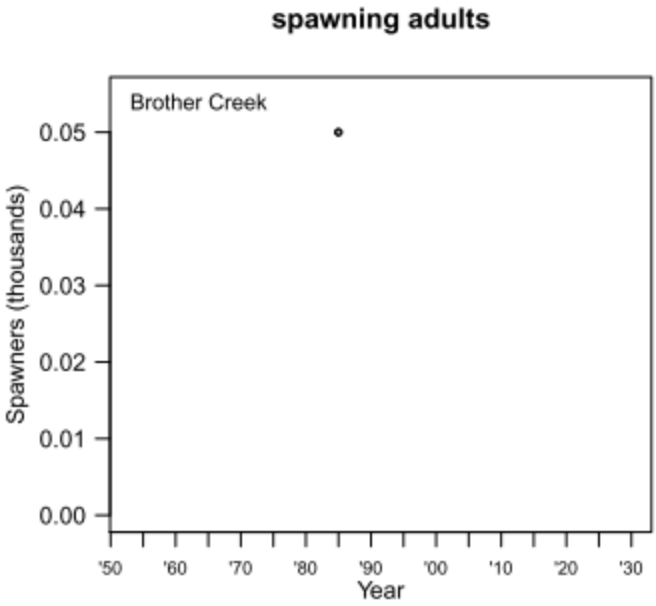


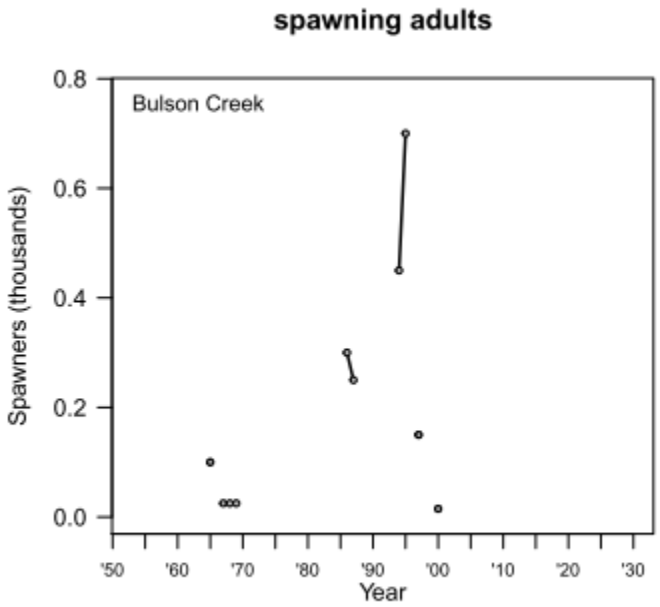


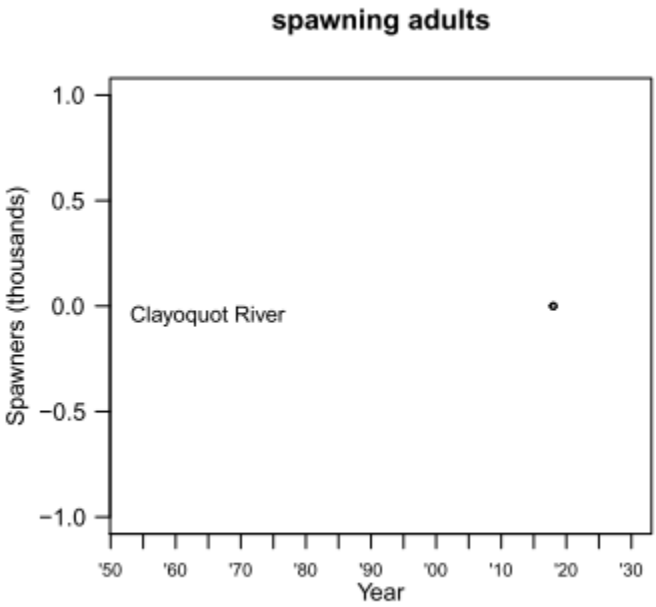


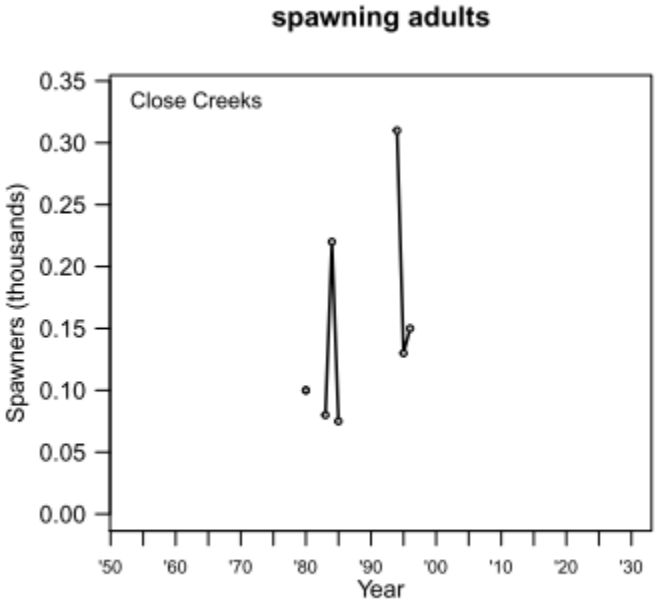


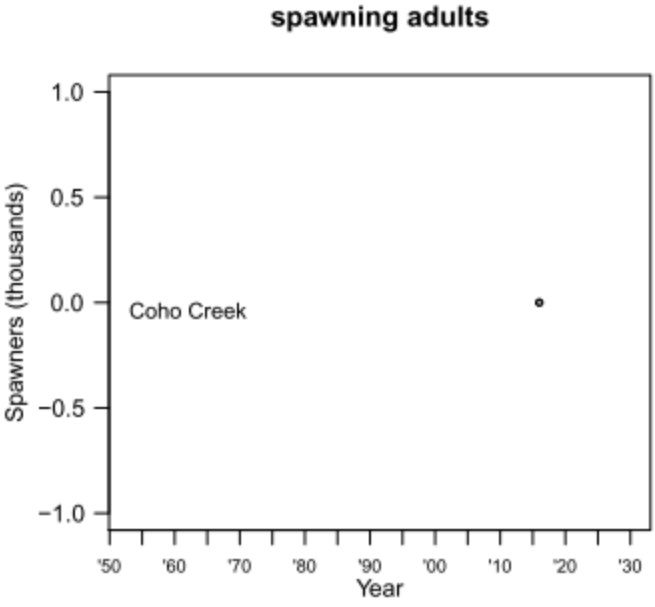

spawning adults
Bedwell System
Spawners (thousands)
0
1
2
3
4
5
6
7
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

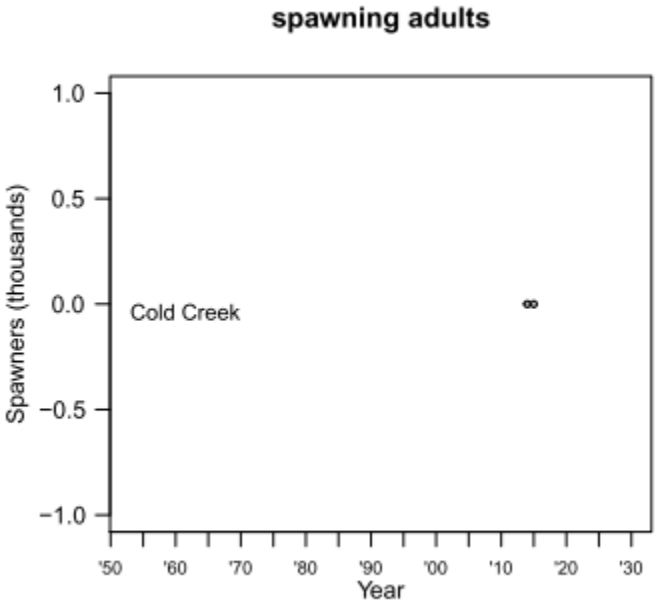

spawning adults
Brother Creek
Spawners (thousands)
0.00
0.01
0.02
0.03
0.04
0.05
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

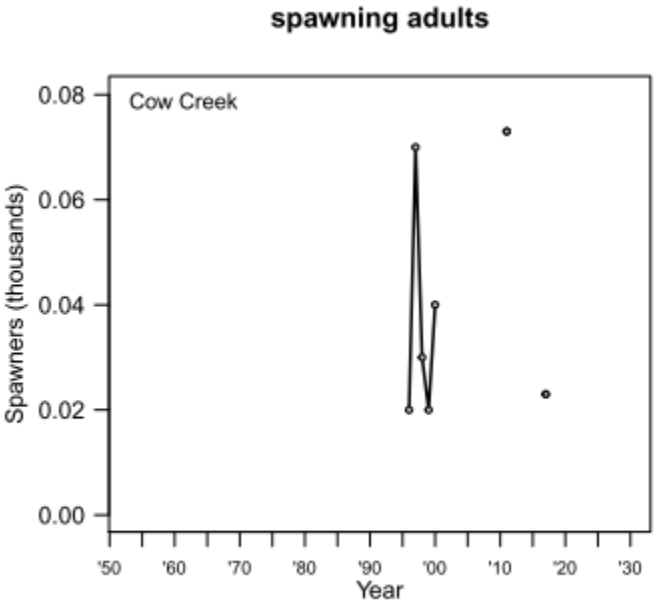

spawning adults
Bulson Creek
Spawners (thousands)
0.0
0.2
0.4
0.6
0.8
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

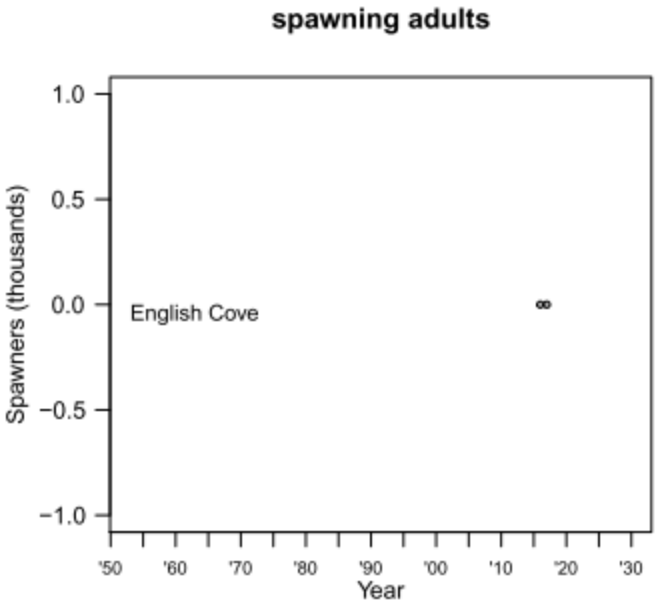

spawning adults
Clayoquot River
Spawners (thousands)
−1.0
−0.5
0.0
0.5
1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

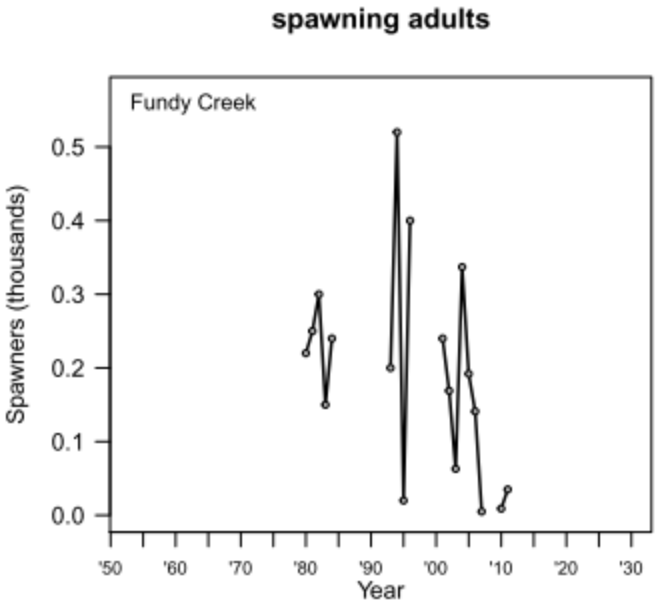

spawning adults
Close Creeks
Spawners (thousands)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

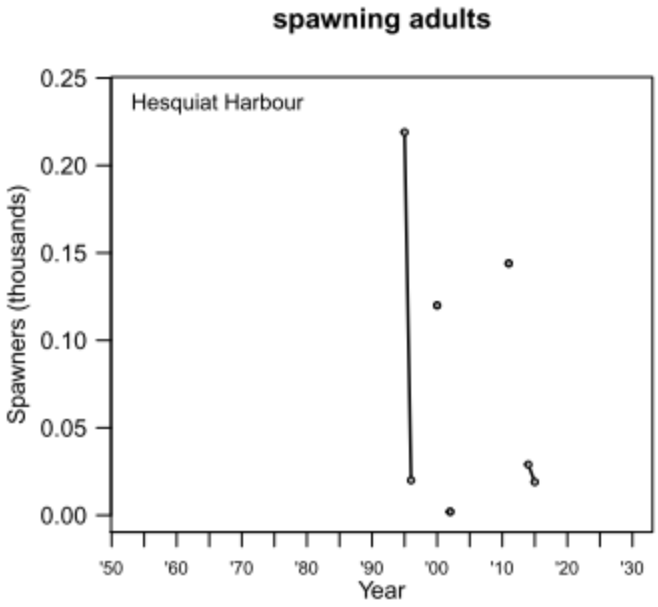

spawning adults
Coho Creek
Spawners (thousands)
1.0
0.5
0.0
−0.5
−1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Cold Creek
Spawners (thousands)
1.0
0.5
0.0
−0.5
−1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

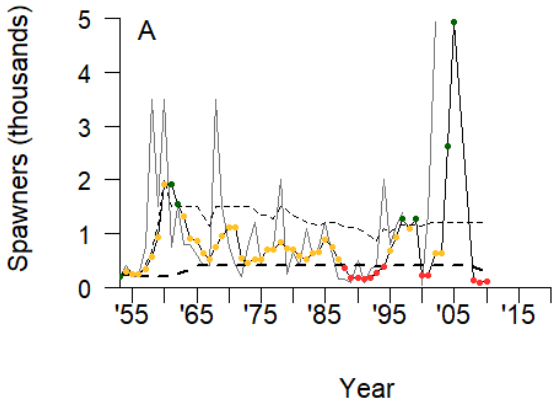

spawning adults
Cow Creek
Spawners (thousands)
0.08
0.06
0.04
0.02
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

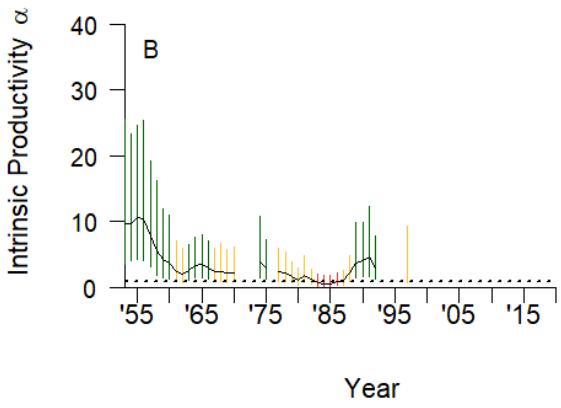

spawning adults
English Cove
Spawners (thousands)
1.0
0.5
0.0
−0.5
−1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Fundy Creek
Spawners (thousands)
0.5
0.4
0.3
0.2
0.1
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

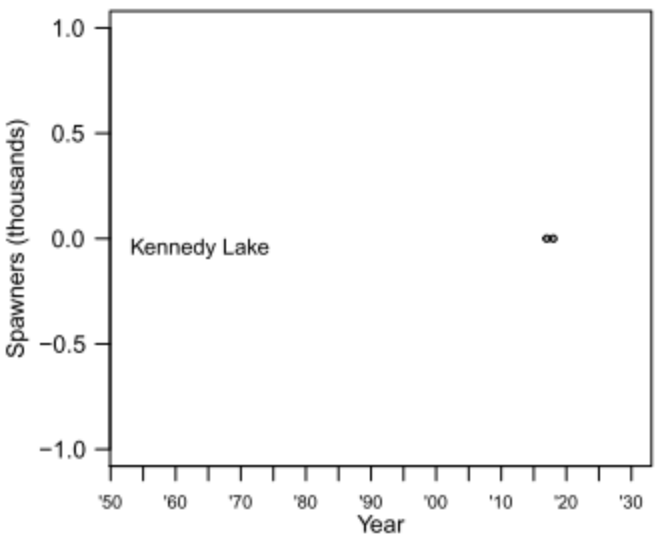

spawning adults
Hesquiat Harbour
Spawners (thousands)
0.25
0.20
0.15
0.10
0.05
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

Ice River Chum

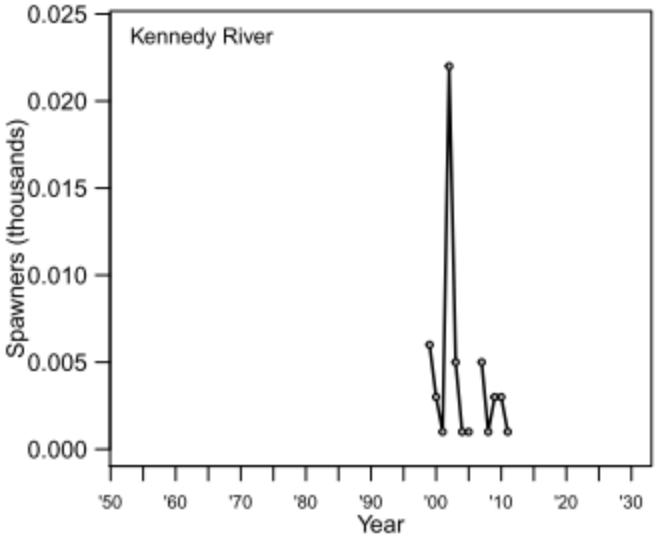


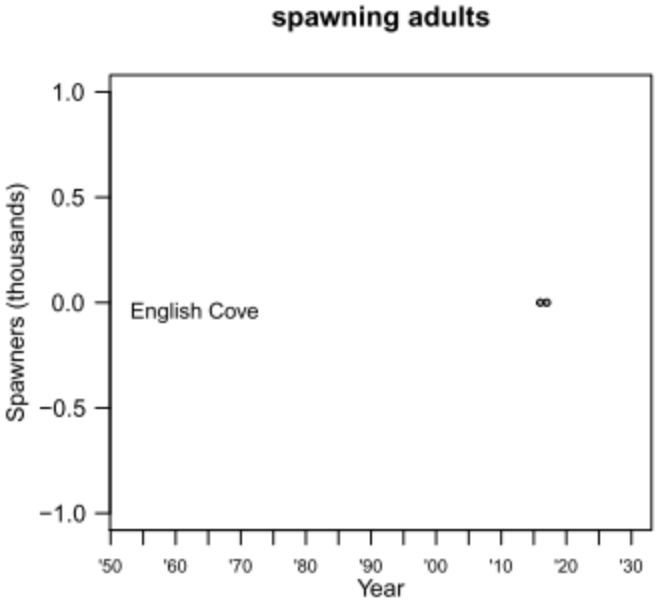


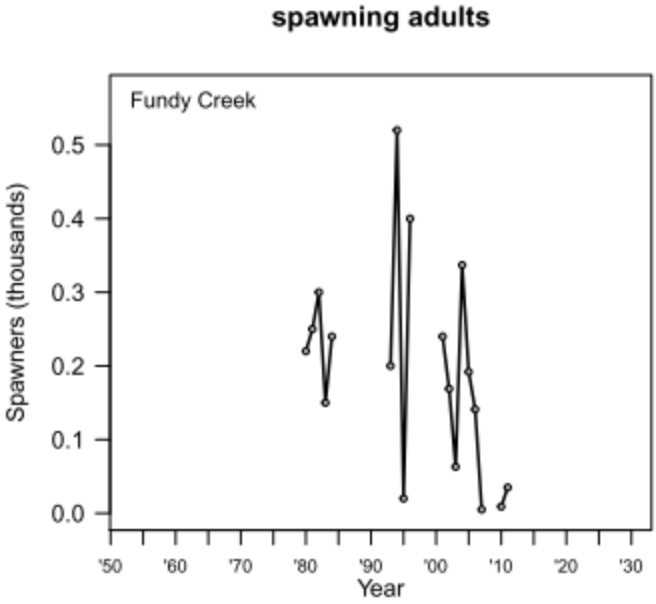
spawning adults

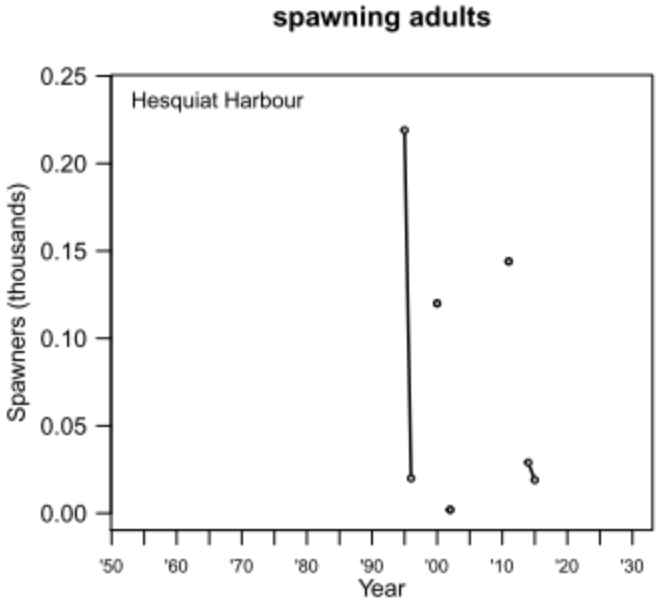


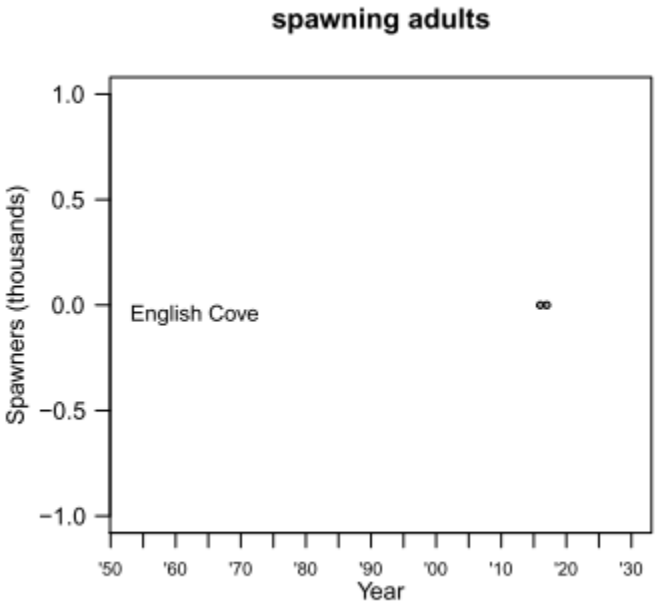
spawning adults

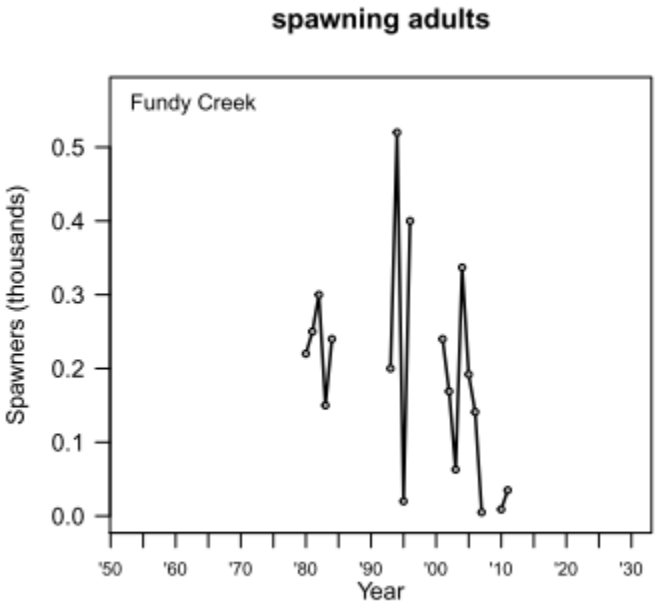


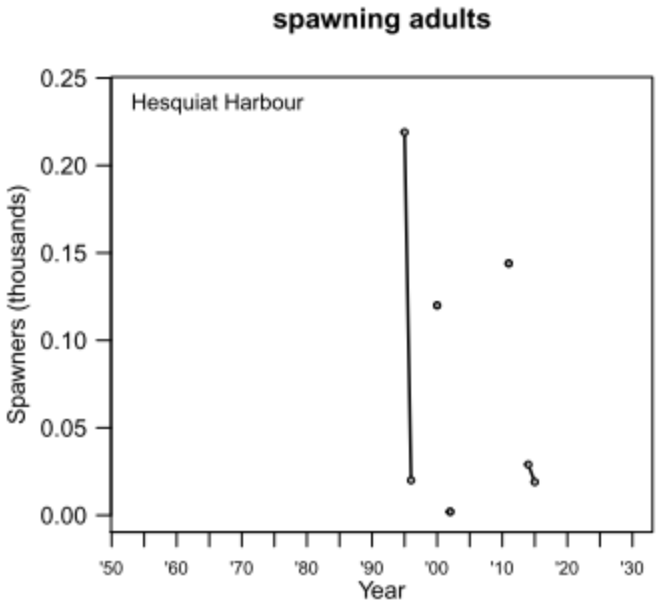

spawning adults
English Cove
Spawners (thousands)
1.0
0.5
0.0
−0.5
−1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Fundy Creek
Spawners (thousands)
0.5
0.4
0.3
0.2
0.1
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

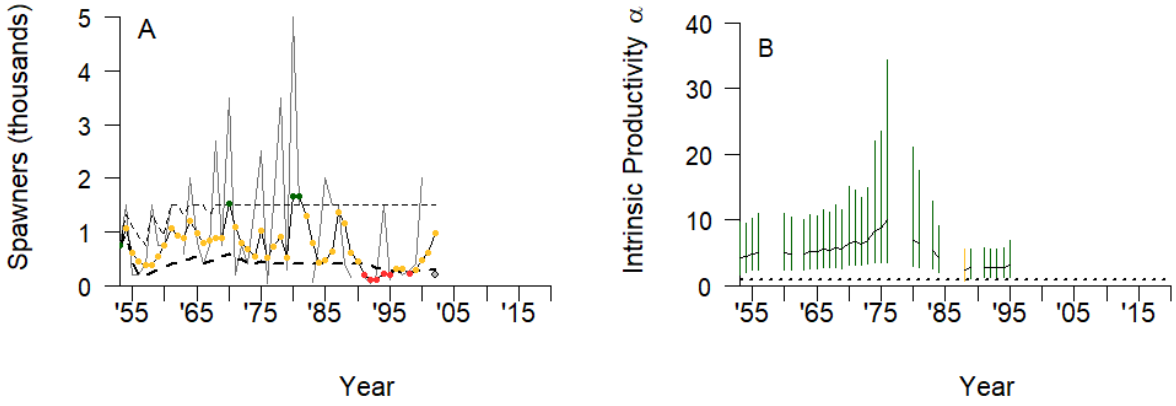

spawning adults
Hesquiat Harbour
Spawners (thousands)
0.25
0.20
0.15
0.10
0.05
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
English Cove
Spawners (thousands)
1.0
0.5
0.0
−0.5
−1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

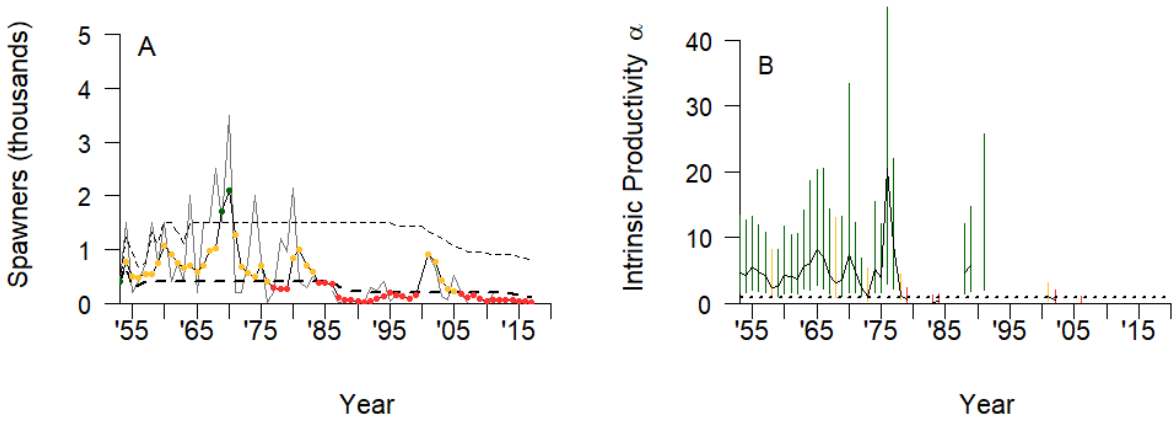

spawning adults
Fundy Creek
Spawners (thousands)
0.5
0.4
0.3
0.2
0.1
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Hesquiat Harbour
Spawners (thousands)
0.25
0.20
0.15
0.10
0.05
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

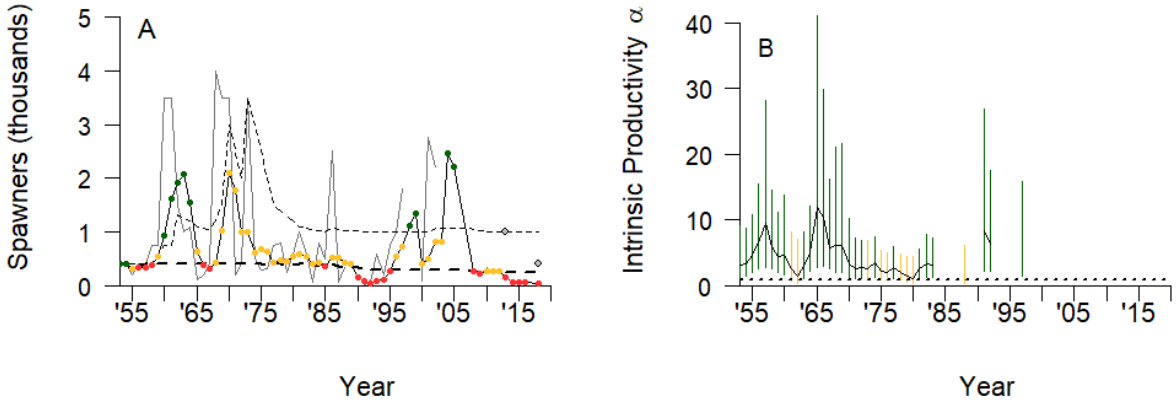
Kootowis Creek Chum



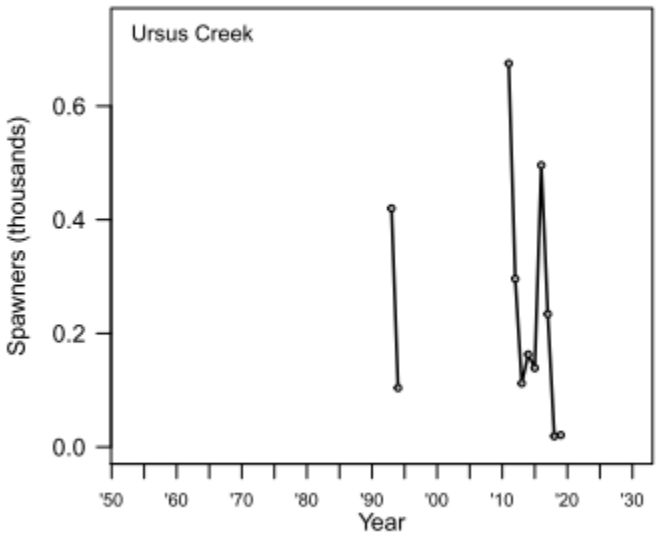
Sutton Mill Creek Chum



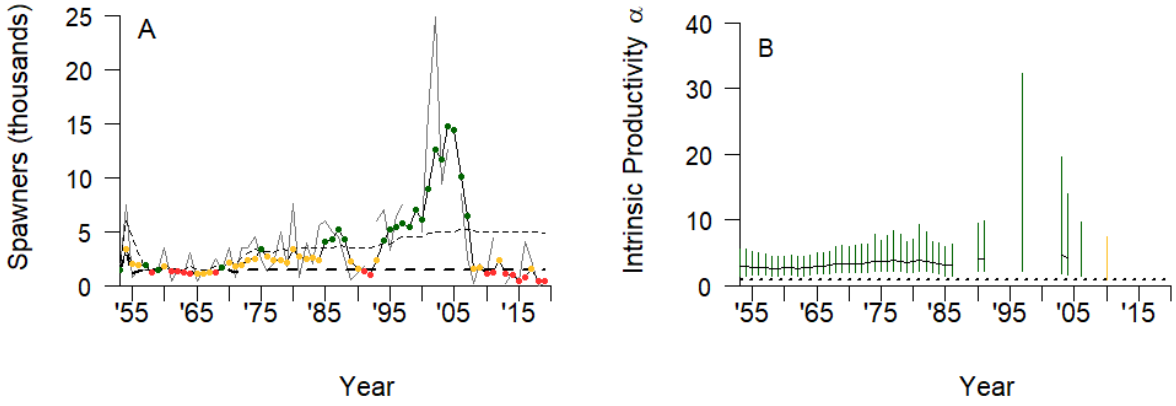
Sydney River Chum



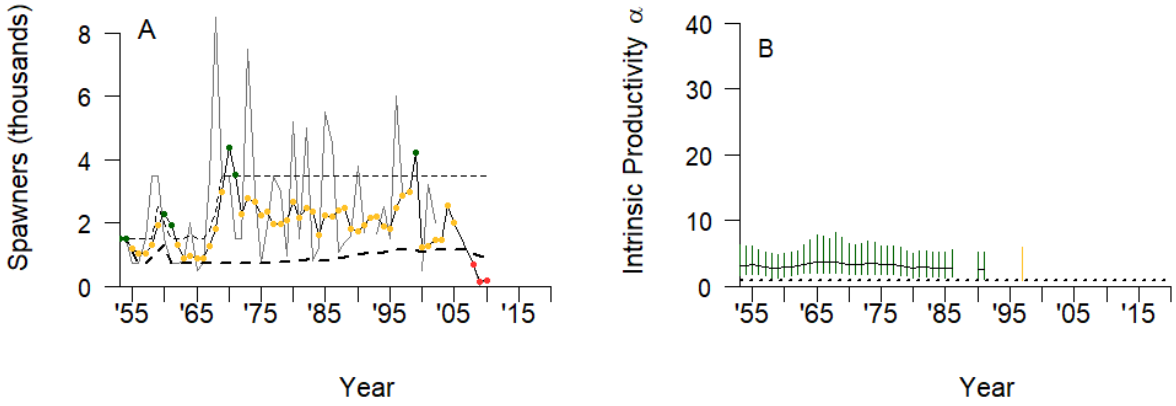
spawning adults



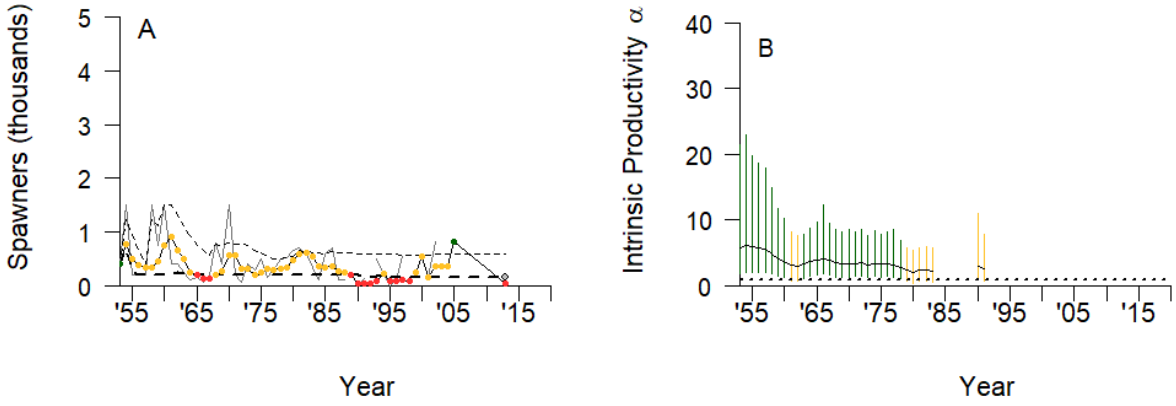
Warn Bay Creek Chum



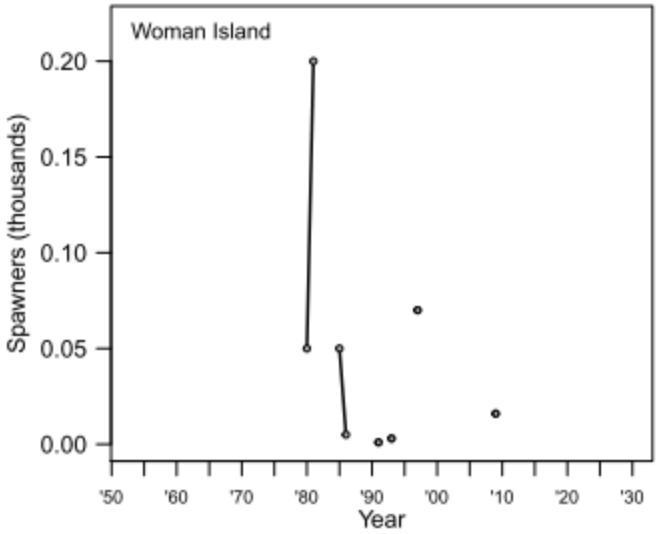
Watta Creek Chum



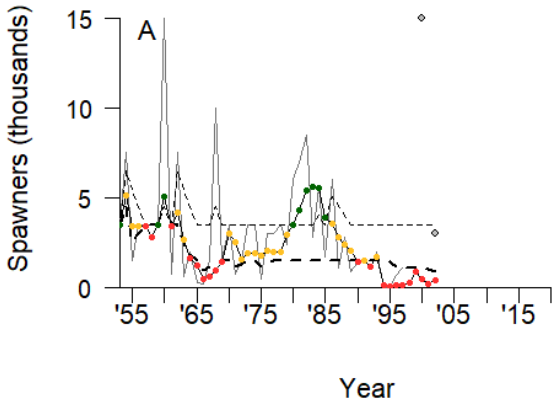
White Pine Cove Creek Chum

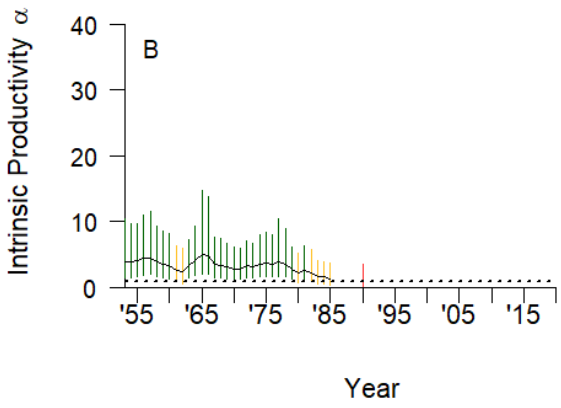


spawning adults

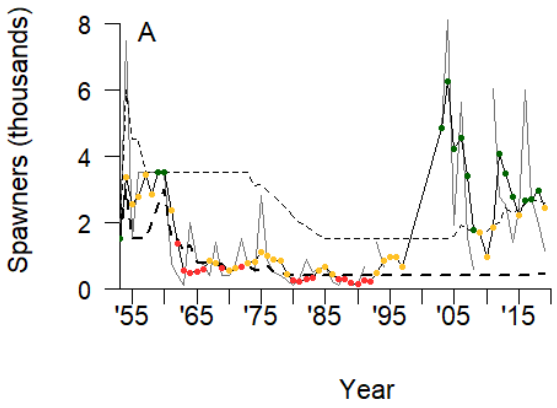


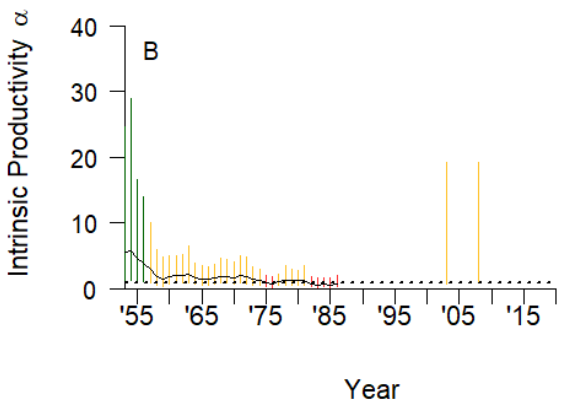
Bawden Creek Chum

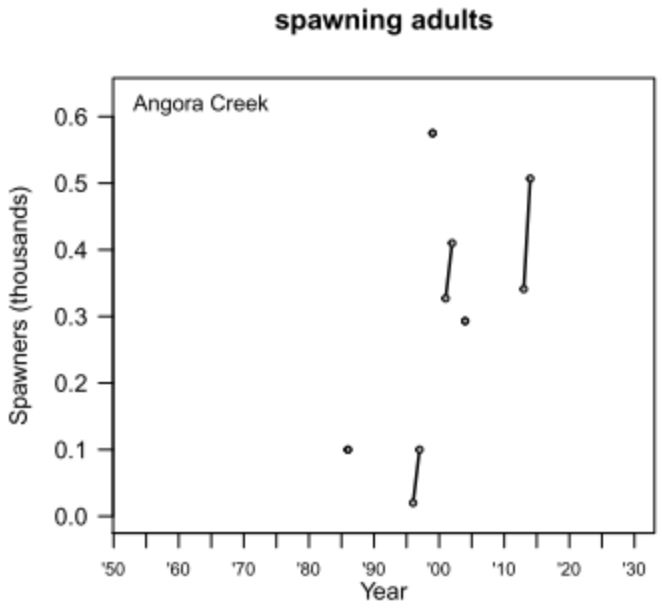


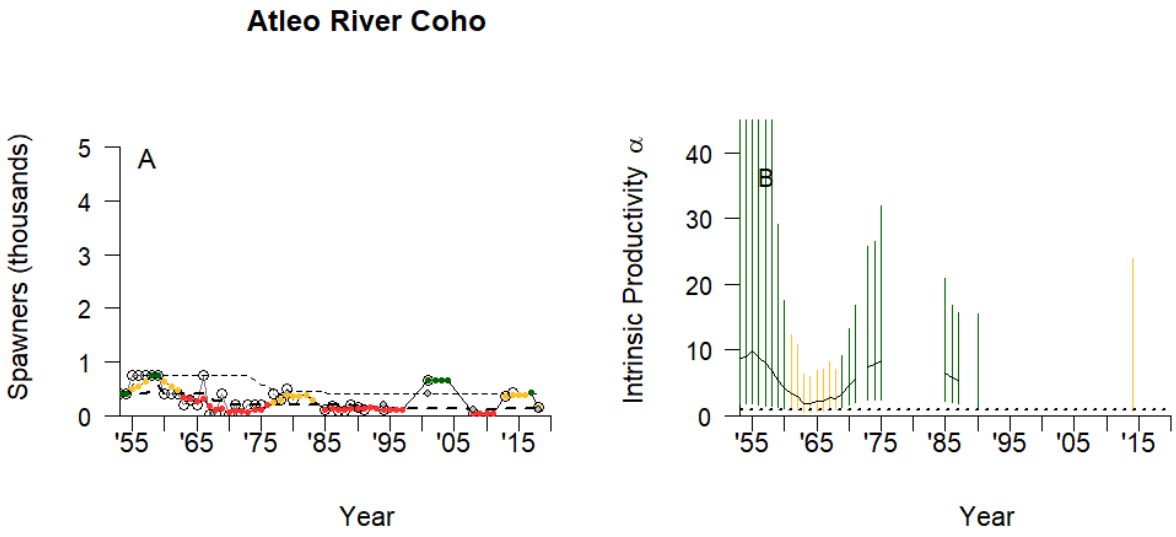


Bedwell River Chum

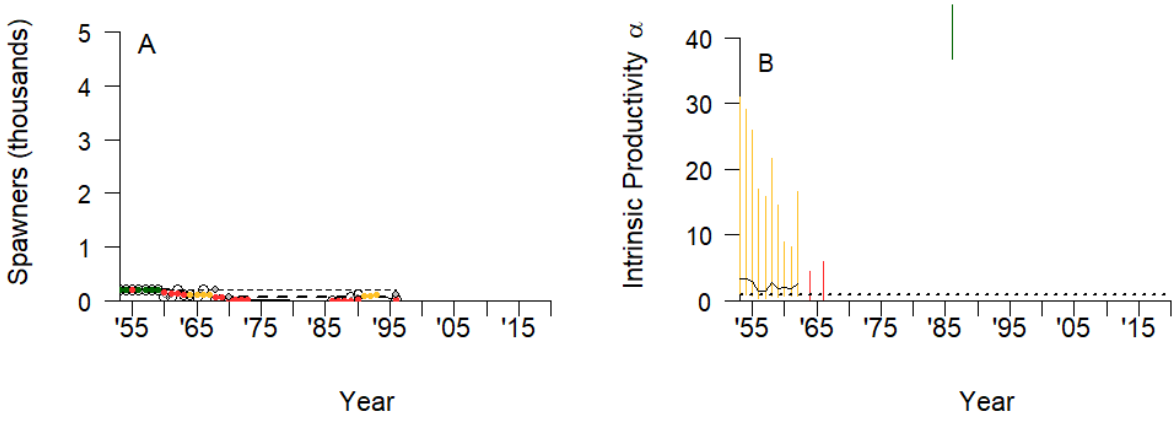




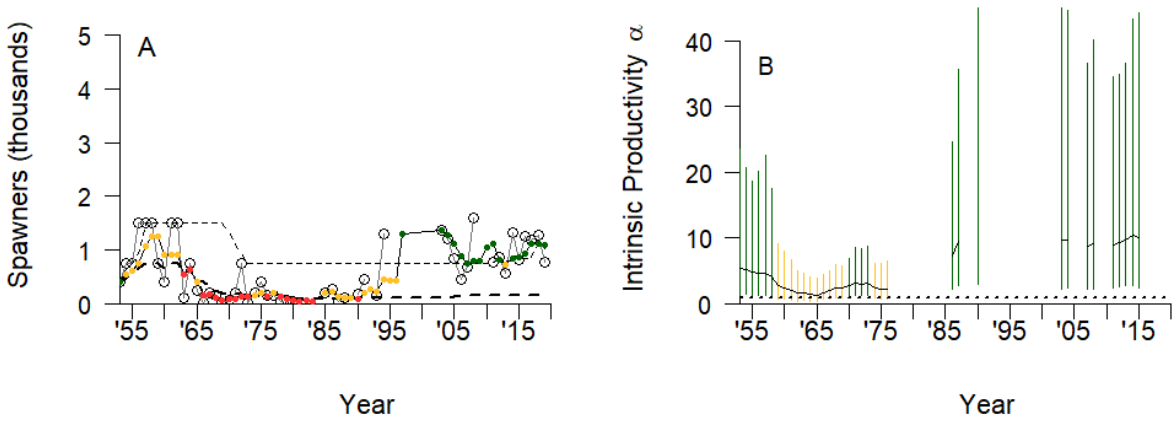

spawning adults
Angora Creek
Spawners (thousands)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

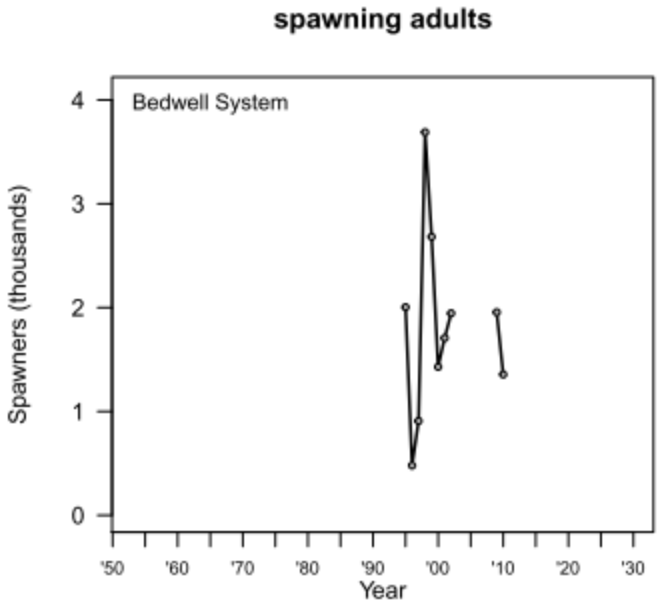

Atleo River Coho
A
Spawners (thousands)
0
1
2
3
4
5
'55
'65
'75
'85
'95
'05
'15
Year
B
Intrinsic Productivity α
0
10
20
30
40
'55
'65
'75
'85
'95
'05
'15
Year

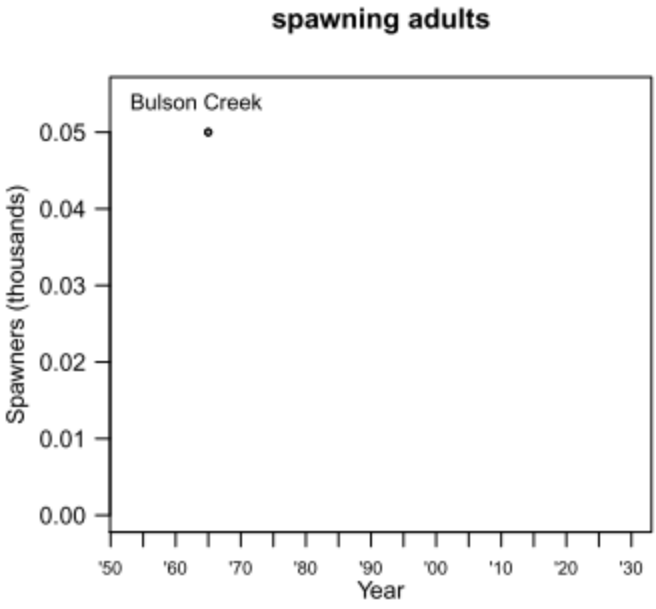
Bawden Creek Coho

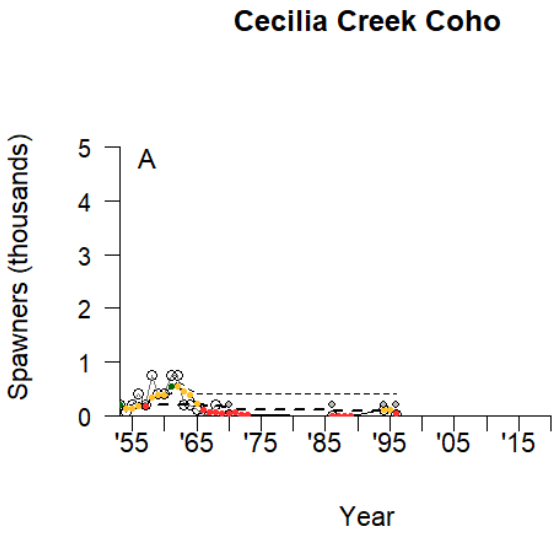


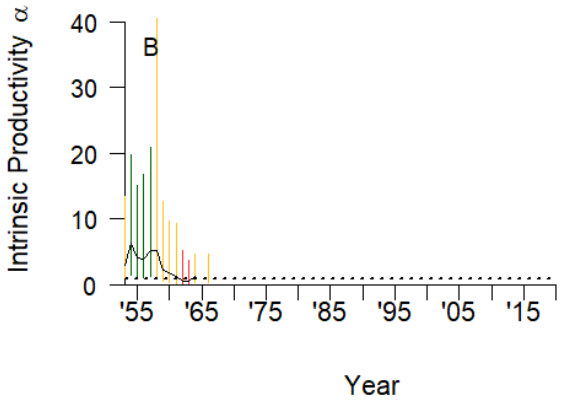
Bedwell River Coho



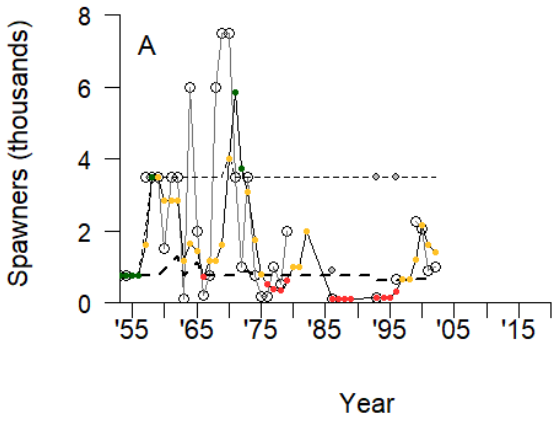

spawning adults
Bedwell System
Spawners (thousands)
0
1
2
3
4
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

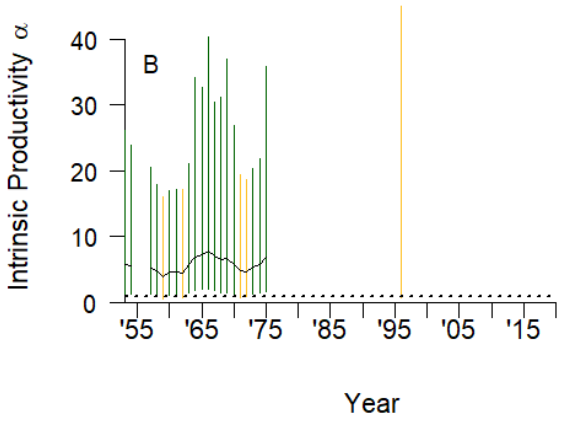

spawning adults
Bulson Creek
Spawners (thousands)
0.00
0.01
0.02
0.03
0.04
0.05
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


Cecilia Creek Coho
A
Spawners (thousands)
0
1
2
3
4
5
'55
'65
'75
'85
'95
'05
'15
Year

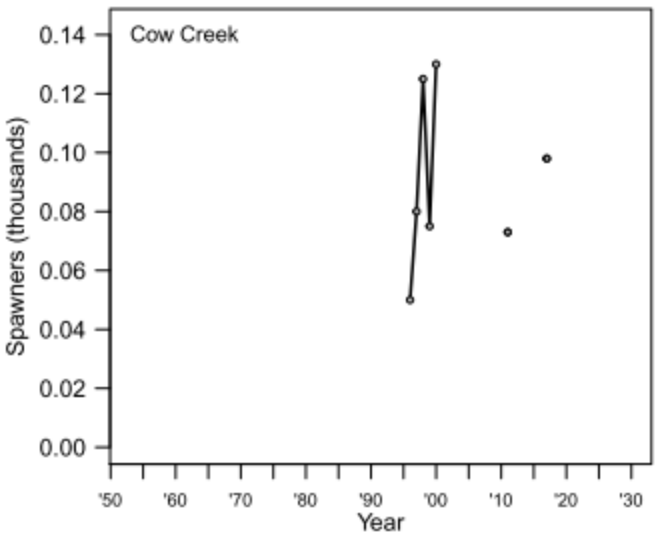

B
Intrinsic Productivity α
0
10
20
30
40
'55
'65
'75
'85
'95
'05
'15
Year

Clayoquot River (Upper) Coho

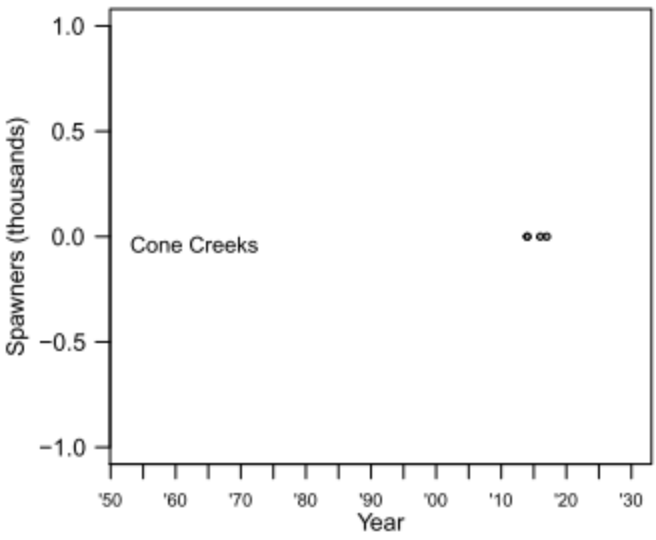


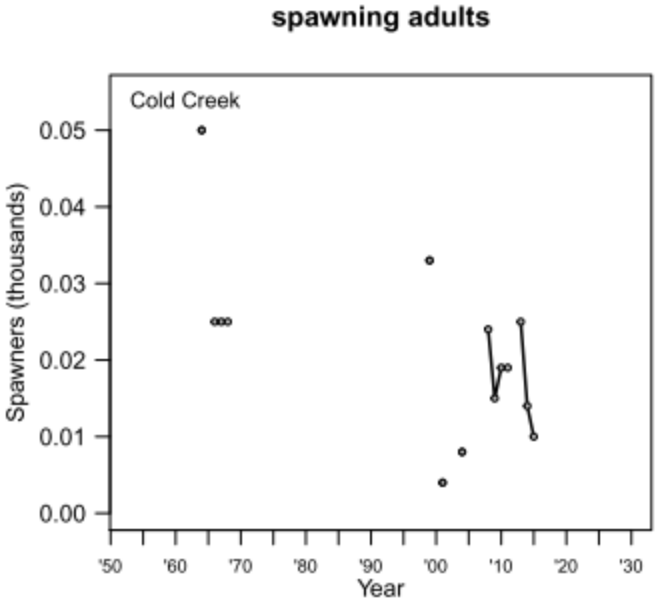


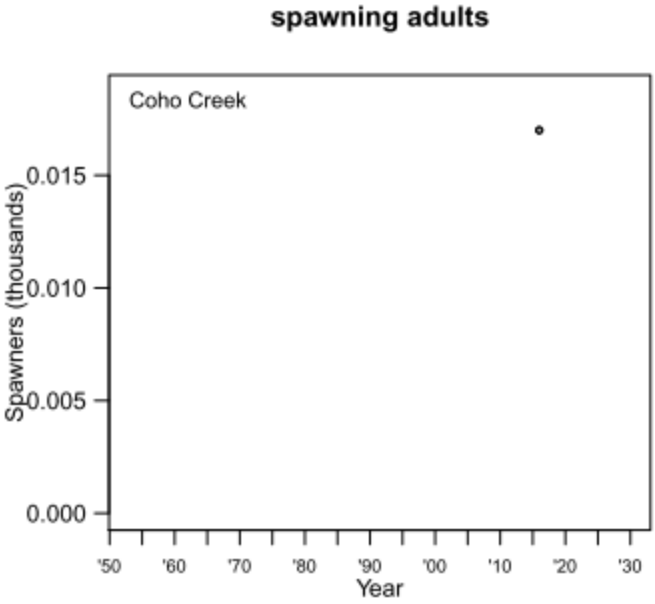
spawning adults

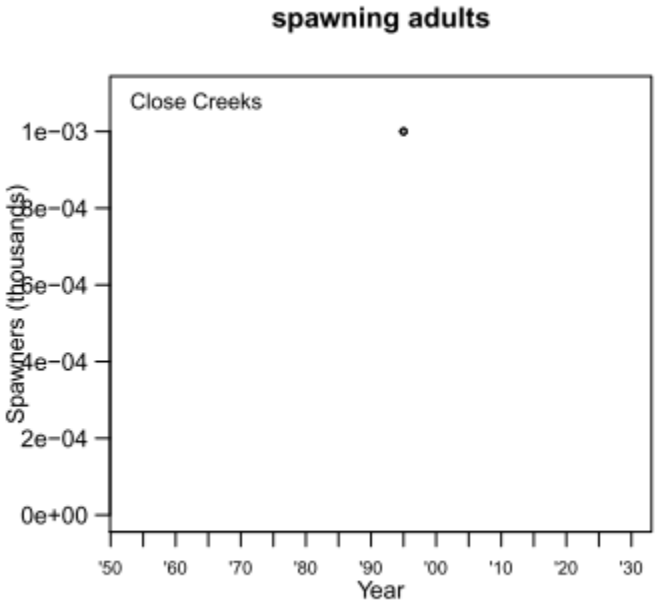


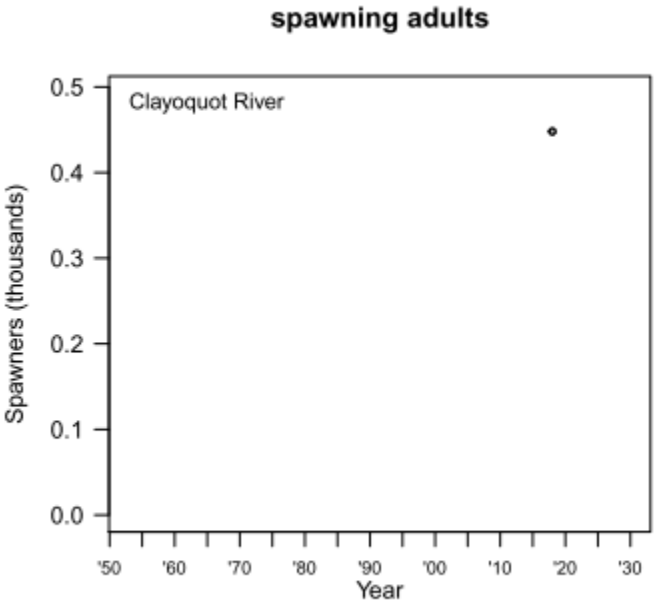
spawning adults



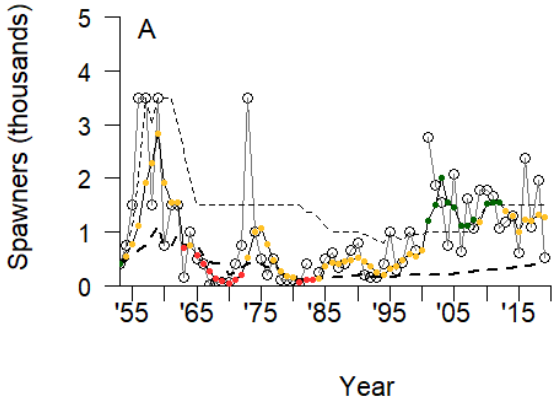

spawning adults
Cold Creek
Spawners (thousands)
0.05
0.04
0.03
0.02
0.01
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

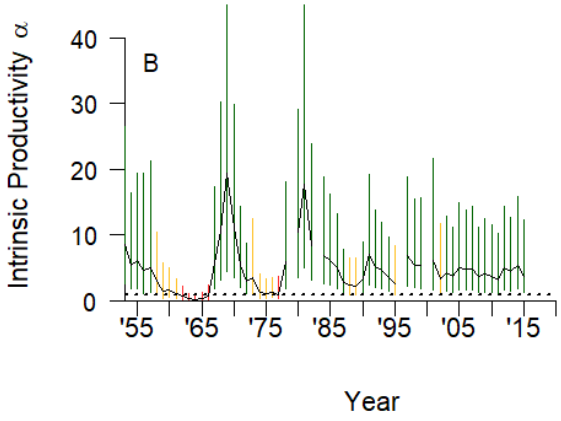

spawning adults
Coho Creek
Spawners (thousands)
0.015
0.010
0.005
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Close Creeks
Spawners (thousands)
1e−03
8e−04
6e−04
4e−04
2e−04
0e+00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

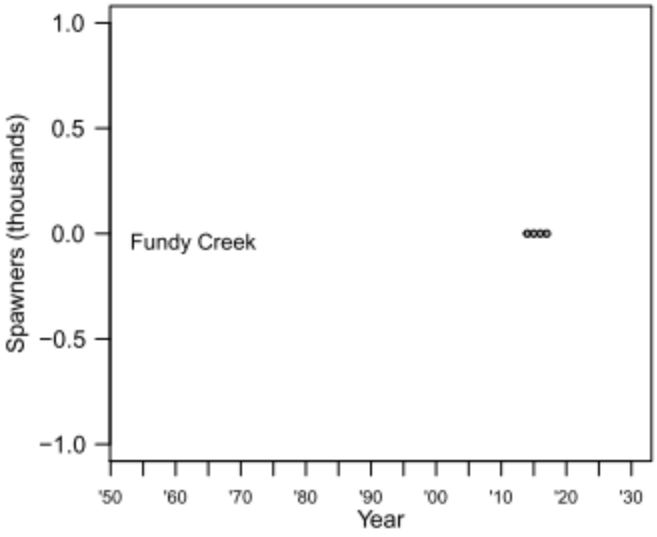

spawning adults
Clayoquot River
Spawners (thousands)
0.5
0.4
0.3
0.2
0.1
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

Cypre River Coho

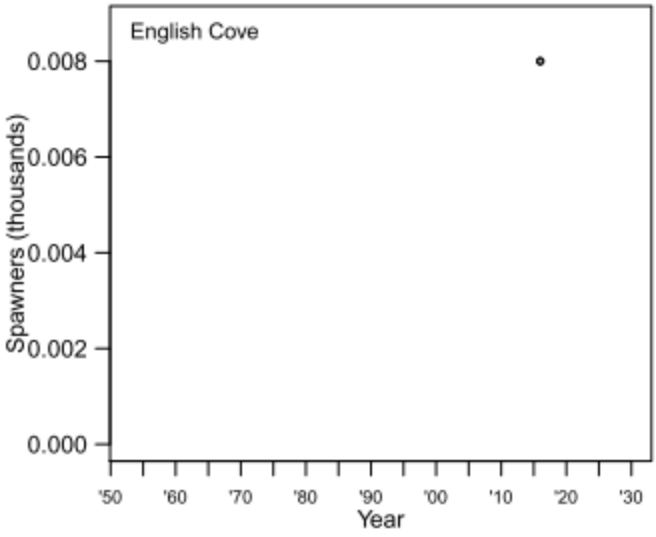


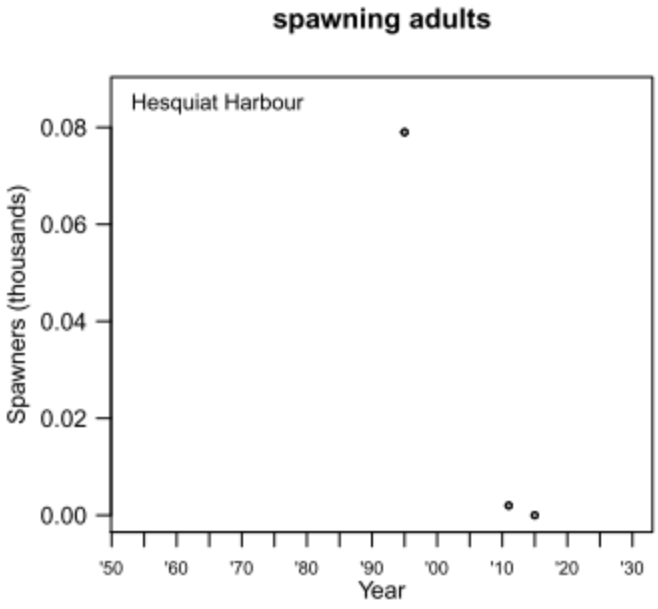


spawning adults

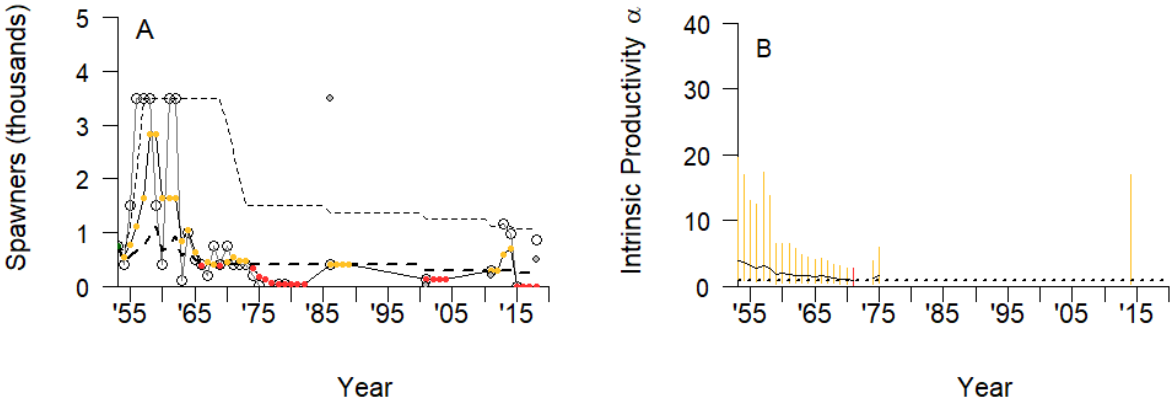


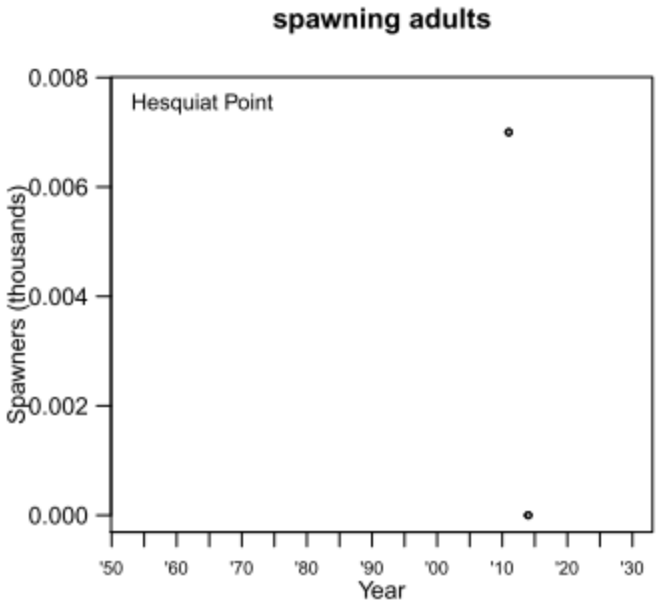
spawning adults

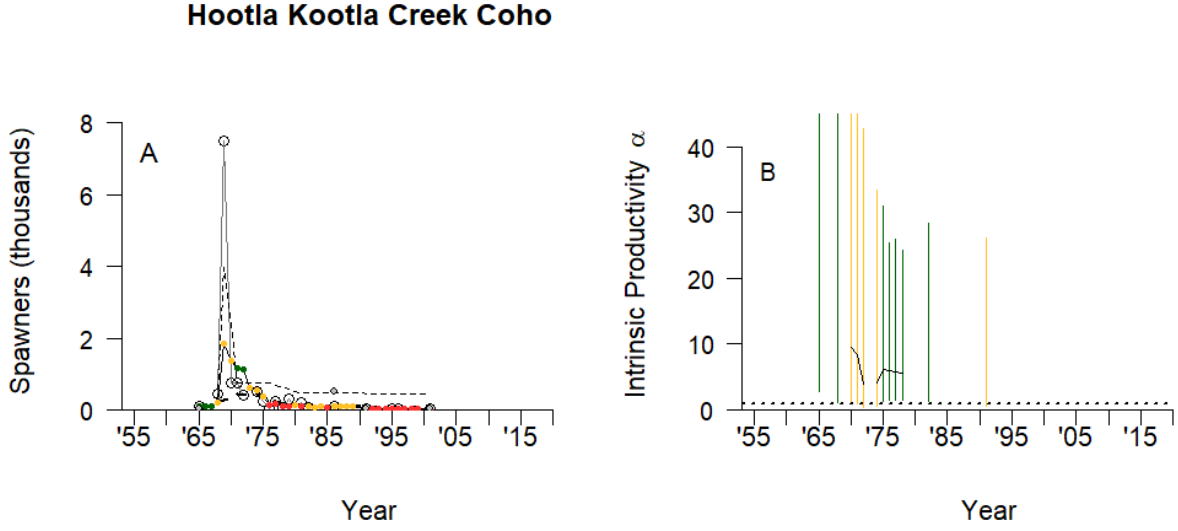




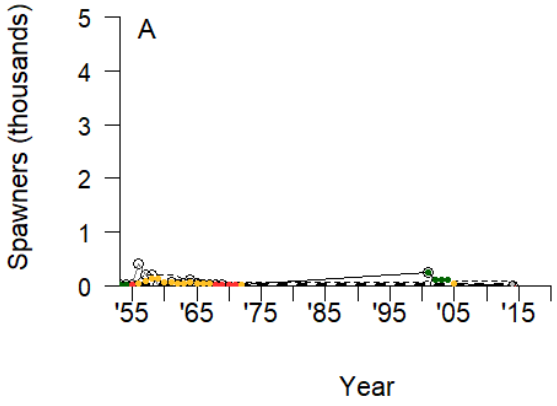
Hesquiat Lake Creek Coho

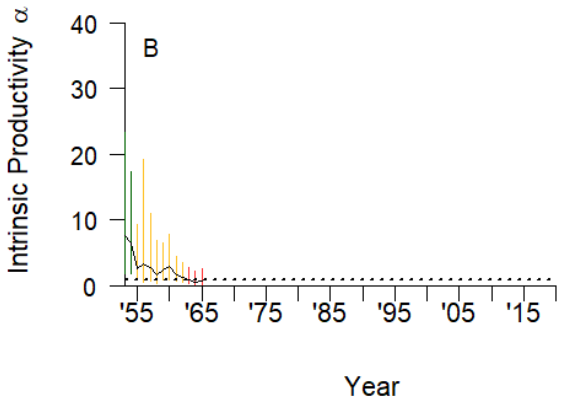



spawning adults
Hesquiat Point
Spawners (thousands)
0.008
0.006
0.004
0.002
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

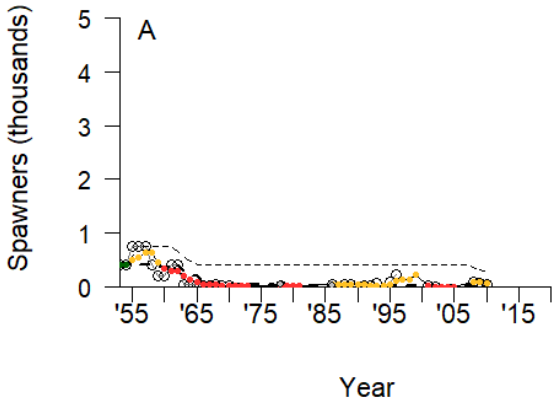

Hootla Kootla Creek Coho
Spawners (thousands)
A
8
6
4
2
0
'55
'65
'75
'85
'95
'05
'15
Year
Intrinsic Productivity α
B
40
30
20
10
0
'55
'65
'75
'85
'95
'05
'15
Year

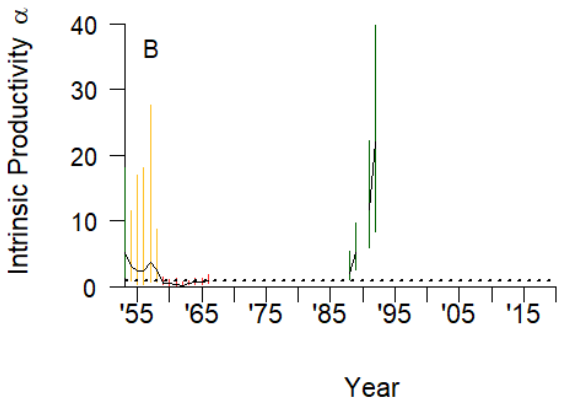
Hot Springs Cove Creek Coho

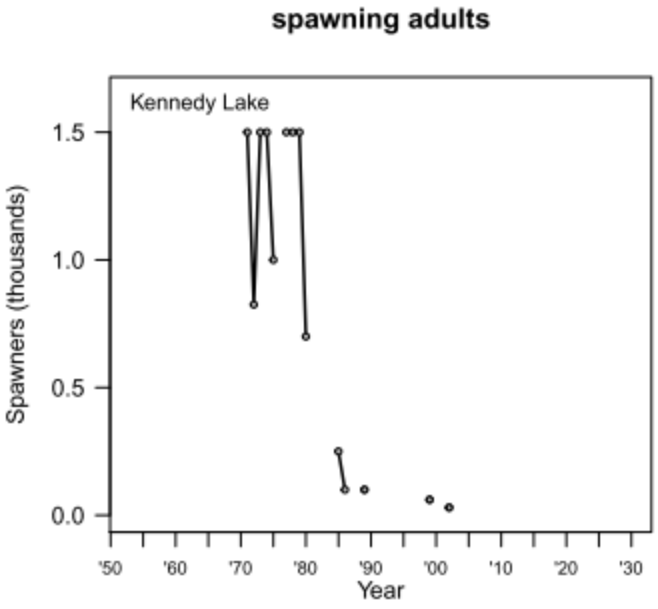


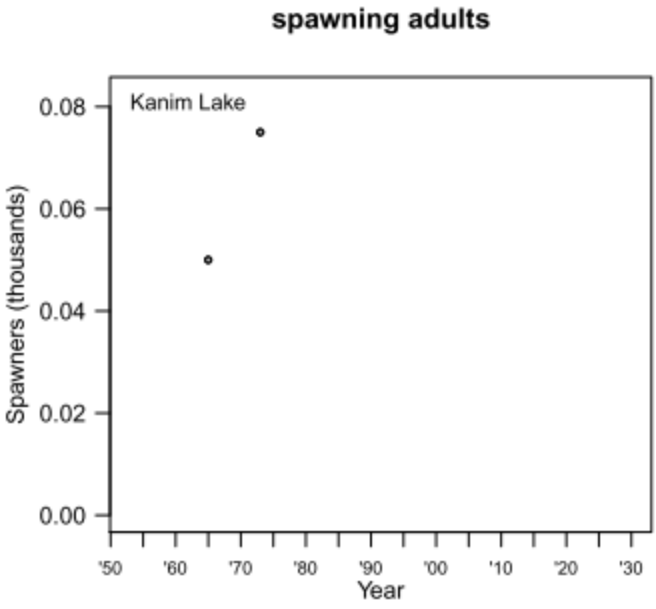


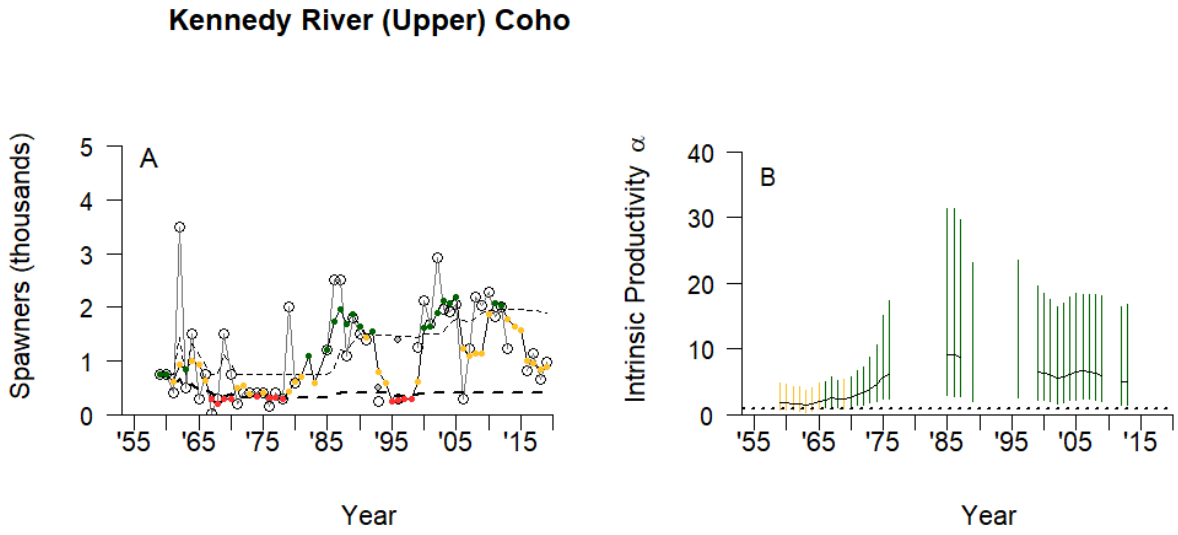
Ice River Coho



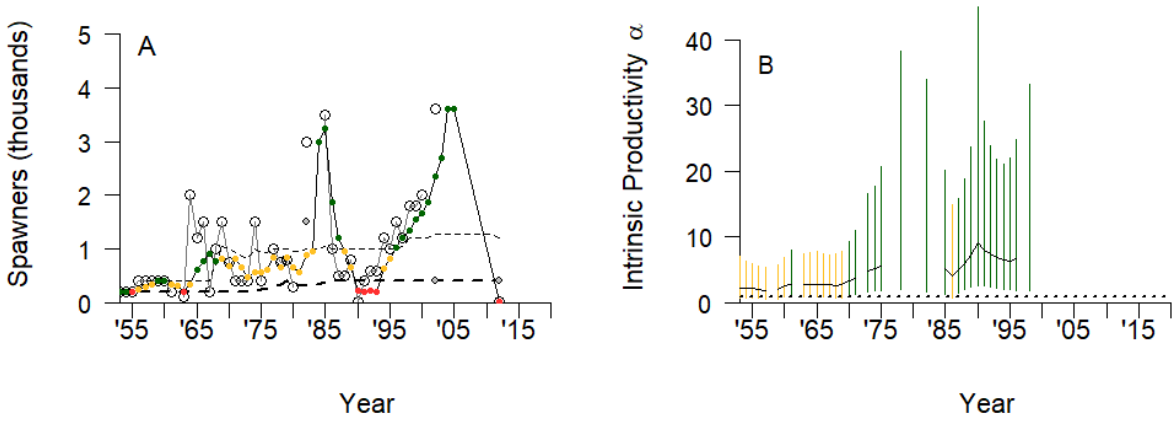



spawning adults
Kennedy Lake
Spawners (thousands)
1.5
1.0
0.5
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

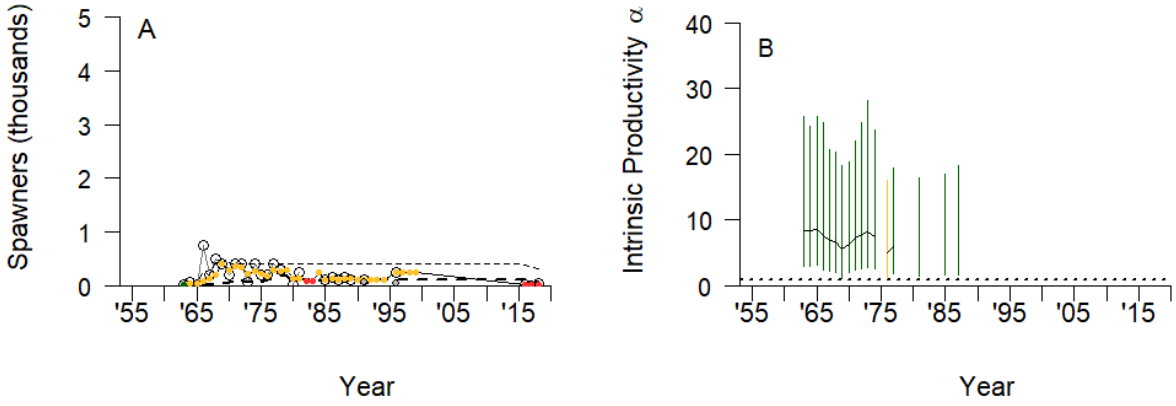

spawning adults
Kanim Lake
Spawners (thousands)
0.08
0.06
0.04
0.02
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

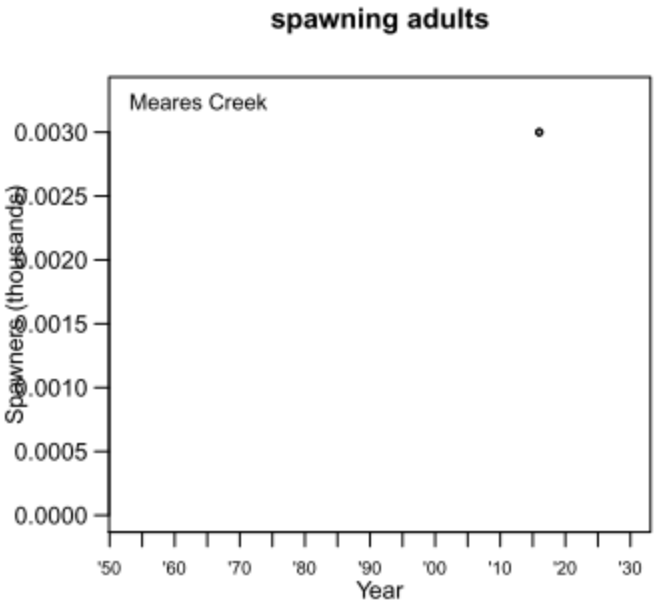

Kennedy River (Upper) Coho
A
Spawners (thousands)
5
4
3
2
1
0
'55
'65
'75
'85
'95
'05
'15
Year
B
Intrinsic Productivity α
40
30
20
10
0
'55
'65
'75
'85
'95
'05
'15
Year

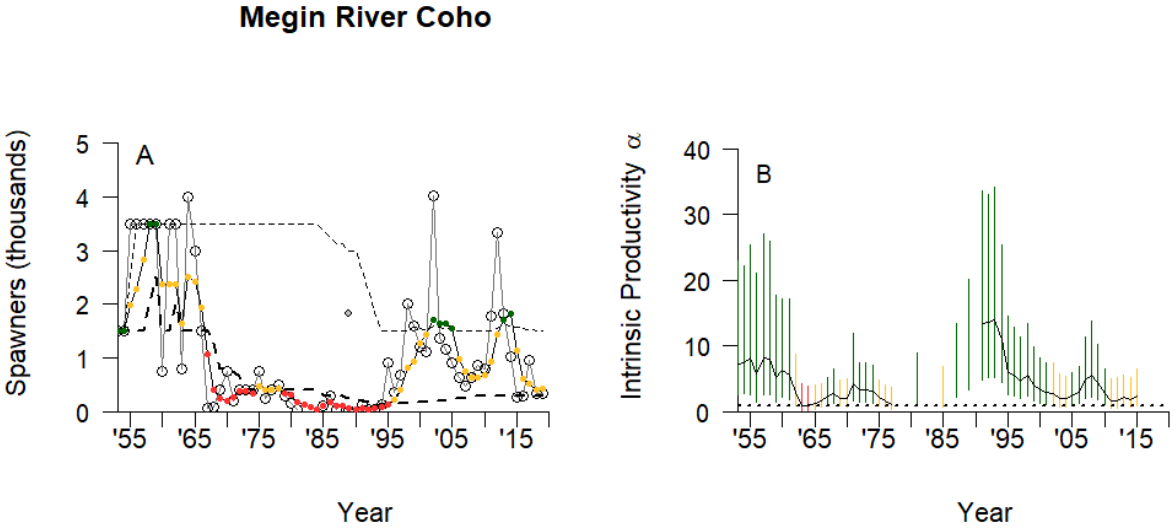
Kootowis Creek Coho



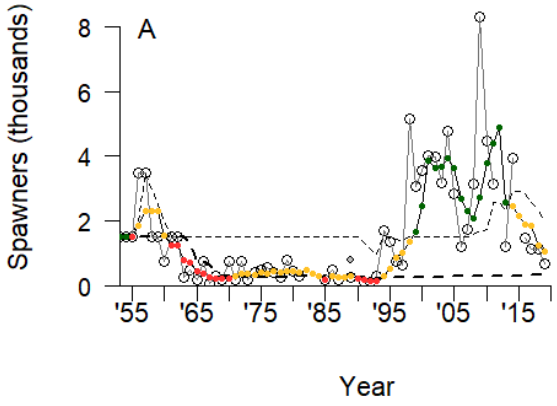
Lost Shoe Creek Coho

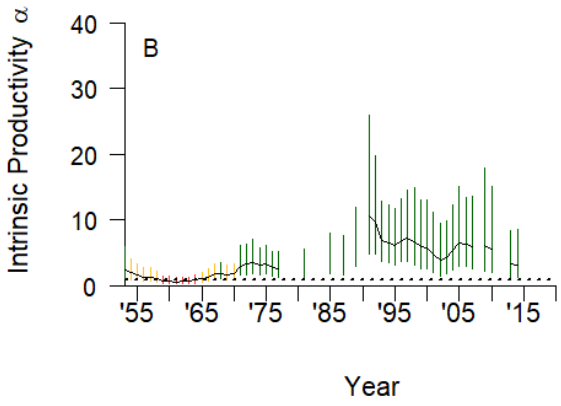



spawning adults
Meares Creek
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
Spawners (thousands)
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

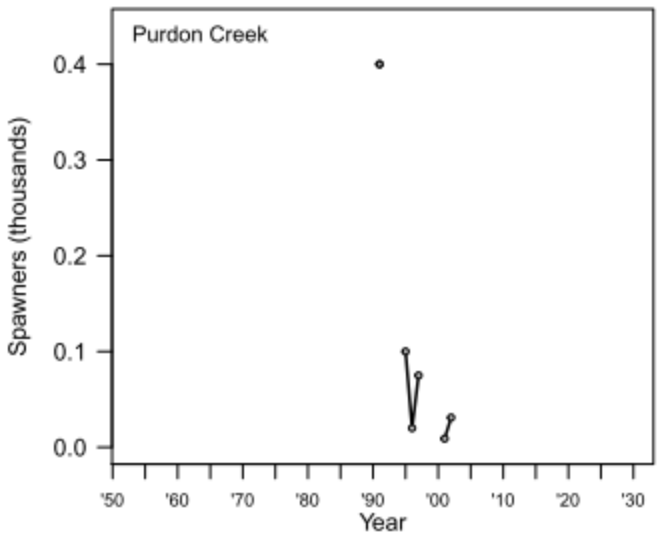

Megin River Coho
A
Spawners (thousands)
5
4
3
2
1
0
'55
'65
'75
'85
'95
'05
'15
Year
B
Intrinsic Productivity α
40
30
20
10
0
'55
'65
'75
'85
'95
'05
'15
Year

Moyeha River Coho

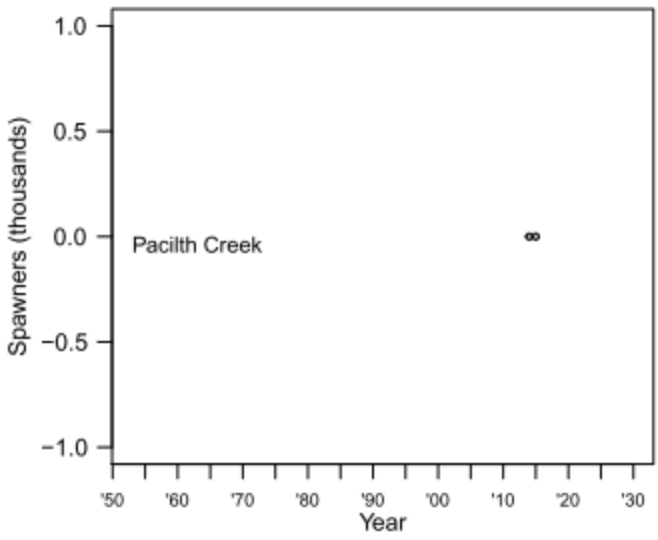


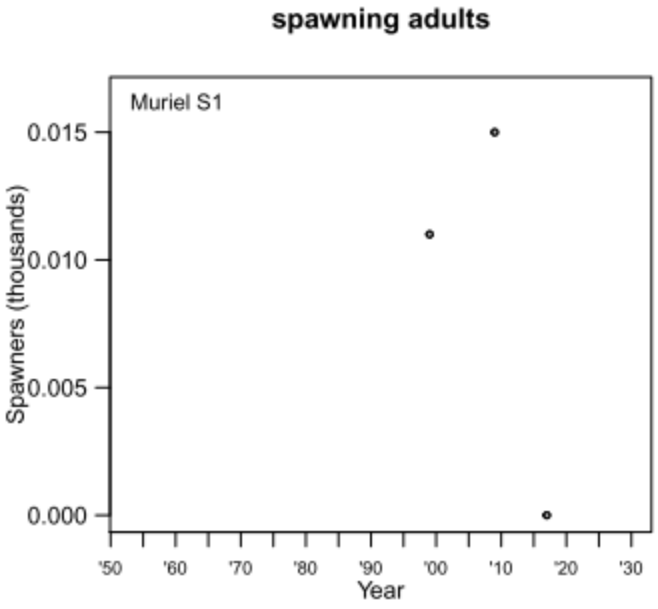


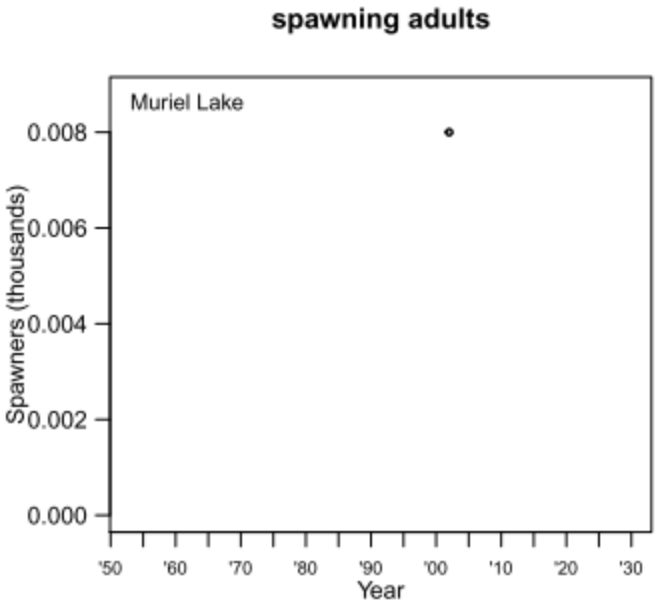
spawning adults

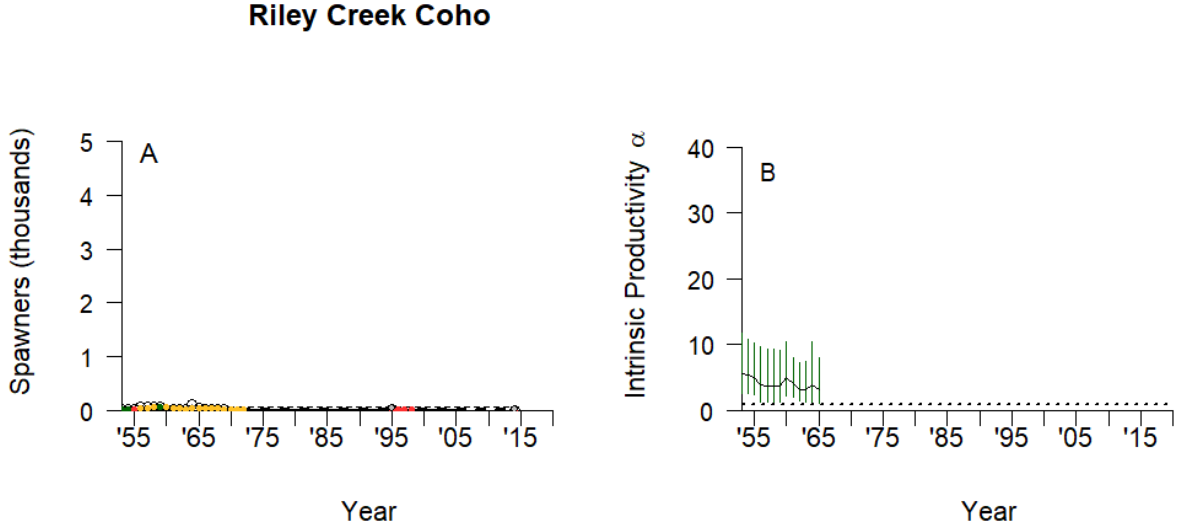


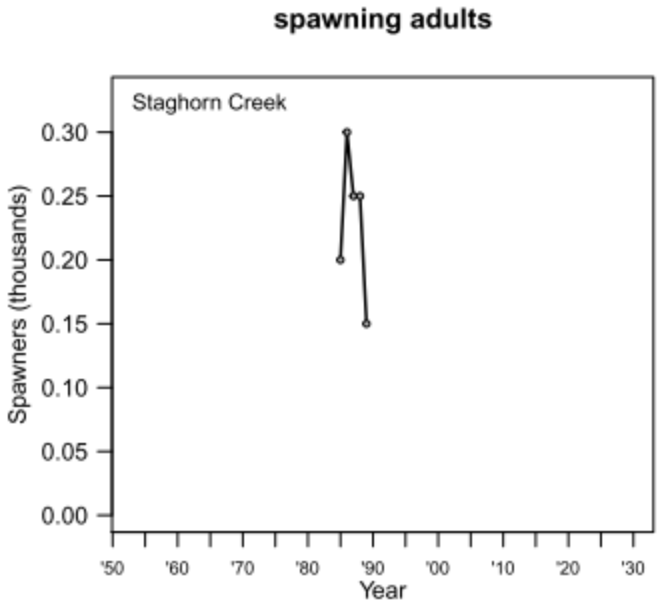
spawning adults

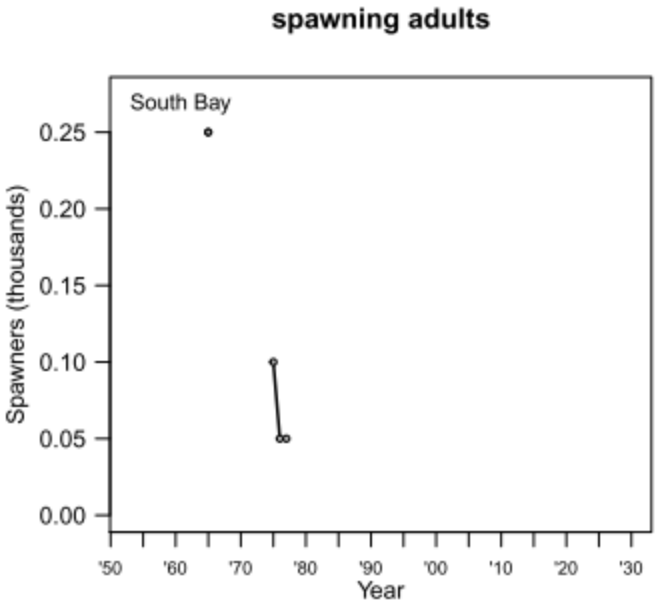


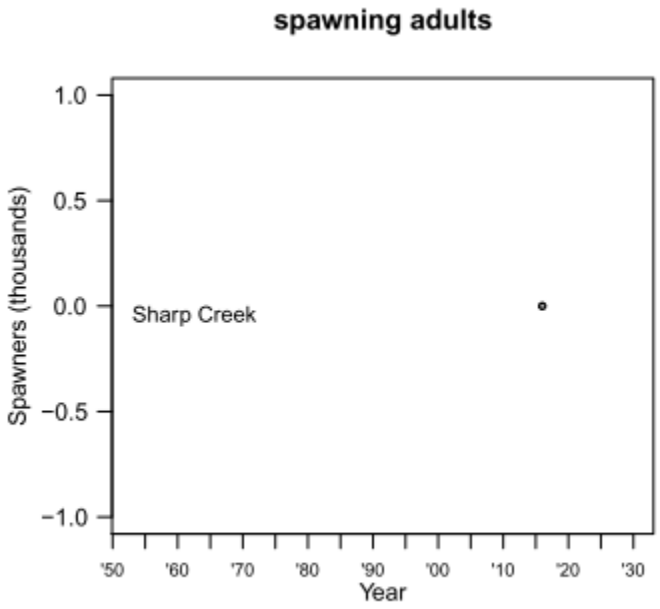

spawning adults
Muriel S1
0.015
0.010
0.005
0.000
Spawners (thousands)
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

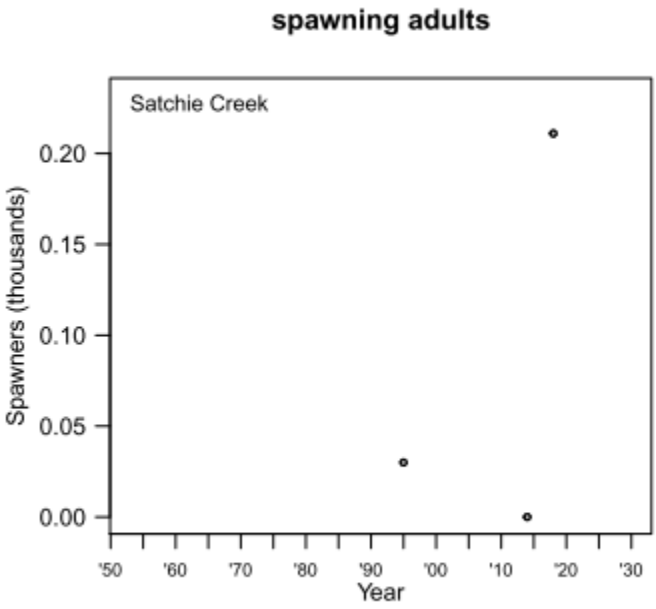

spawning adults
Muriel Lake
0.008
0.006
0.004
0.002
0.000
Spawners (thousands)
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

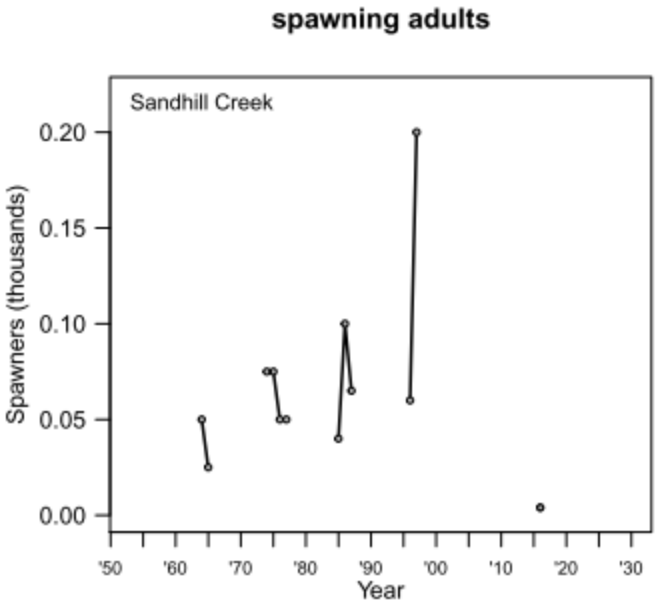

Riley Creek Coho
A
5
4
3
2
1
0
Spawners (thousands)
'55
'65
'75
'85
'95
'05
'15
Year
B
40
30
20
10
0
Intrinsic Productivity α
'55
'65
'75
'85
'95
'05
'15
Year

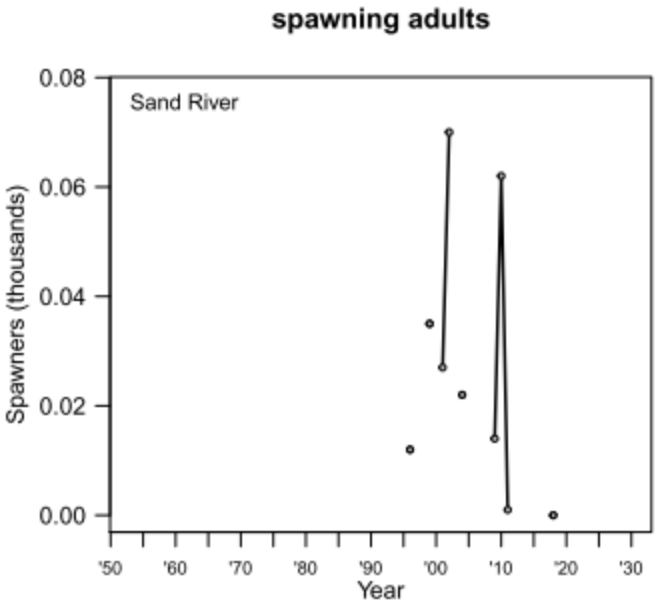

spawning adults
Staghorn Creek
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

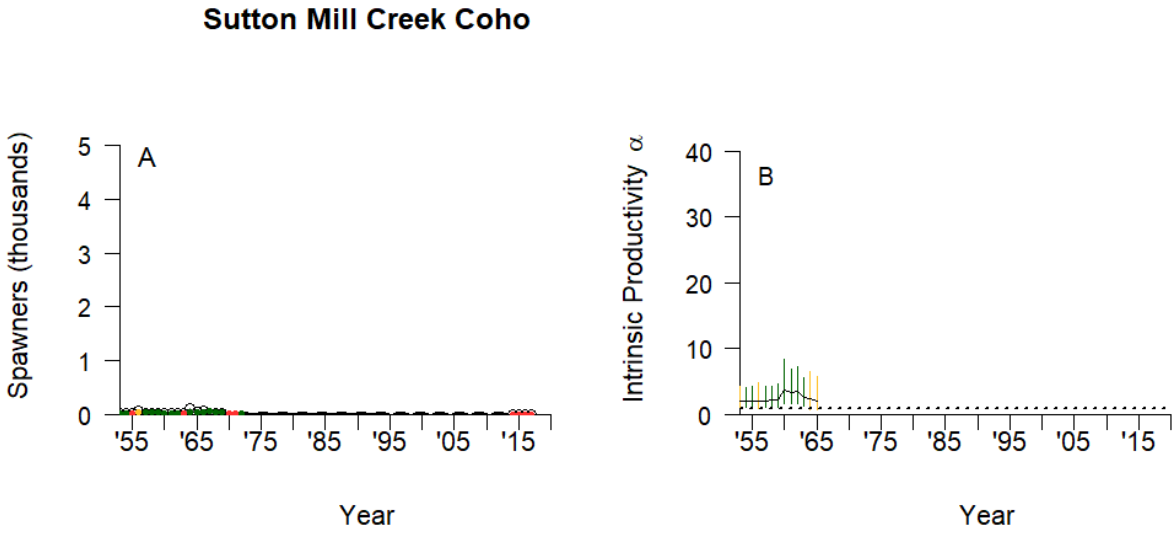

spawning adults
South Bay
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
0.25
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Sharp Creek
Spawners (thousands)
−1.0
−0.5
0.0
0.5
1.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

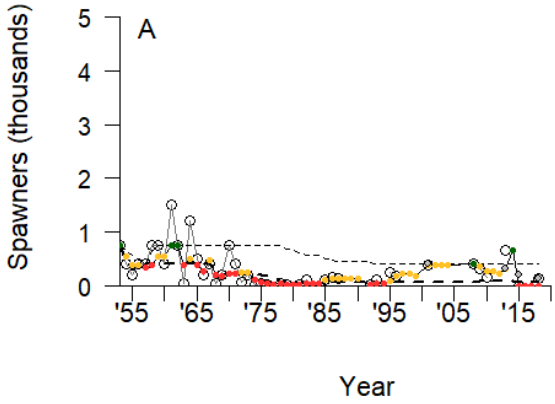

spawning adults
Satchie Creek
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

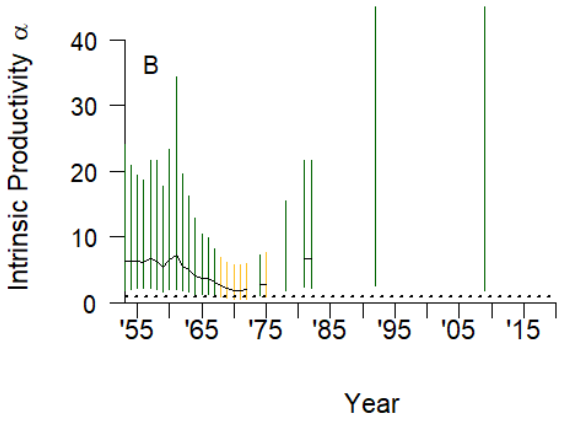

spawning adults
Sandhill Creek
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Sand River
Spawners (thousands)
0.00
0.02
0.04
0.06
0.08
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

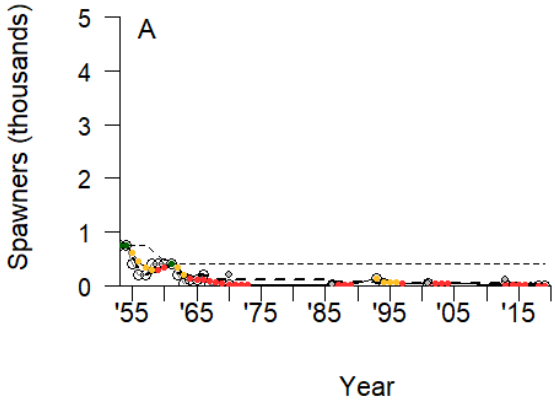

Sutton Mill Creek Coho
A
Spawners (thousands)
0
1
2
3
4
5
'55
'65
'75
'85
'95
'05
'15
Year
B
Intrinsic Productivity α
0
10
20
30
40
'55
'65
'75
'85
'95
'05
'15
Year

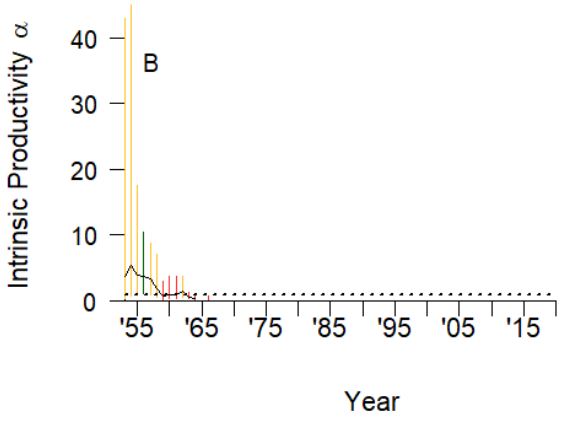
Sydney River Coho



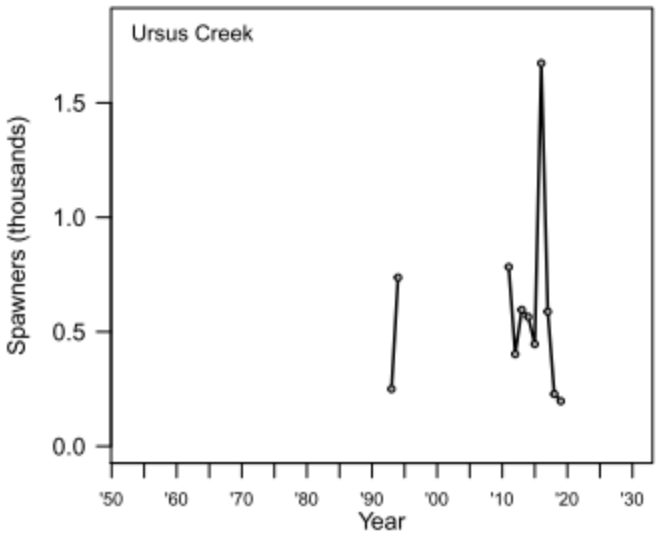


Tofino Creek Coho

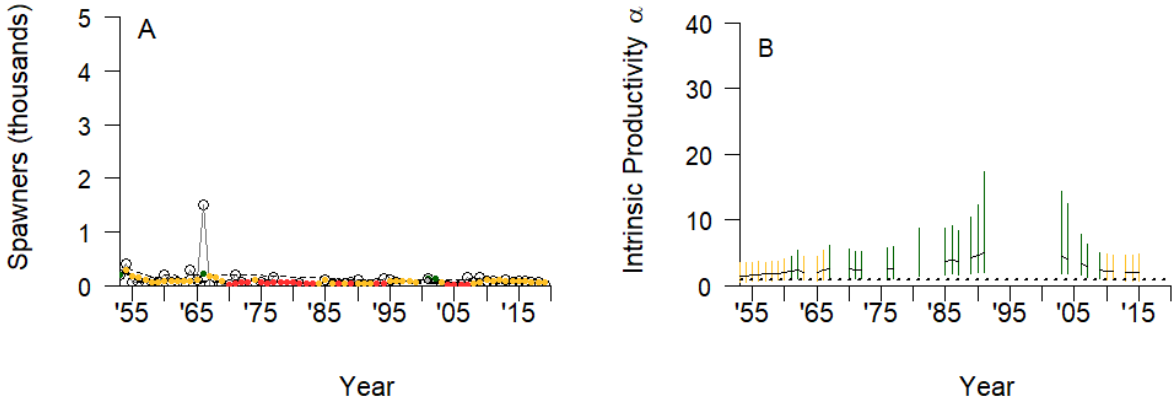




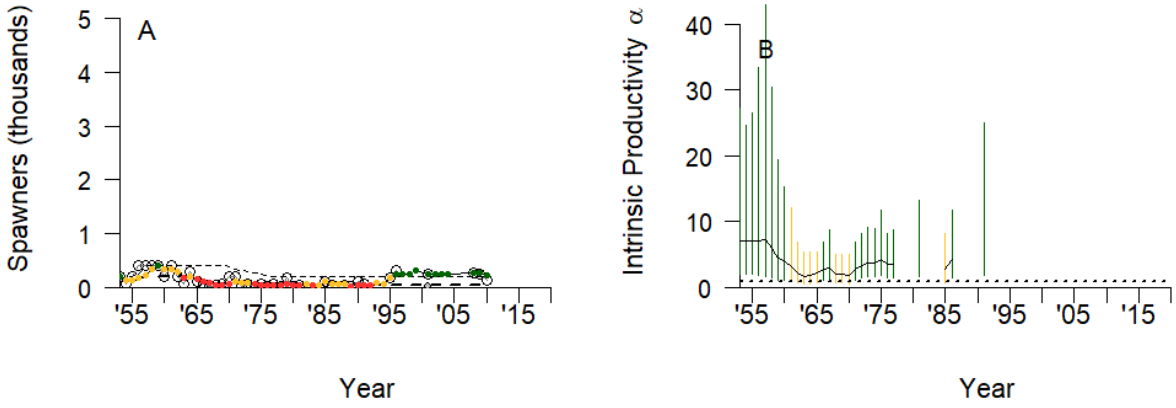
spawning adults



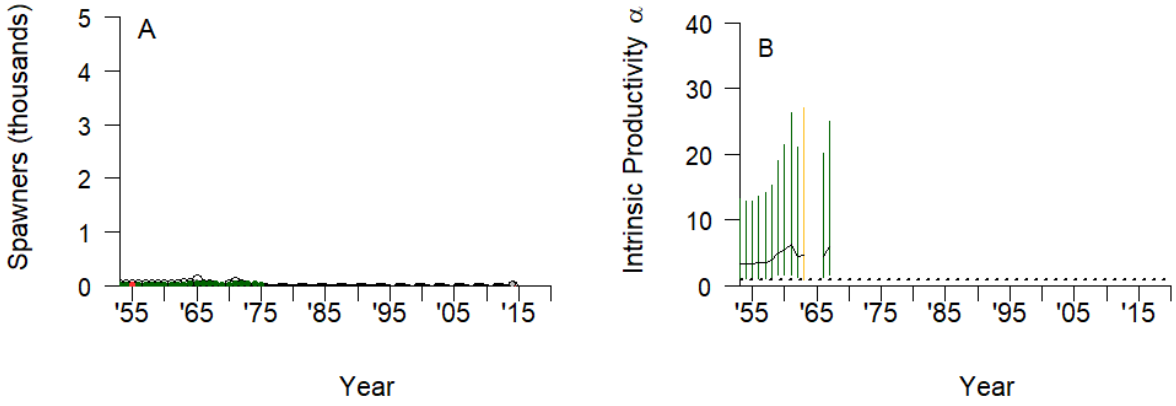
Warn Bay Creek Coho

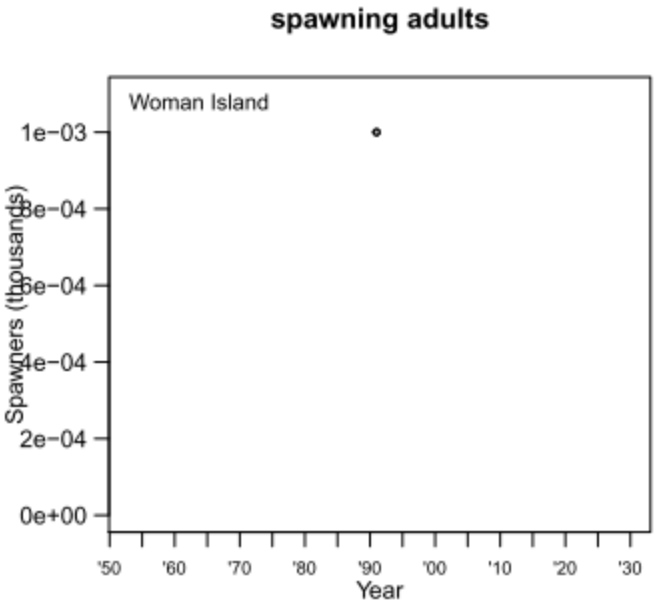


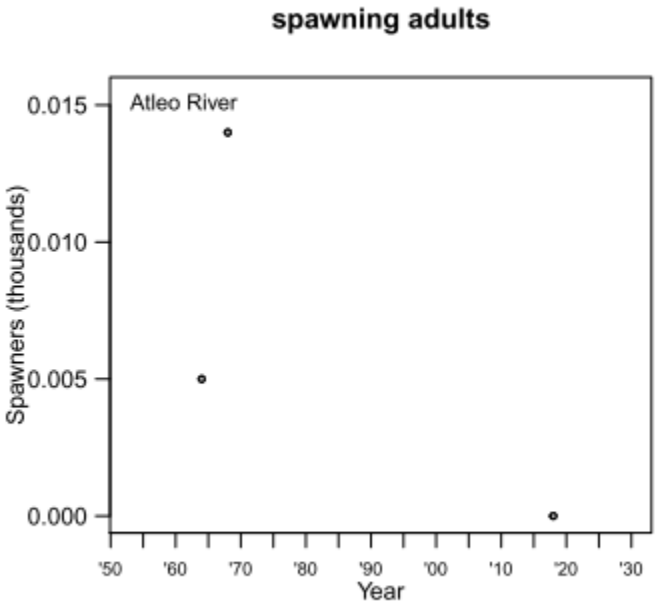
Watta Creek Coho

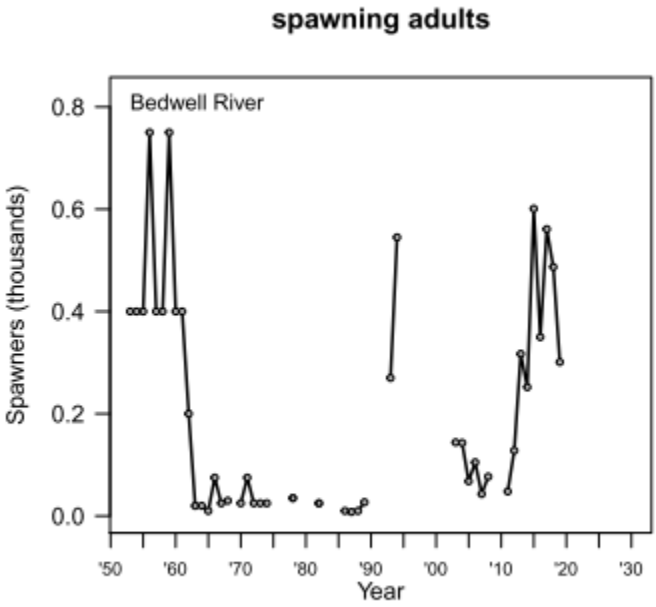


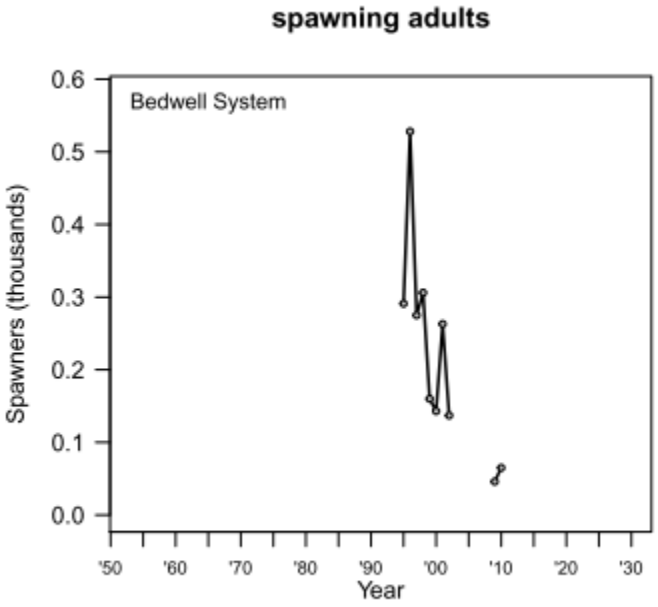
White Pine Cove Creek Coho

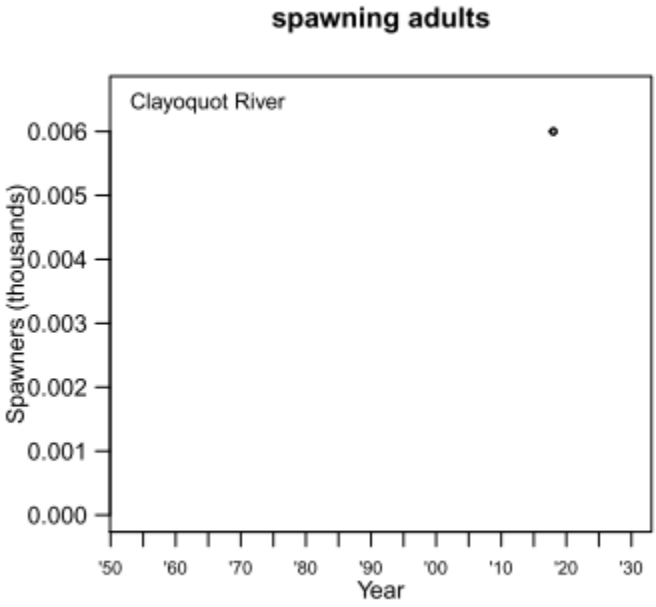


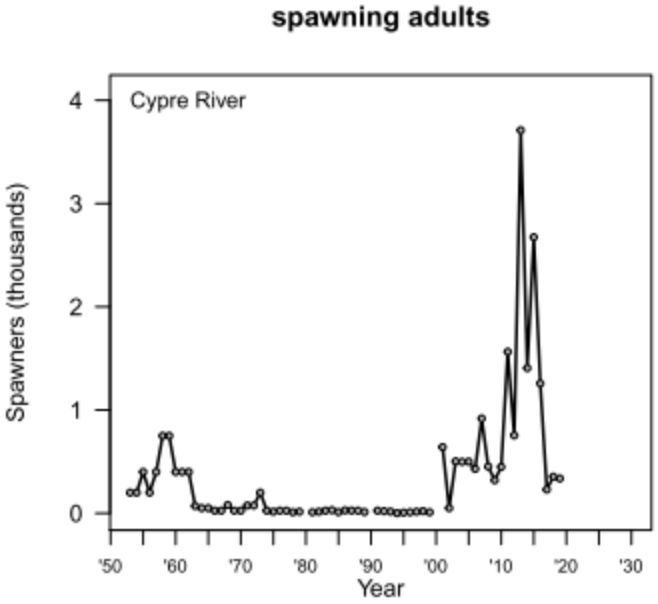

spawning adults
Woman Island
1e−03
8e−04
6e−04
4e−04
2e−04
0e+00
Spawners (thousands)
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

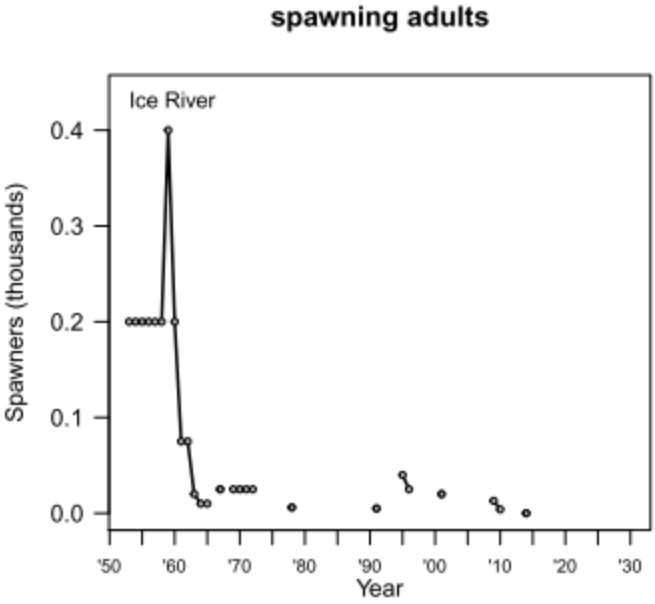

spawning adults
Atleo River
Spawners (thousands)
0.015
0.010
0.005
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

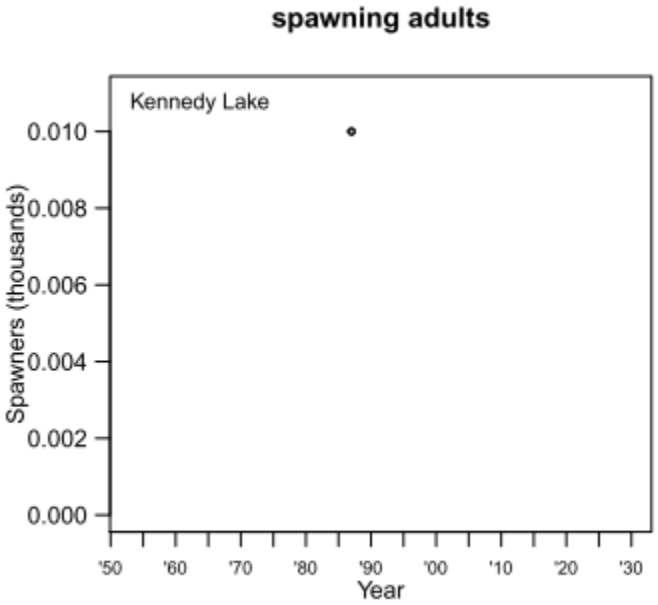

spawning adults
Bedwell River
Spawners (thousands)
0.8
0.6
0.4
0.2
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

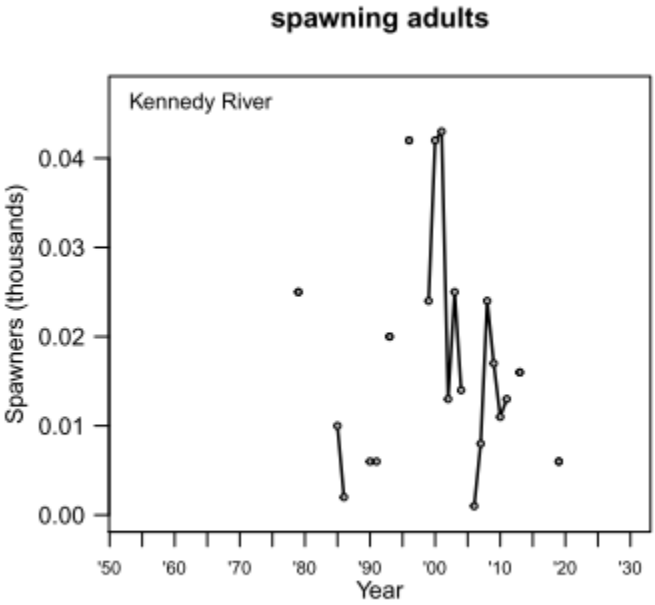

spawning adults
Bedwell System
Spawners (thousands)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

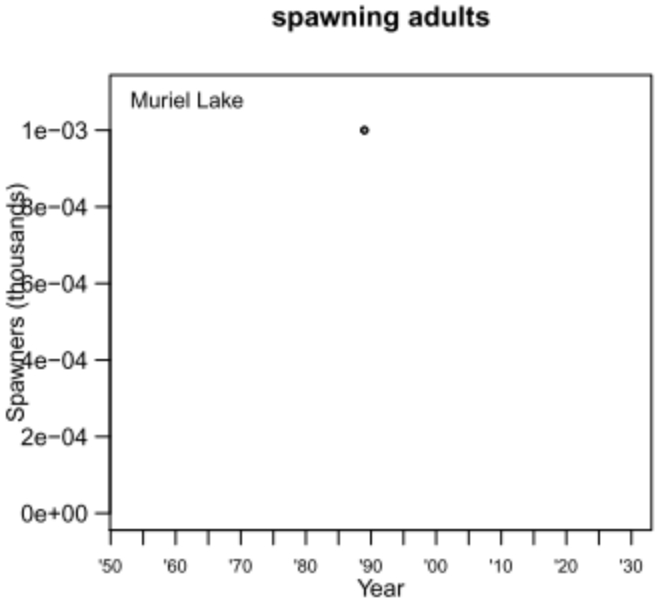

spawning adults
Clayoquot River
Spawners (thousands)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

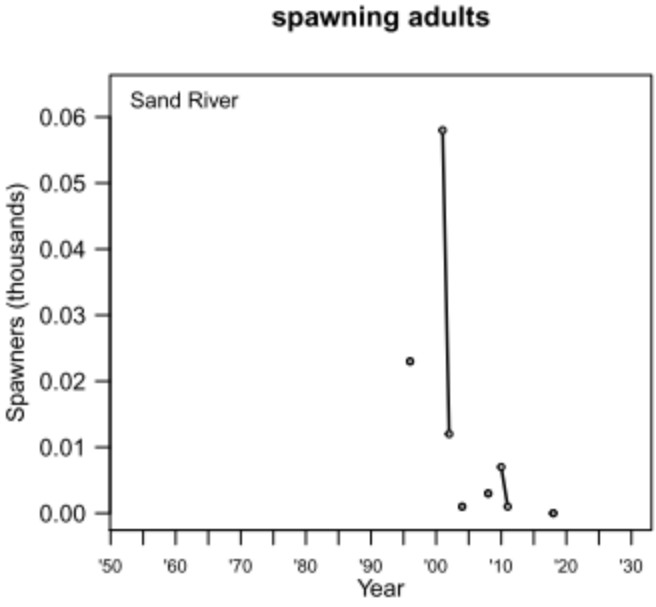

spawning adults
Cypre River
Spawners (thousands)
0
1
2
3
4
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

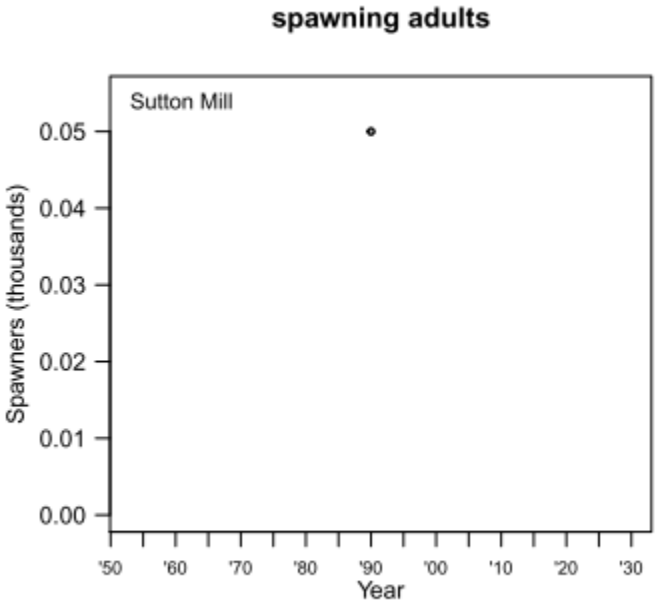

spawning adults
Ice River
Spawners (thousands)
0.0
0.1
0.2
0.3
0.4
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

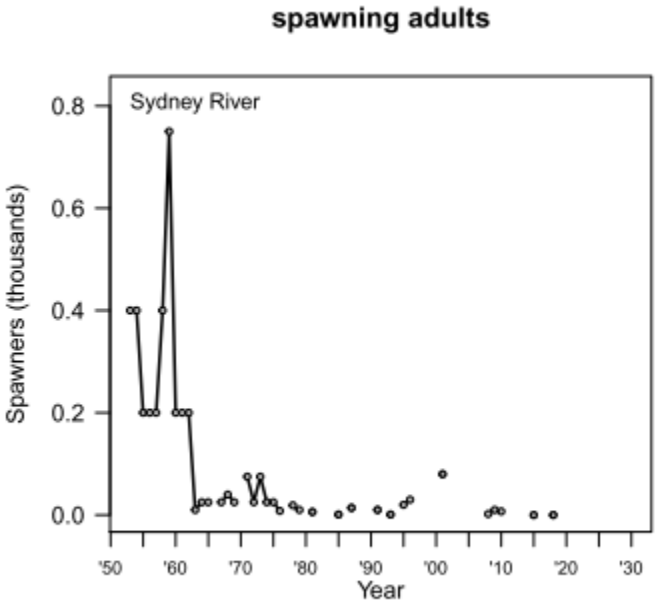

spawning adults
Kennedy Lake
Spawners (thousands)
0.000
0.002
0.004
0.006
0.008
0.010
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

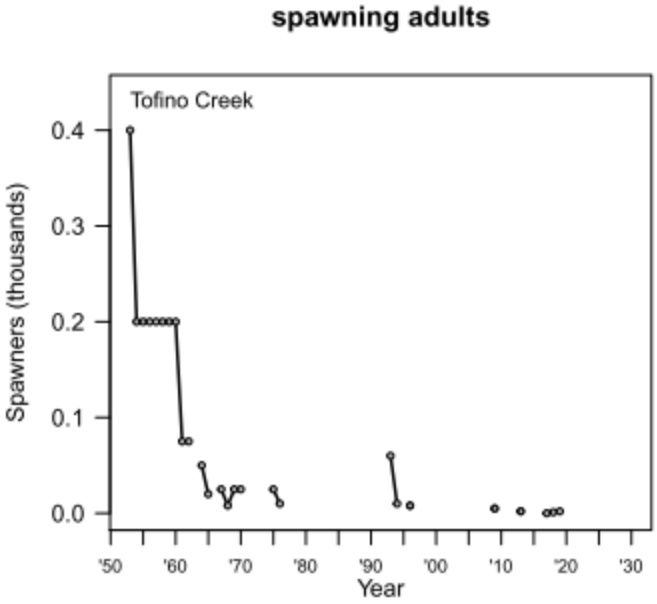

spawning adults
Kennedy River
Spawners (thousands)
0.00
0.01
0.02
0.03
0.04
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

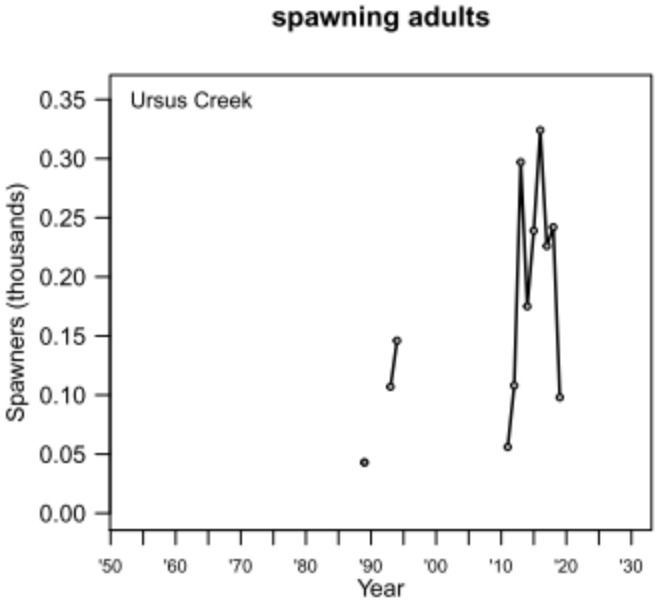

spawning adults
Muriel Lake
Spawners (thousands)
1e−03
8e−04
6e−04
4e−04
2e−04
0e+00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

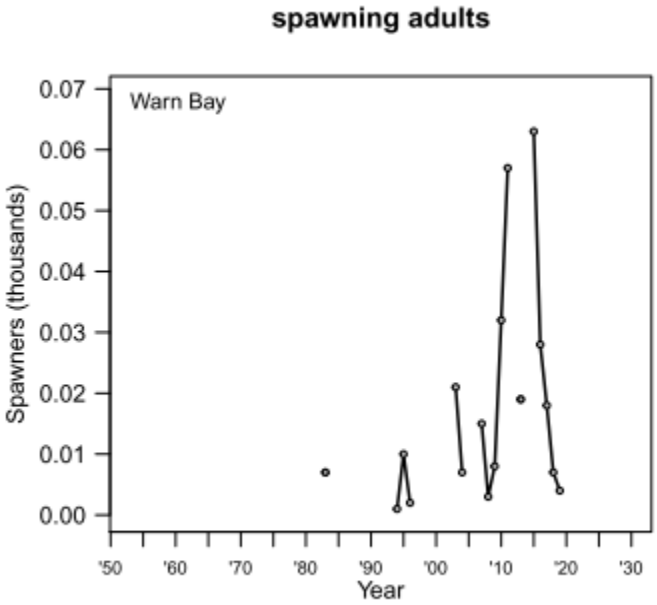

spawning adults
Sand River
Spawners (thousands)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

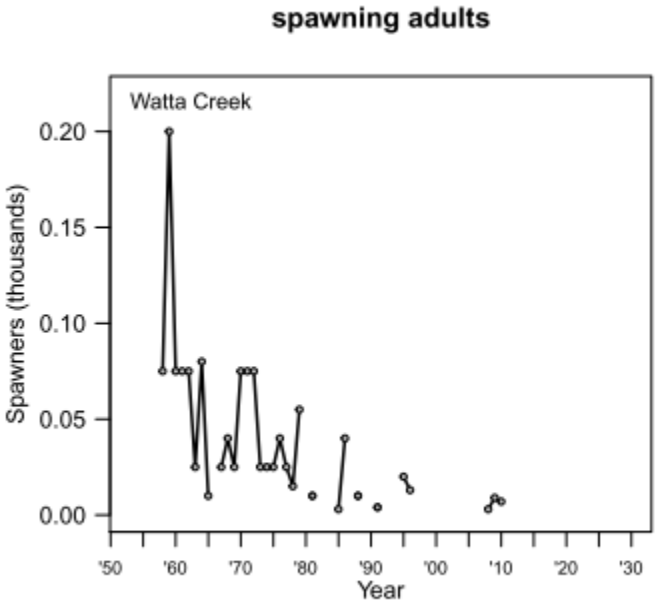

spawning adults
Sutton Mill
Spawners (thousands)
0.05
0.04
0.03
0.02
0.01
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

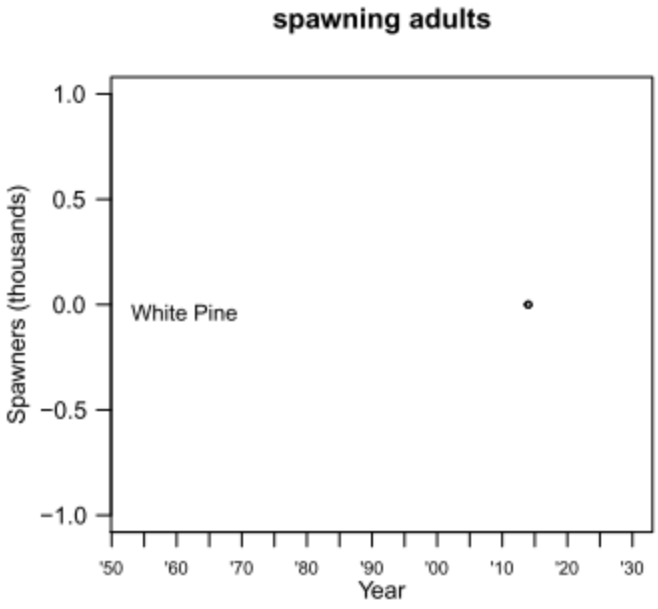

spawning adults
Sydney River
Spawners (thousands)
0.8
0.6
0.4
0.2
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

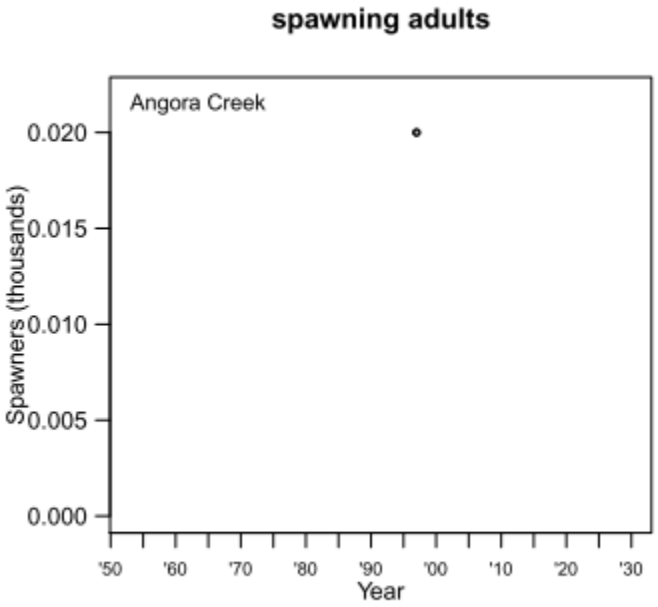

spawning adults
Tofino Creek
Spawners (thousands)
0.0
0.1
0.2
0.3
0.4
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

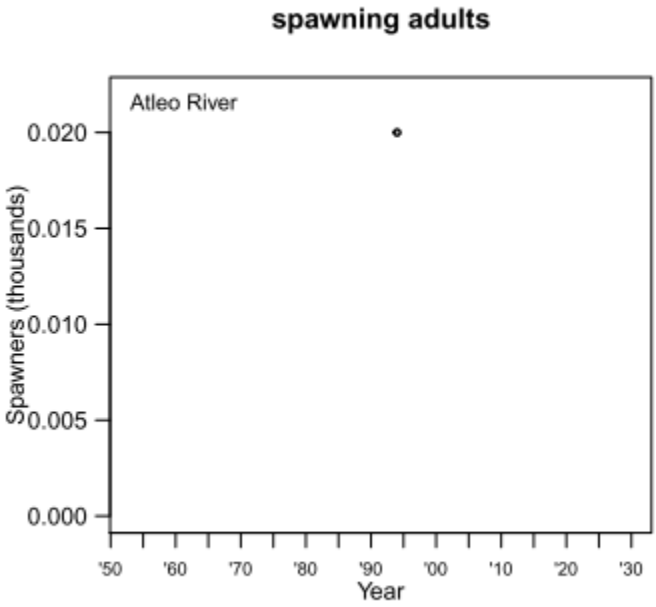

spawning adults
Ursus Creek
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

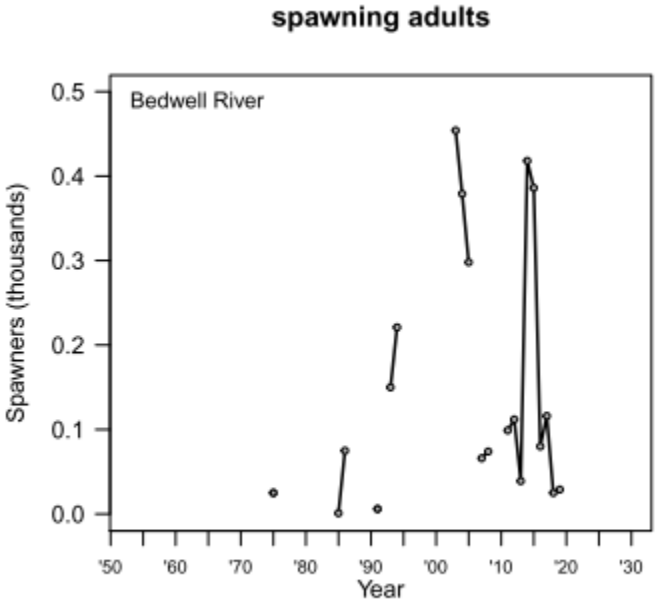

spawning adults
Warn Bay
Spawners (thousands)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

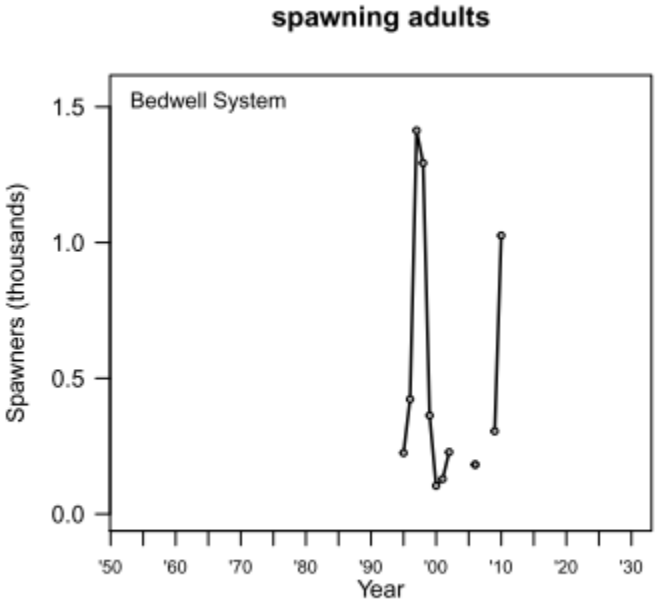

spawning adults
Watta Creek
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
1.0
0.5
0.0
−0.5
−1.0
Spawners (thousands)
White Pine
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

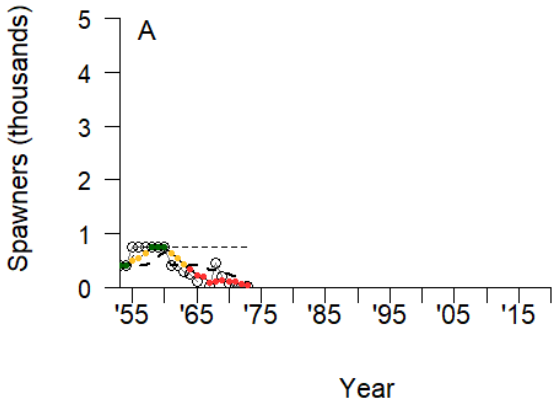

spawning adults
Angora Creek
Spawners (thousands)
0.020
0.015
0.010
0.005
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

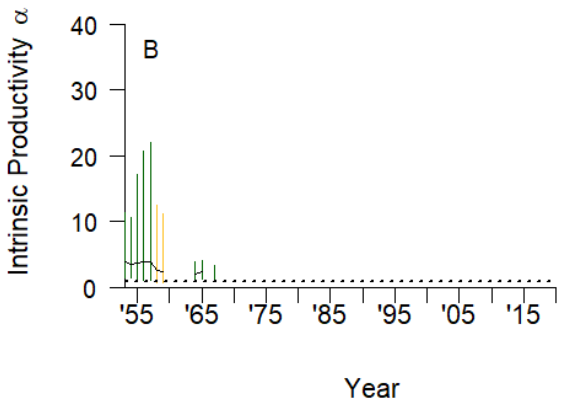

spawning adults
Atleo River
Spawners (thousands)
0.020
0.015
0.010
0.005
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Bedwell River
Spawners (thousands)
0.5
0.4
0.3
0.2
0.1
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

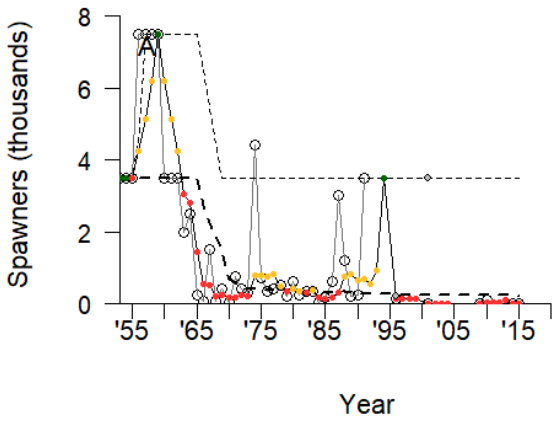

spawning adults
Bedwell System
Spawners (thousands)
1.5
1.0
0.5
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

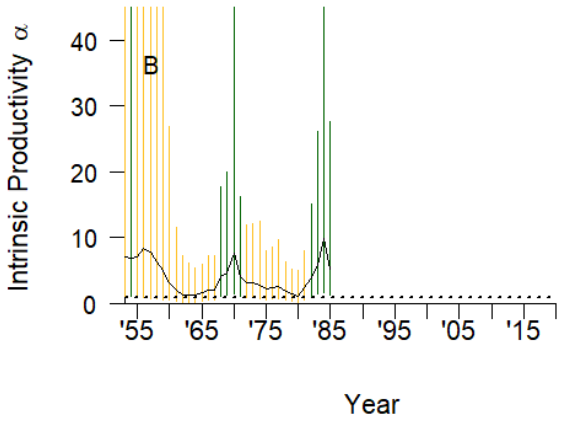
Cecilia Creek (Tofino) Sockeye Run 1

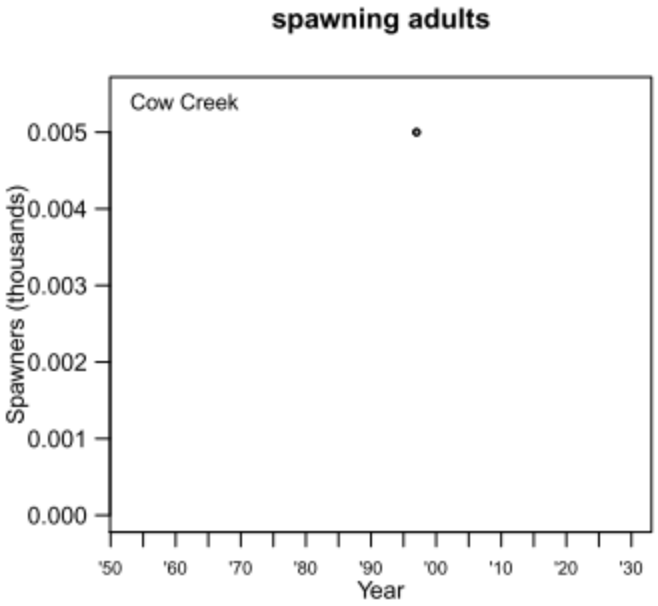


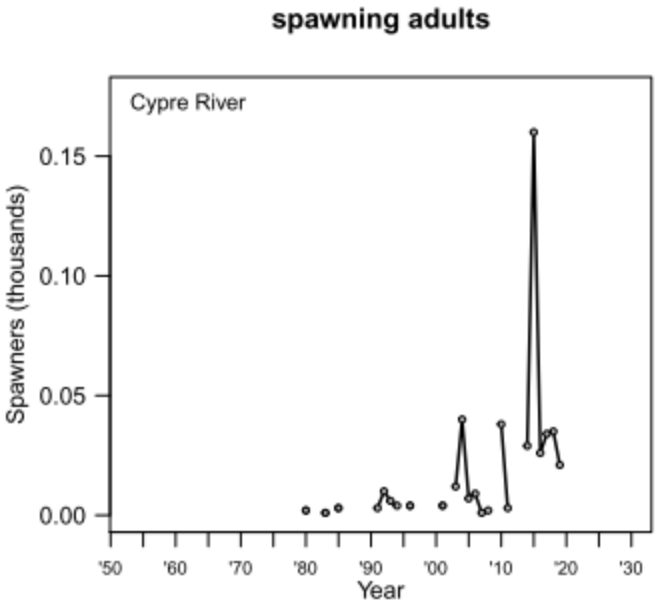


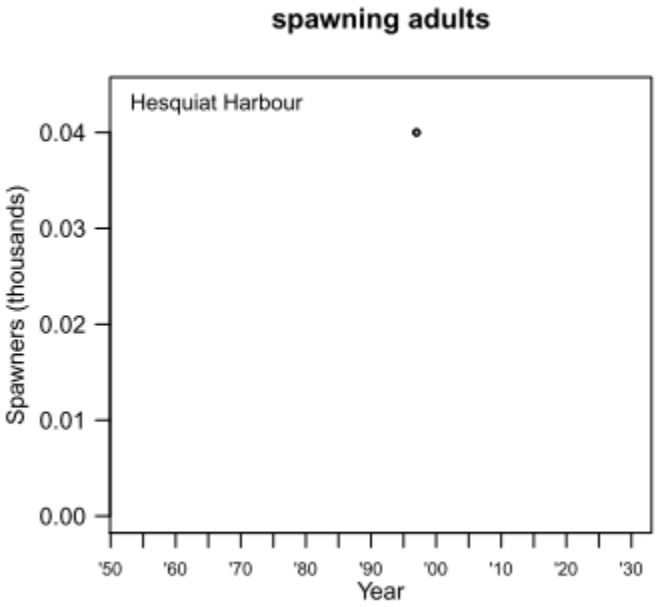
Cold Creek Sockeye

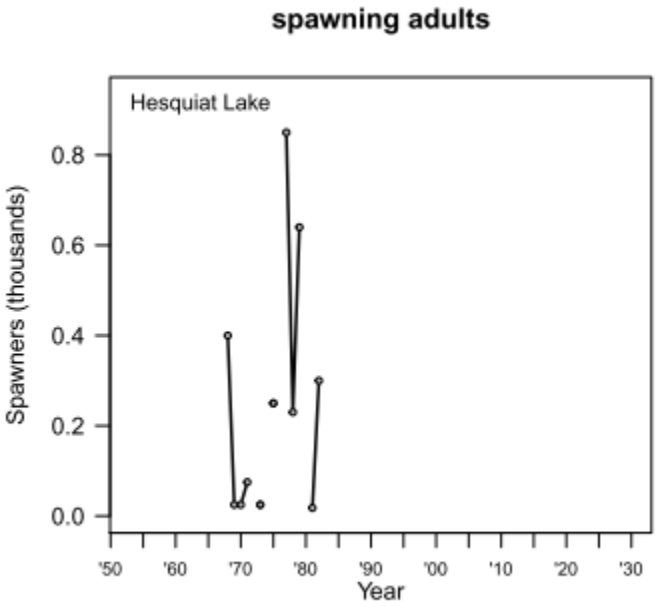


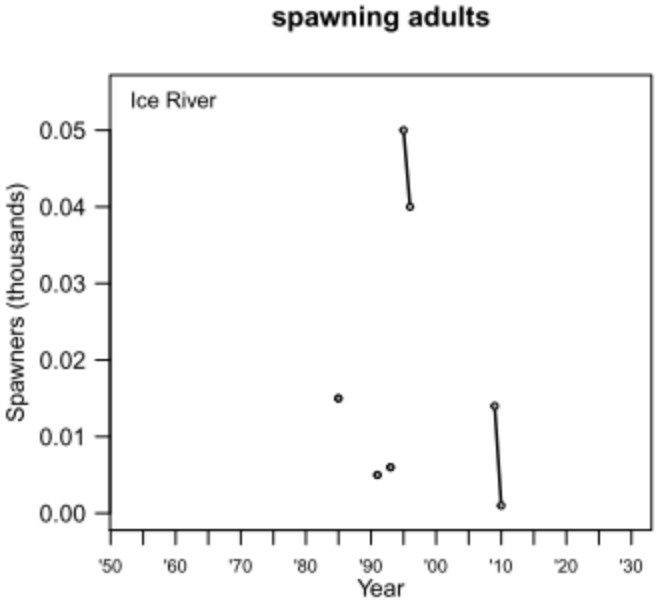


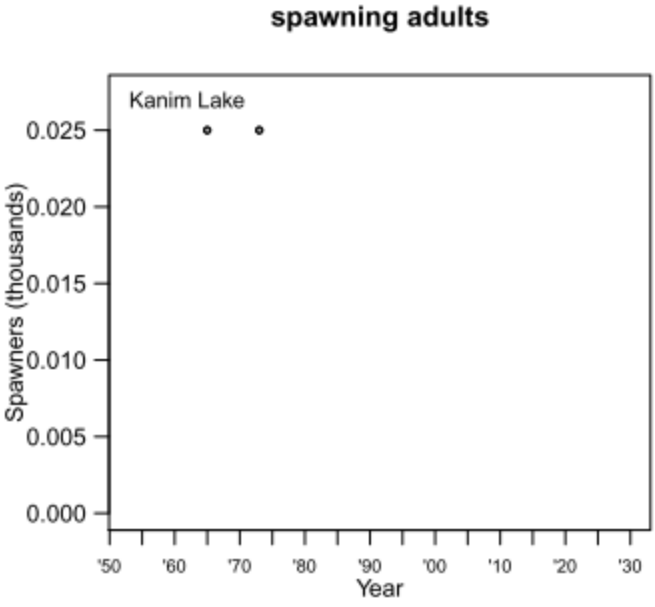

spawning adults
Cow Creek
Spawners (thousands)
0.005
0.004
0.003
0.002
0.001
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

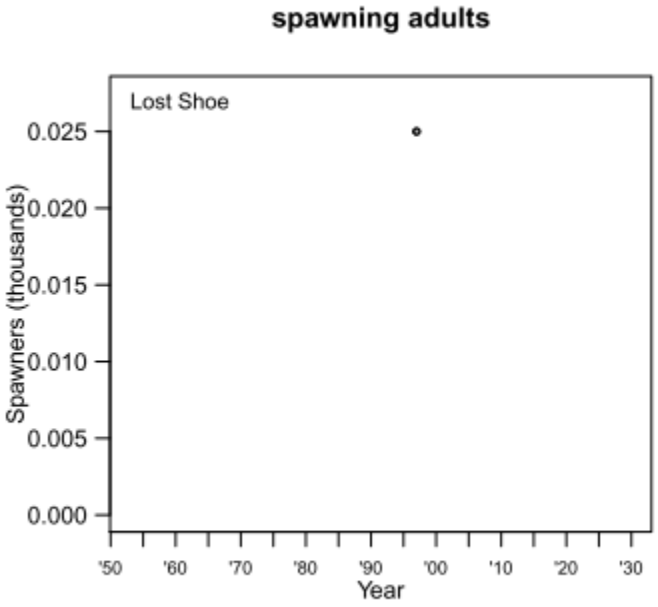

spawning adults
Cypre River
Spawners (thousands)
0.15
0.10
0.05
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

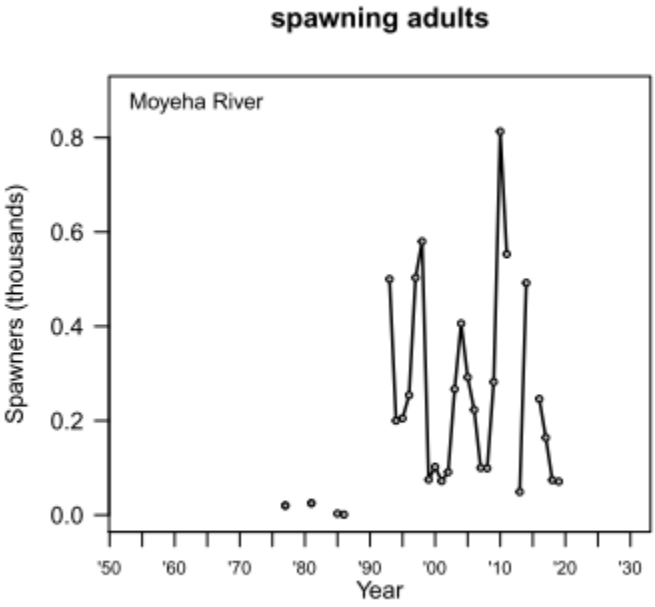

spawning adults
Hesquiat Harbour
Spawners (thousands)
0.04
0.03
0.02
0.01
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

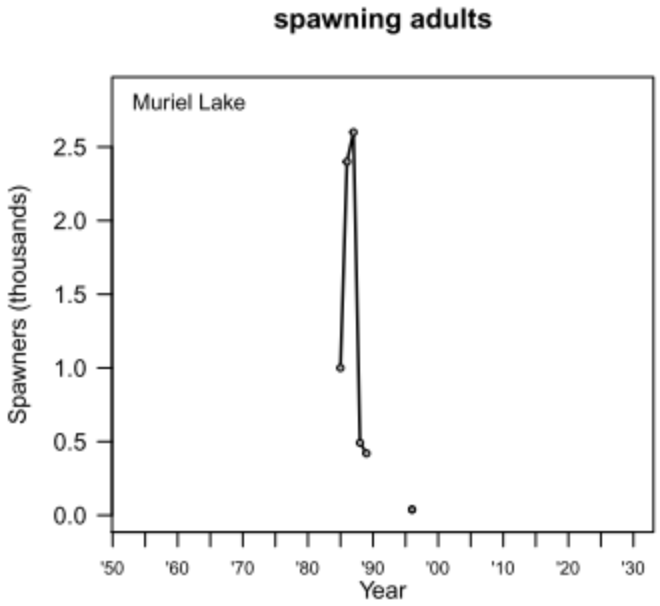

spawning adults
Hesquiat Lake
Spawners (thousands)
0.8
0.6
0.4
0.2
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

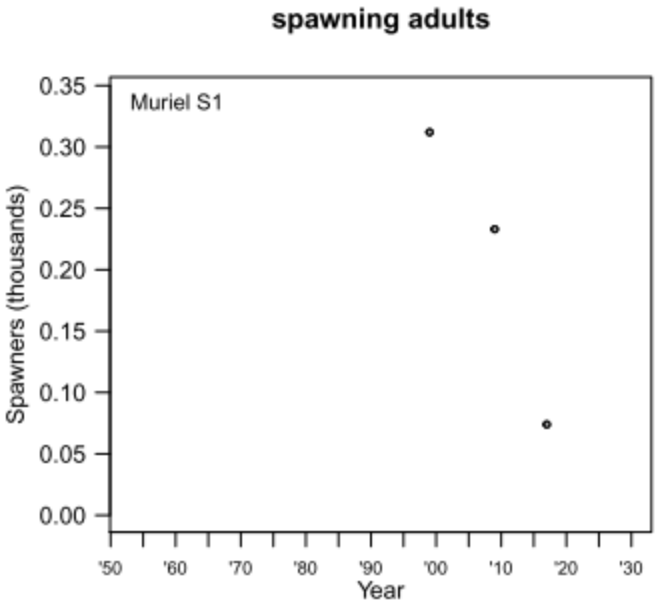

spawning adults
Ice River
Spawners (thousands)
0.05
0.04
0.03
0.02
0.01
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

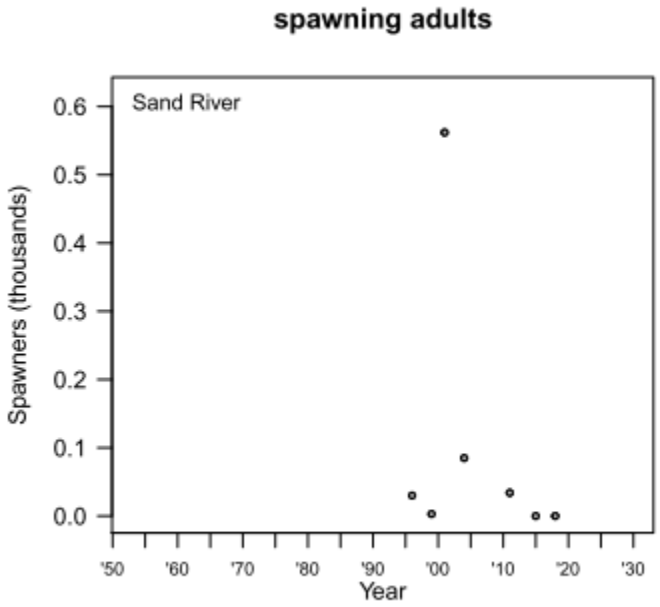

spawning adults
Kanim Lake
Spawners (thousands)
0.025
0.020
0.015
0.010
0.005
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

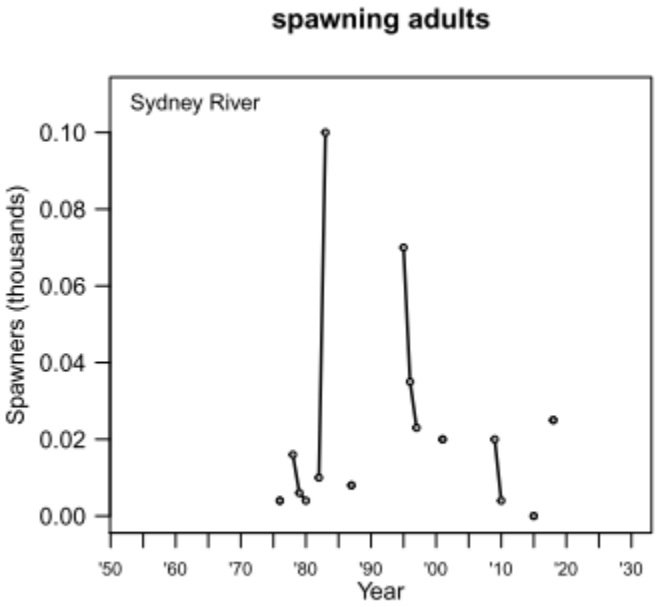

spawning adults
Lost Shoe
Spawners (thousands)
0.025
0.020
0.015
0.010
0.005
0.000
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

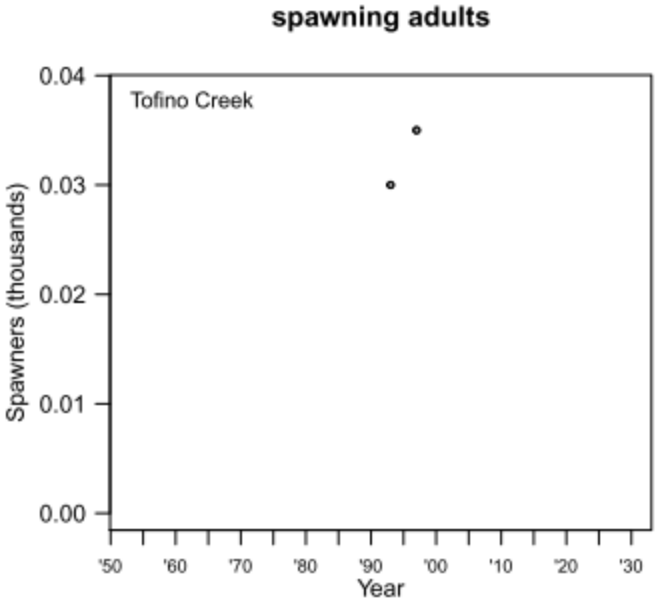

spawning adults
Moyeha River
Spawners (thousands)
0.8
0.6
0.4
0.2
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

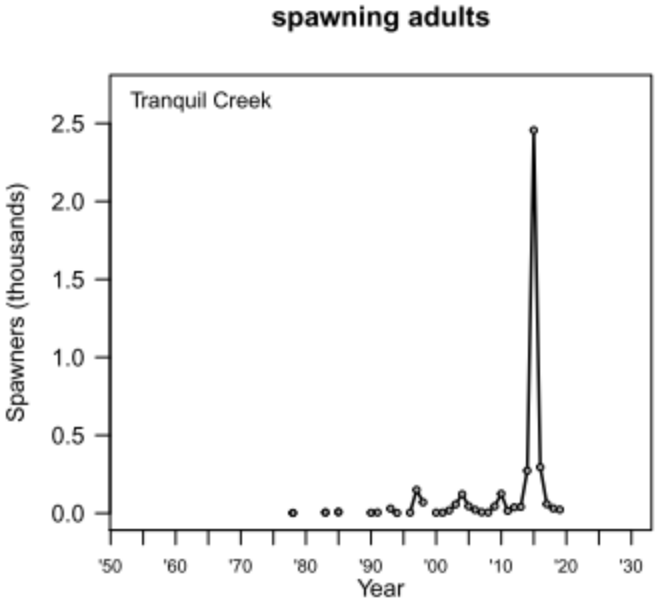

spawning adults
Muriel Lake
Spawners (thousands)
0.0
0.5
1.0
1.5
2.0
2.5
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

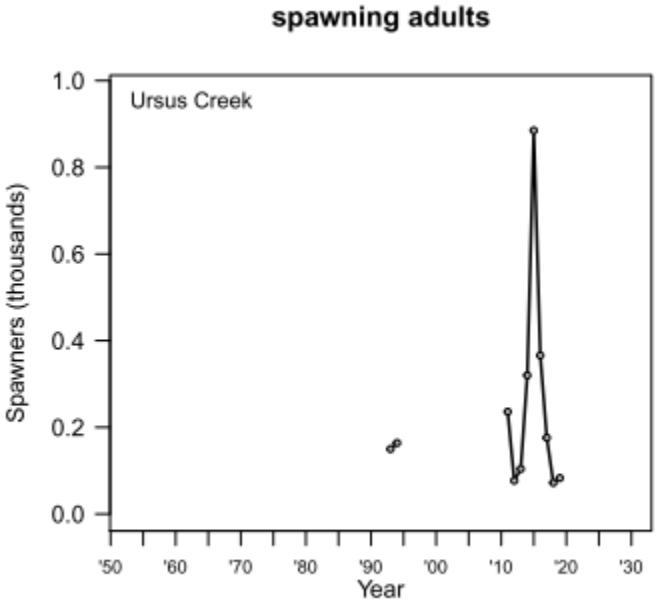

spawning adults
Muriel S1
Spawners (thousands)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

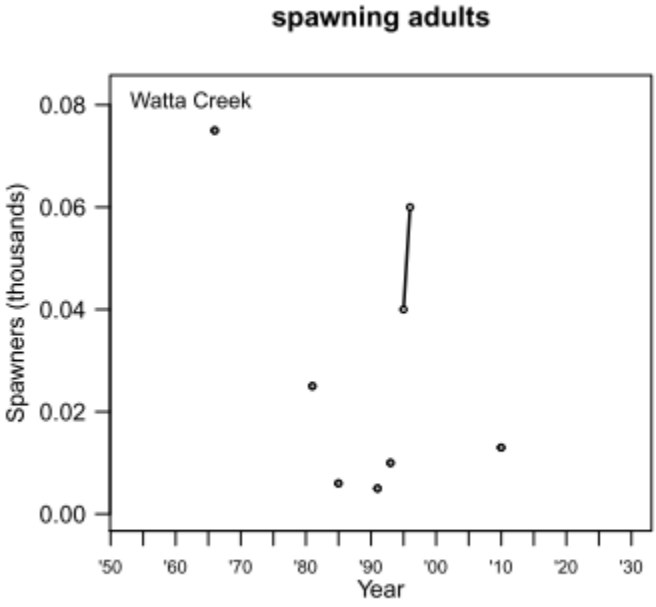

spawning adults
Sand River
Spawners (thousands)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

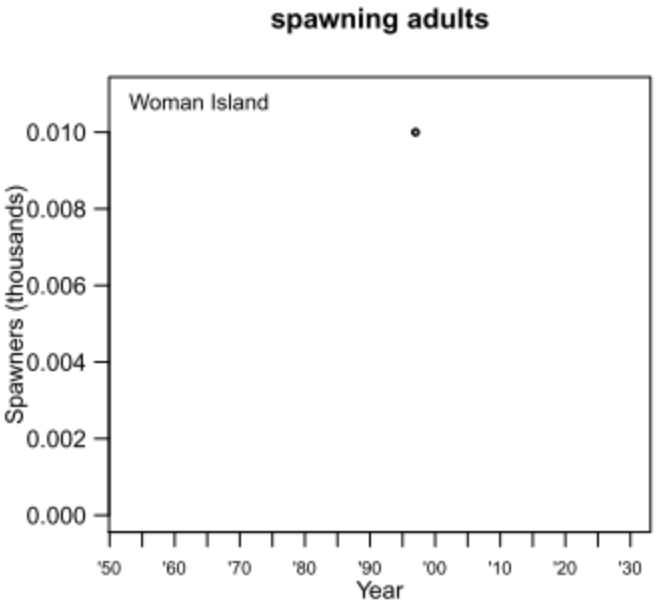

spawning adults
Sydney River
Spawners (thousands)
0.00
0.02
0.04
0.06
0.08
0.10
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Tofino Creek
Spawners (thousands)
0.04
0.03
0.02
0.01
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Tranquil Creek
Spawners (thousands)
2.5
2.0
1.5
1.0
0.5
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Ursus Creek
Spawners (thousands)
1.0
0.8
0.6
0.4
0.2
0.0
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

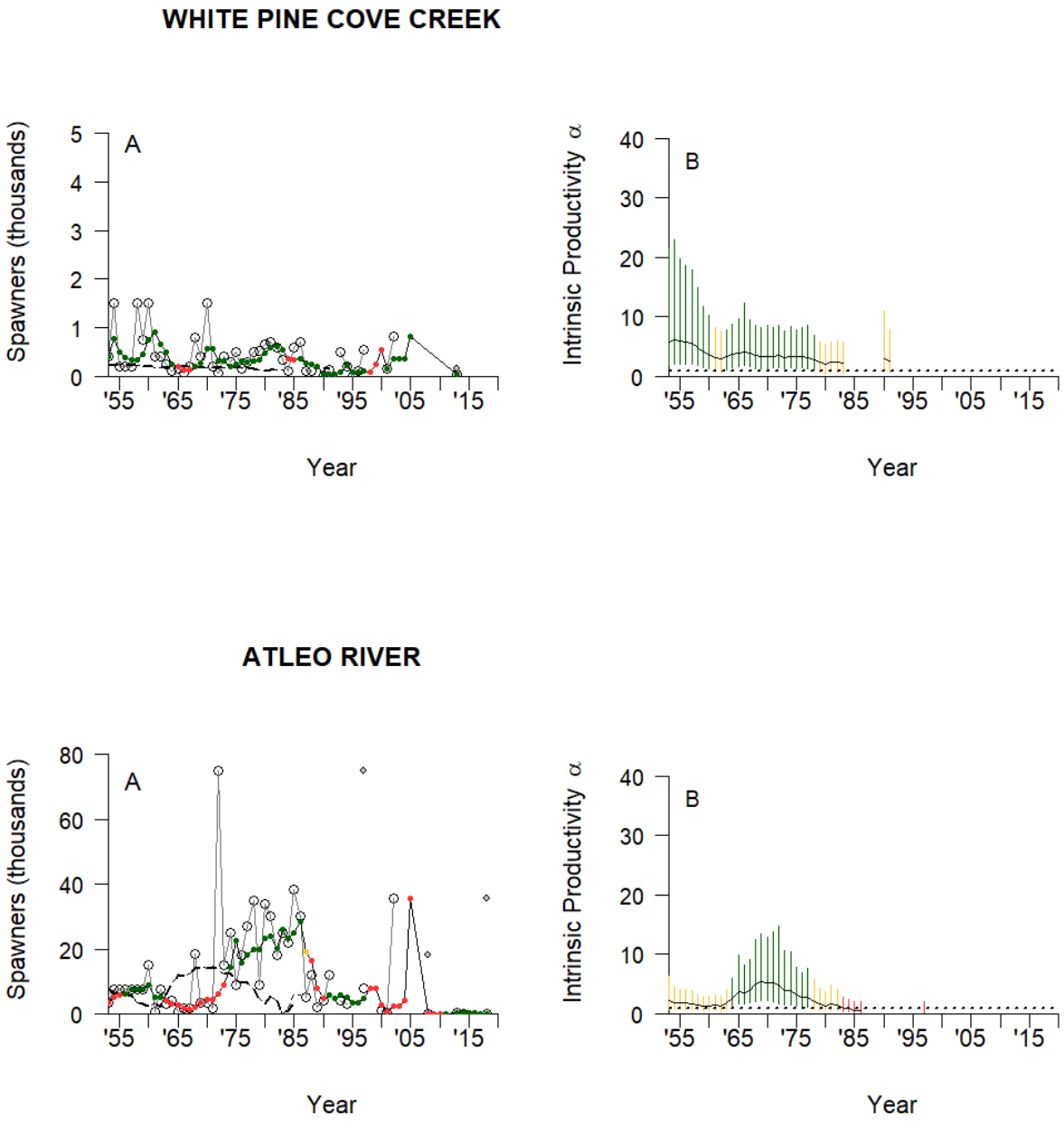

spawning adults
Watta Creek
Spawners (thousands)
0.08
0.06
0.04
0.02
0.00
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year


spawning adults
Woman Island
0.010
0.008
0.006
0.004
0.002
0.000
Spawners (thousands)
'50
'60
'70
'80
'90
'00
'10
'20
'30
Year

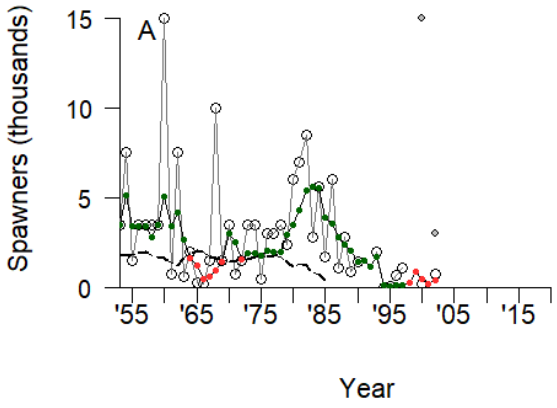
Appendix B

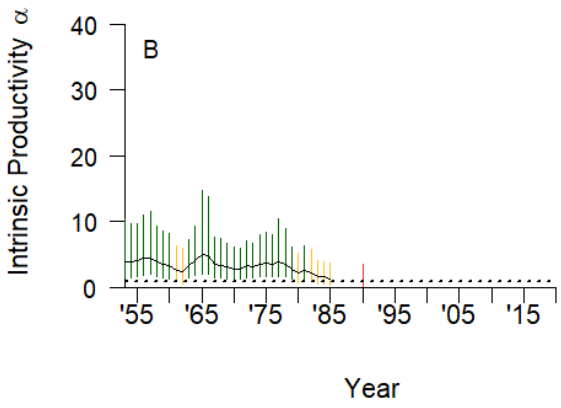
Panel A shows escapement time series (1953 - 2020) for all Clayoquot Sound Populations of Chum, Coho, Chinook, and Sockeye, showing spawner-recruit status assignments benchmarks and (S_{GEN} - S_{MSY}). Escapement is given in the thousands. Panel B shows productivity status assignments throughout time, relative to the productivity benchmark (dotted line): intrinsic productivity (S/R when density dependence is 0) at replacement (intrinsic productivity = 1). Mean intrinsic productivity is given as the solid black line while the 95% confidence interval and subsequent productivity status assignment is given by coloured bars.

Chum

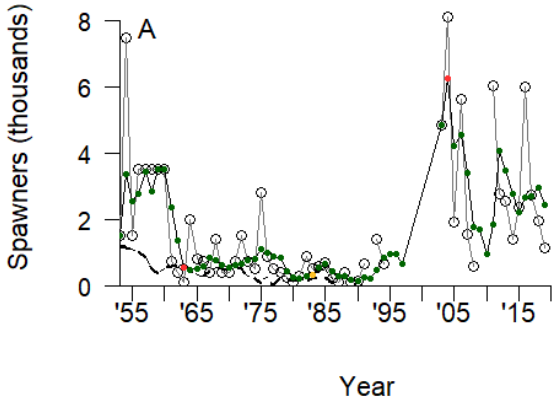


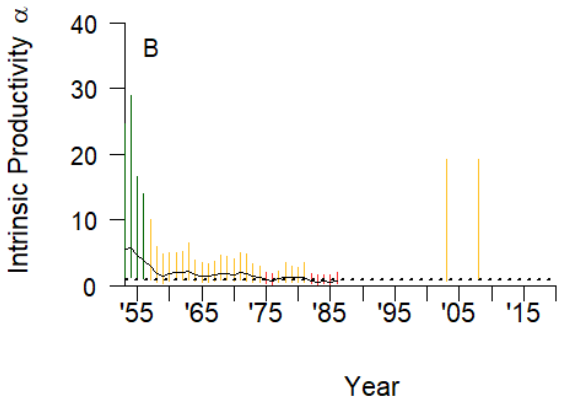
BAWDEN CREEK



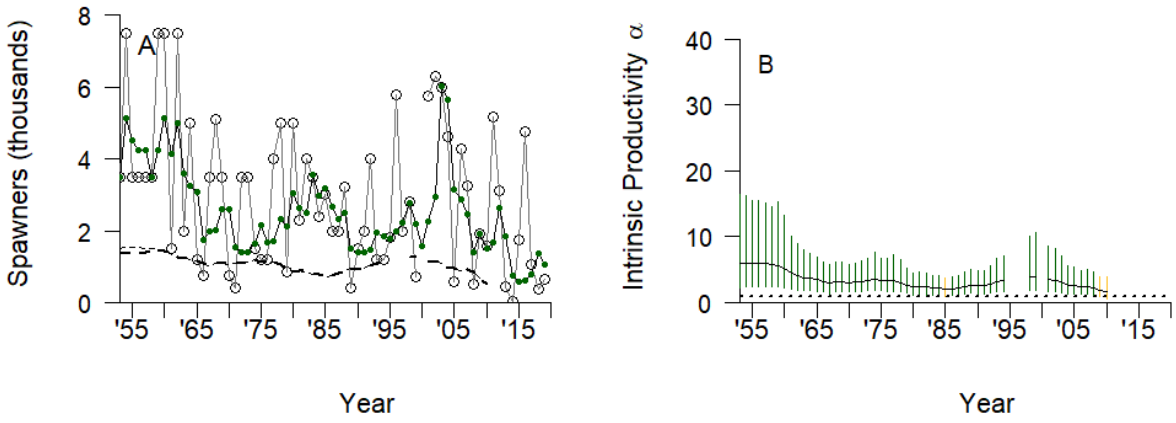


BEDWELL RIVER

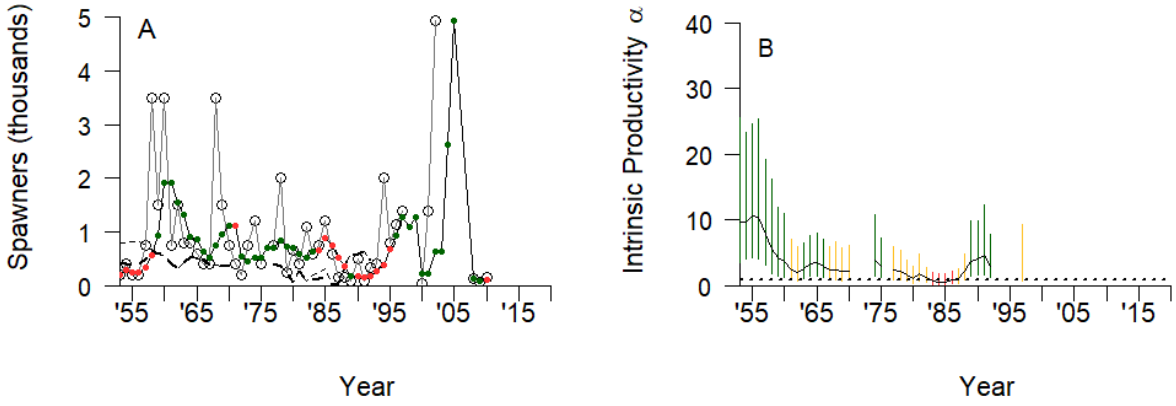




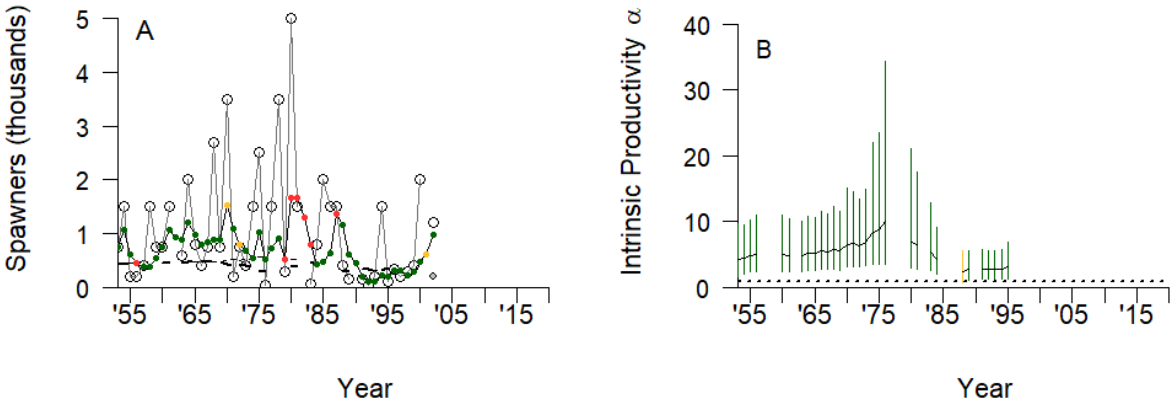
CYPRE RIVER



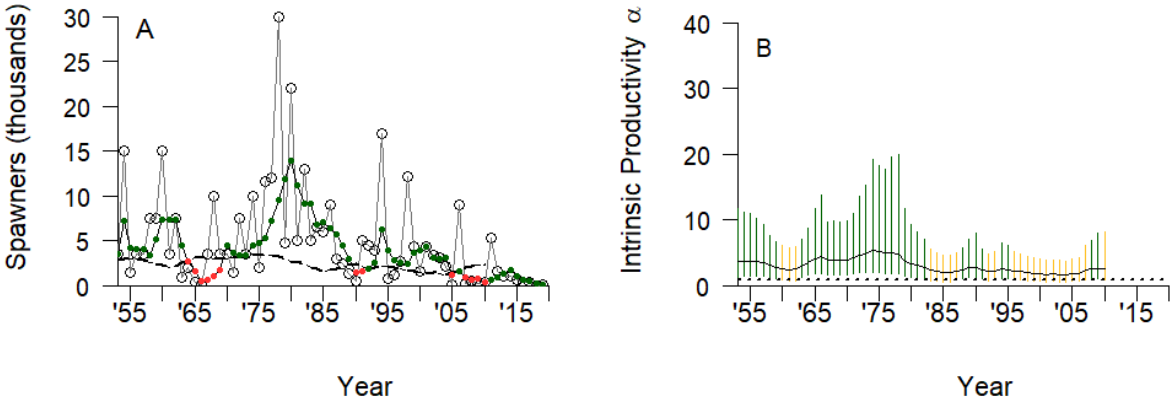
ICE RIVER



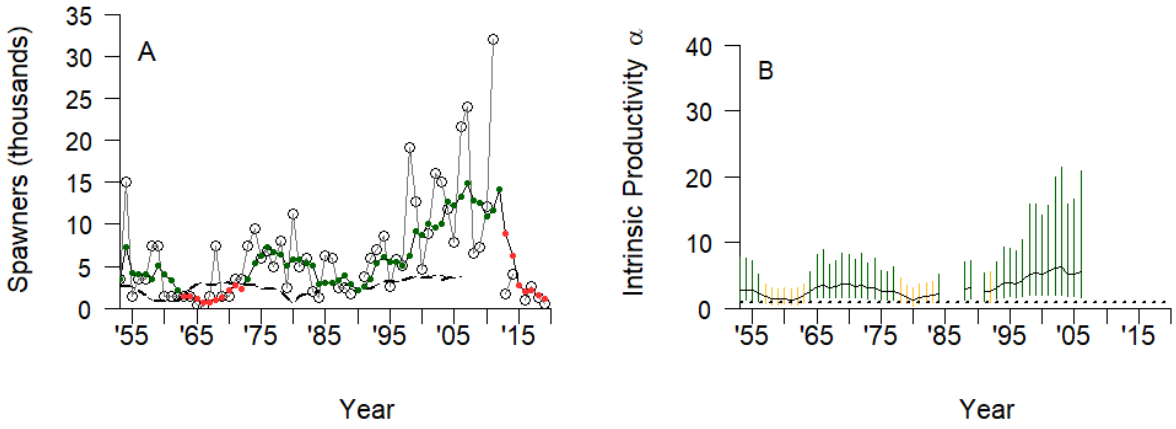
KOOTOWIS CREEK



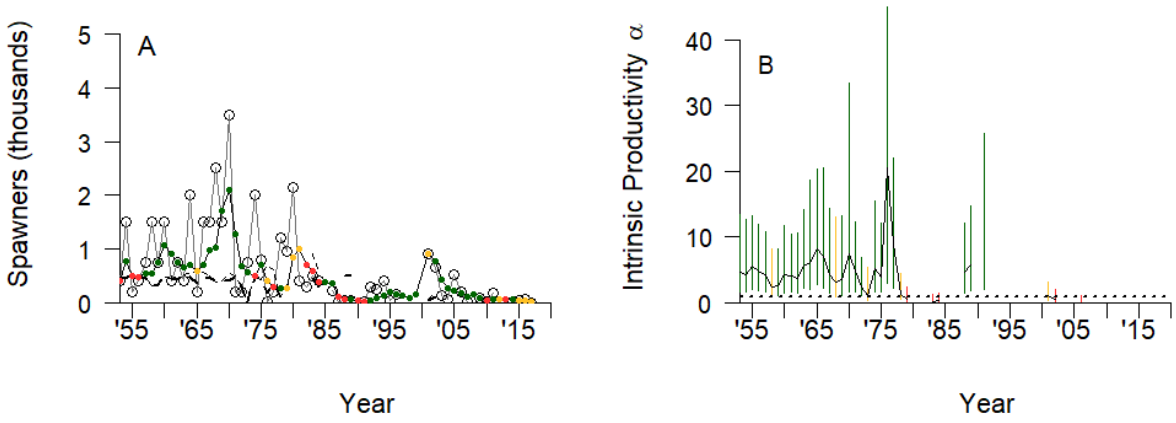
MEGIN RIVER



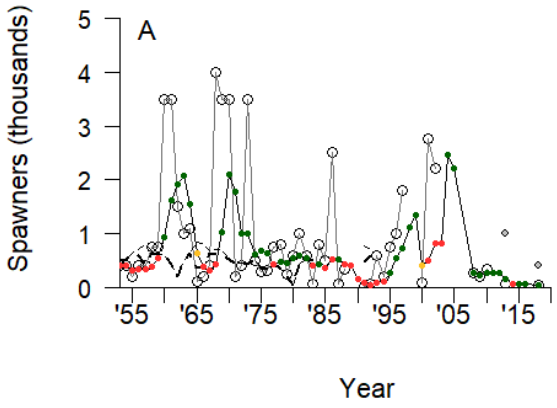
MOYEHA RIVER

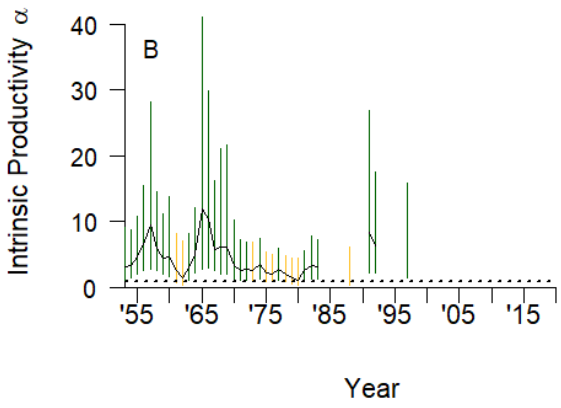


SUTTON MILL CREEK

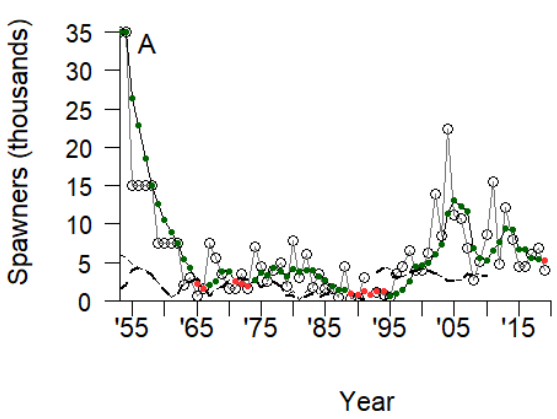


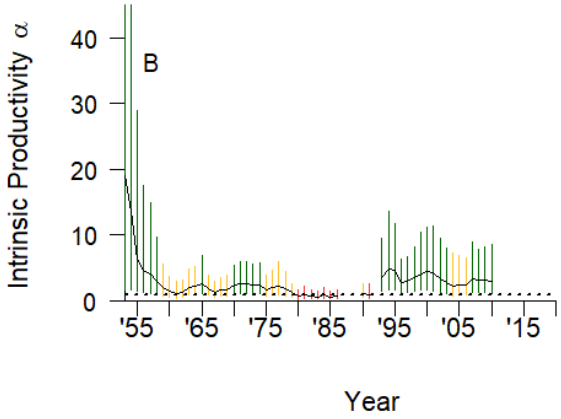
SYDNEY RIVER



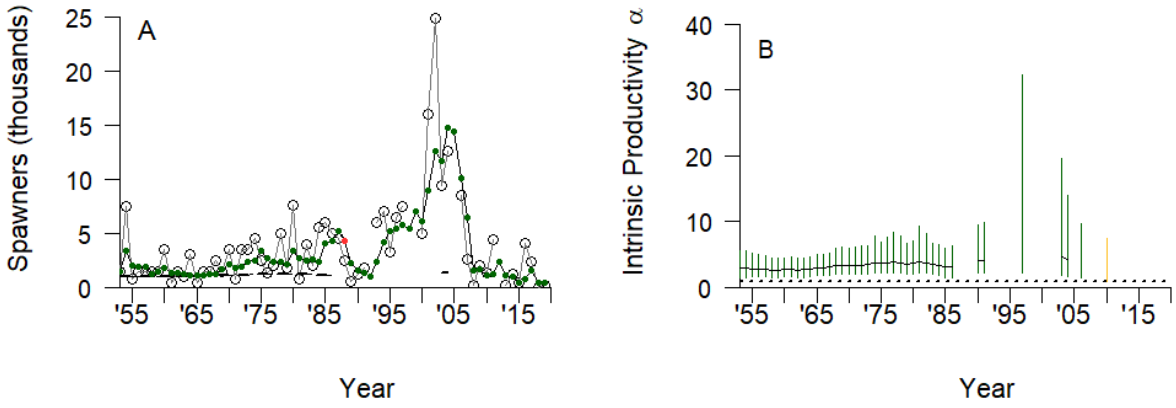


TRANQUIL CREEK

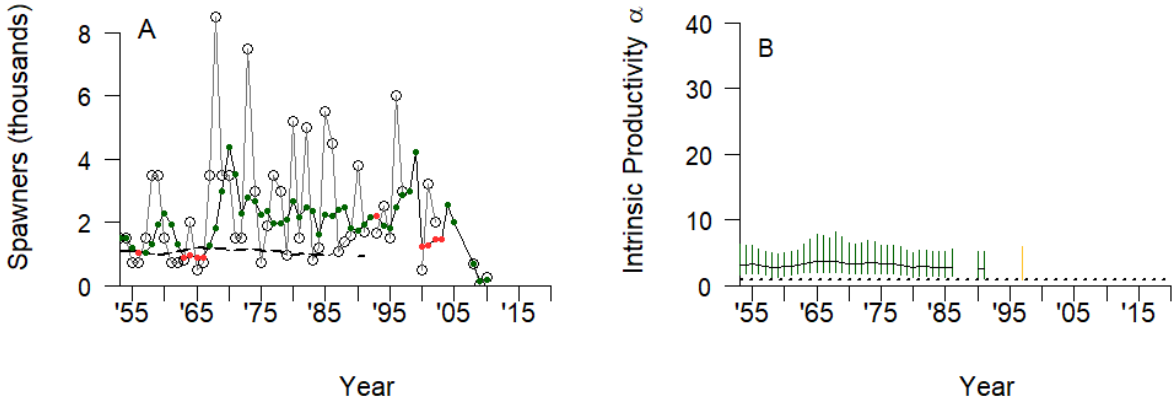




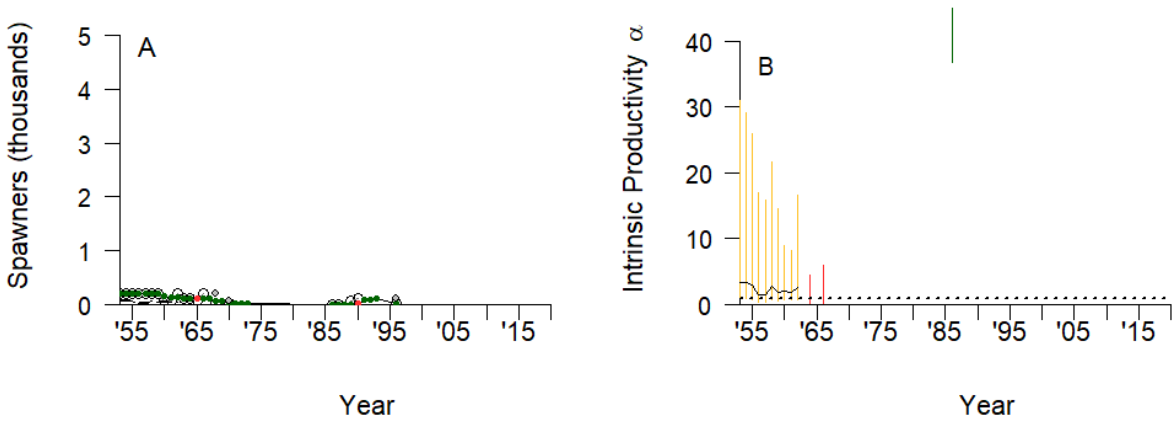
WARN BAY CREEK



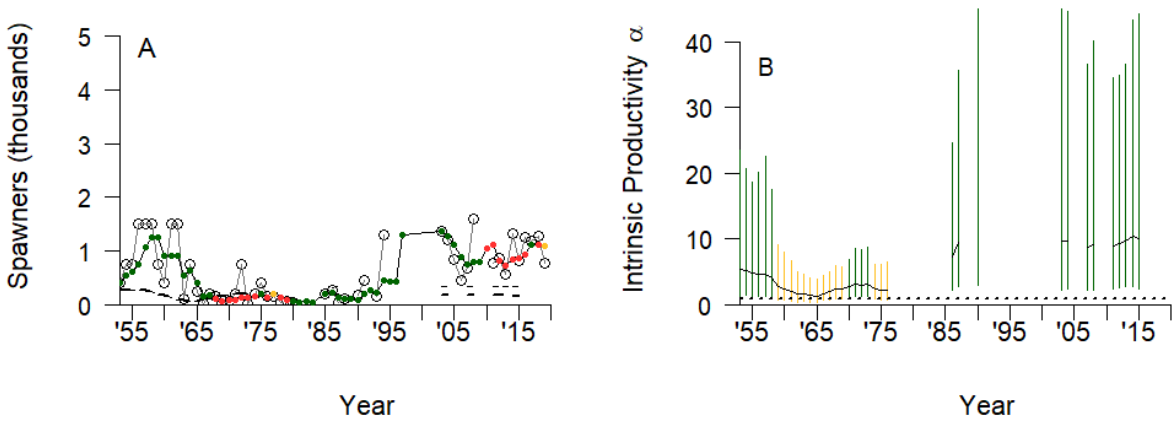
WATTA CREEK



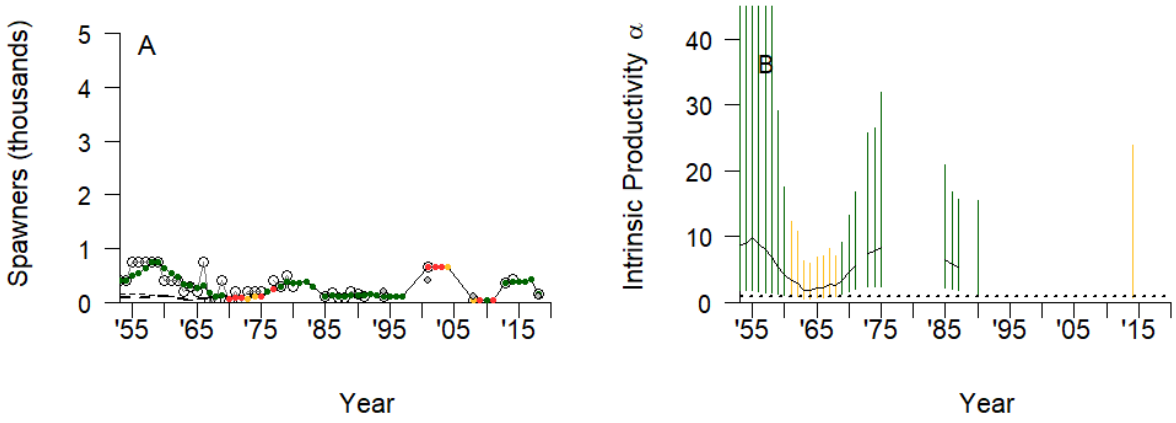
Bawden Creek Coho



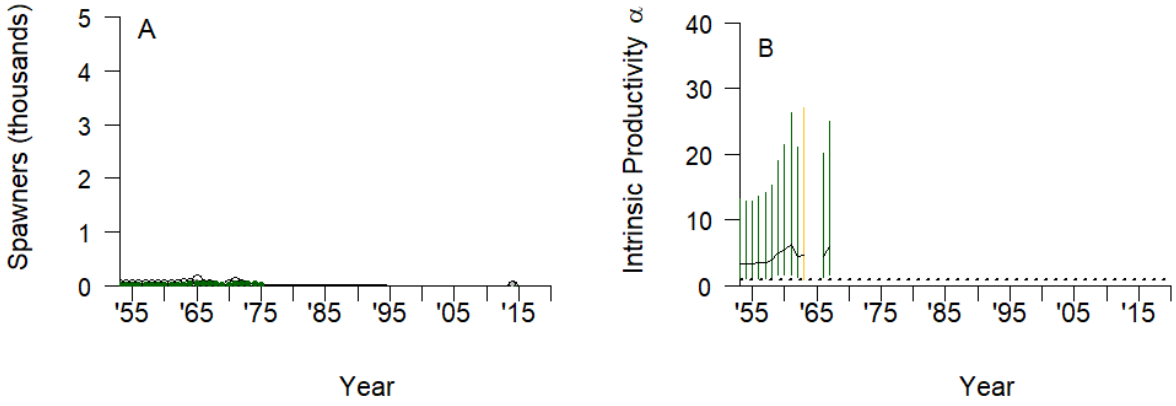
Bedwell River Coho



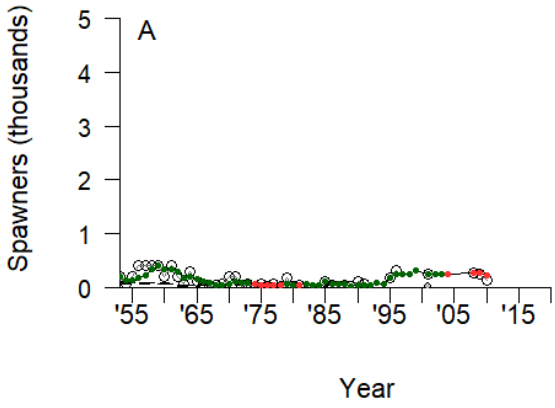
Atleo River Coho

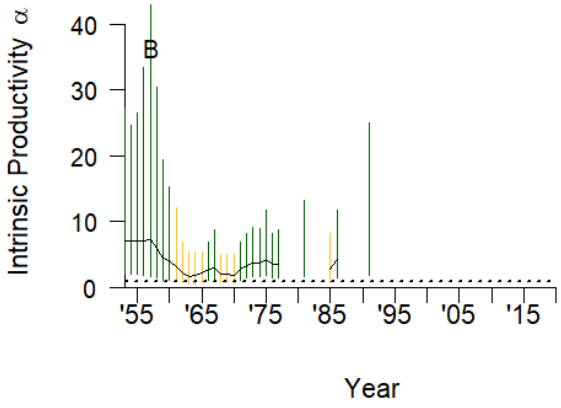


White Pine Cove Creek Coho

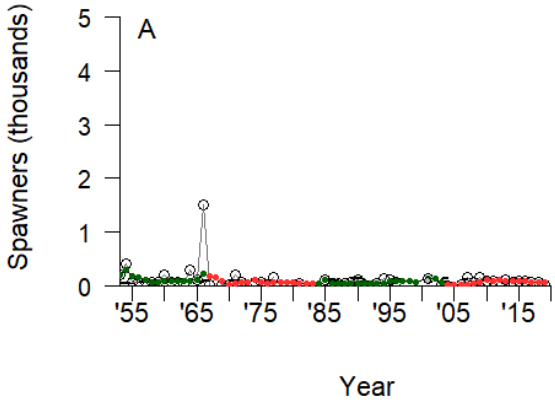


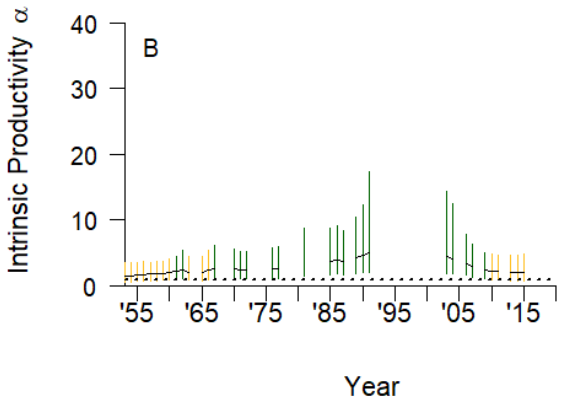
Watta Creek Coho



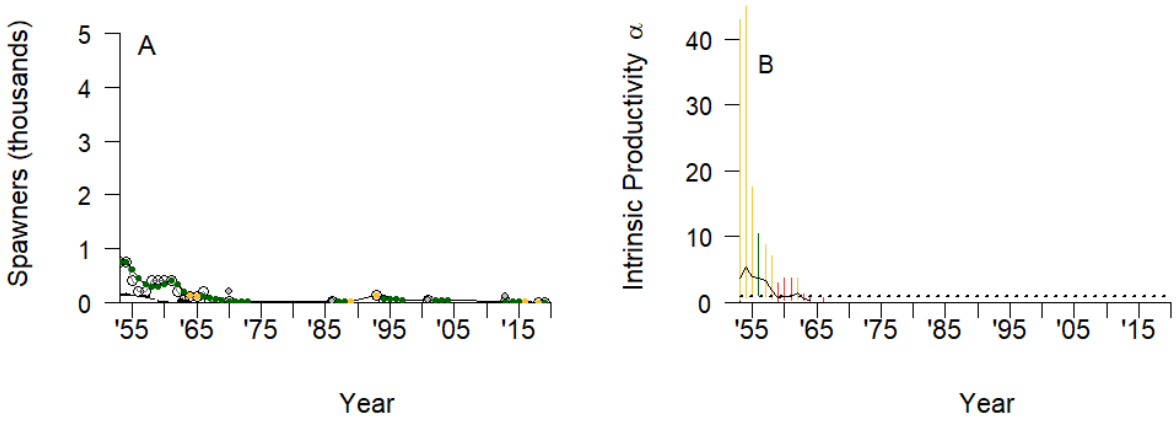


Warn Bay Creek Coho

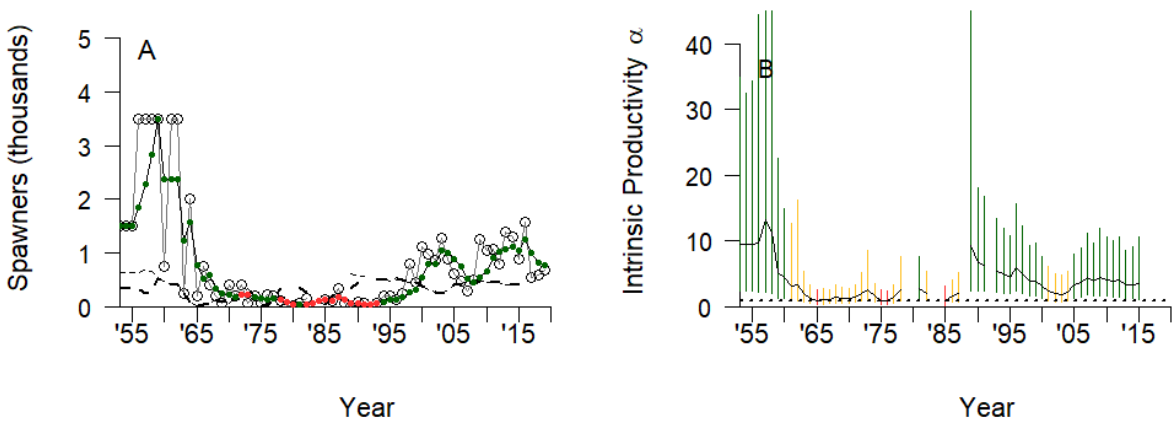




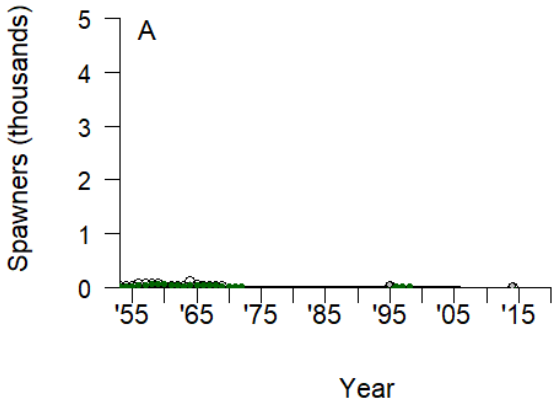
Tofino Creek Coho

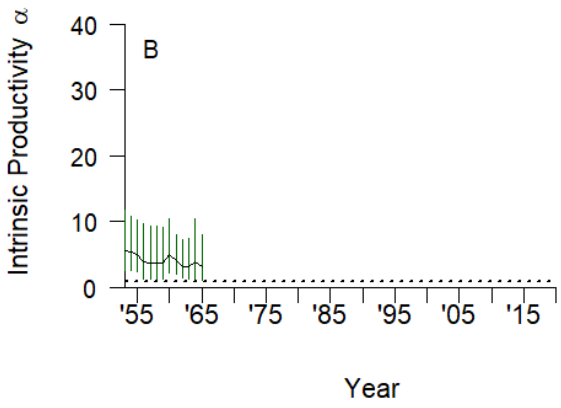


Tranquil Creek Coho

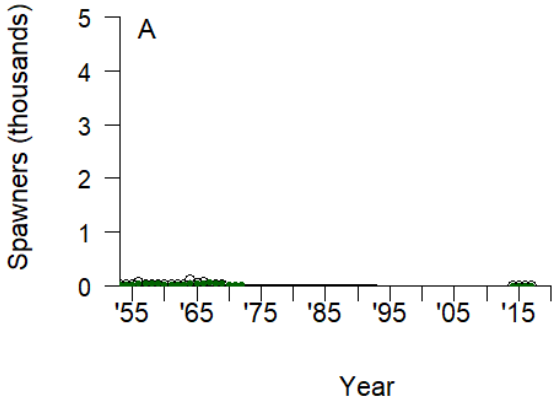


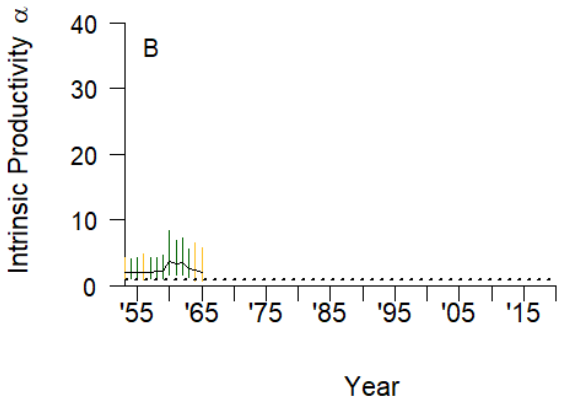
Riley Creek Coho



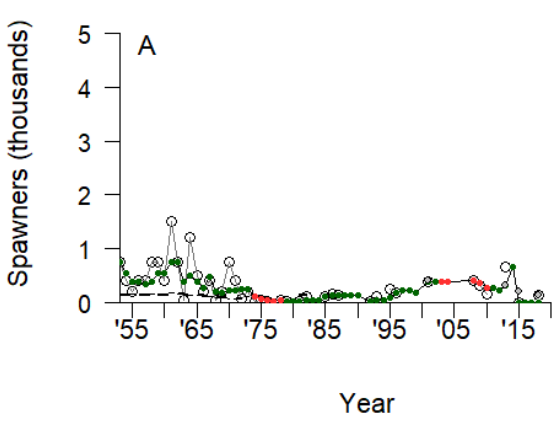


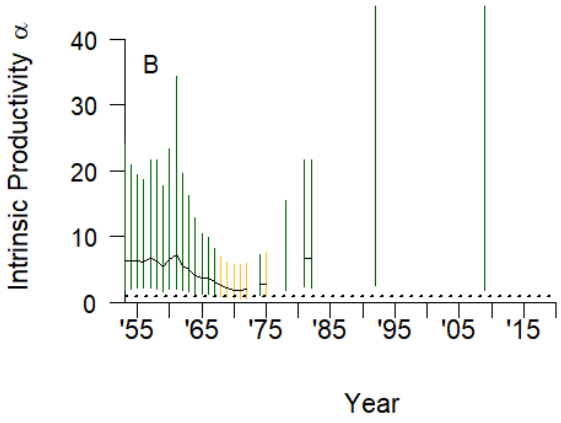
Sutton Mill Creek Coho



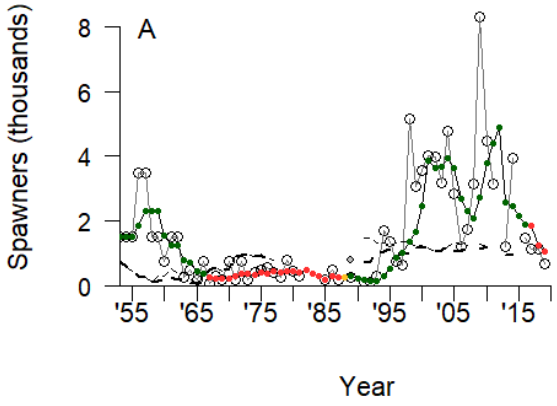


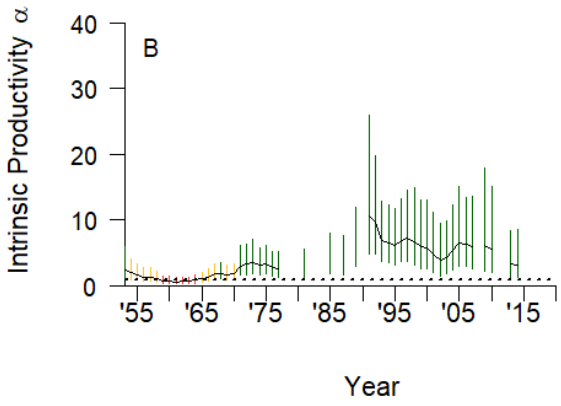
Sydney River Coho



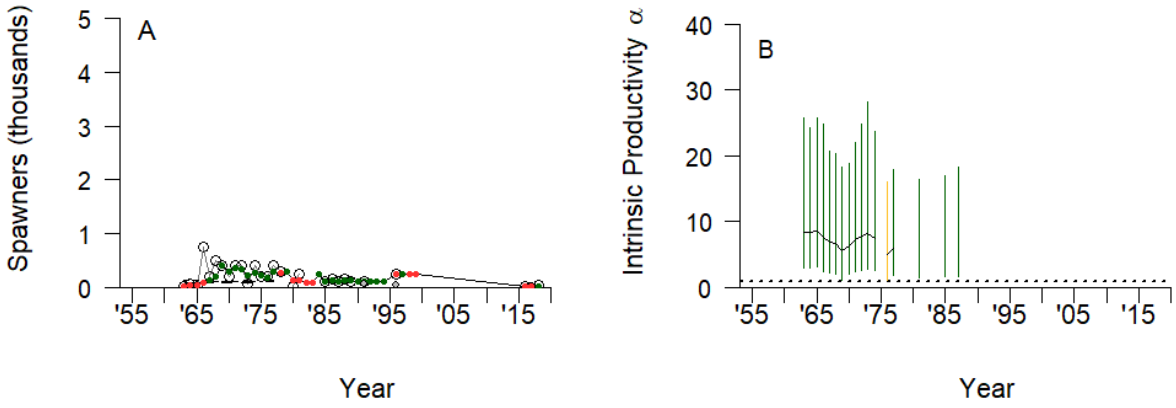


Moyeha River Coho

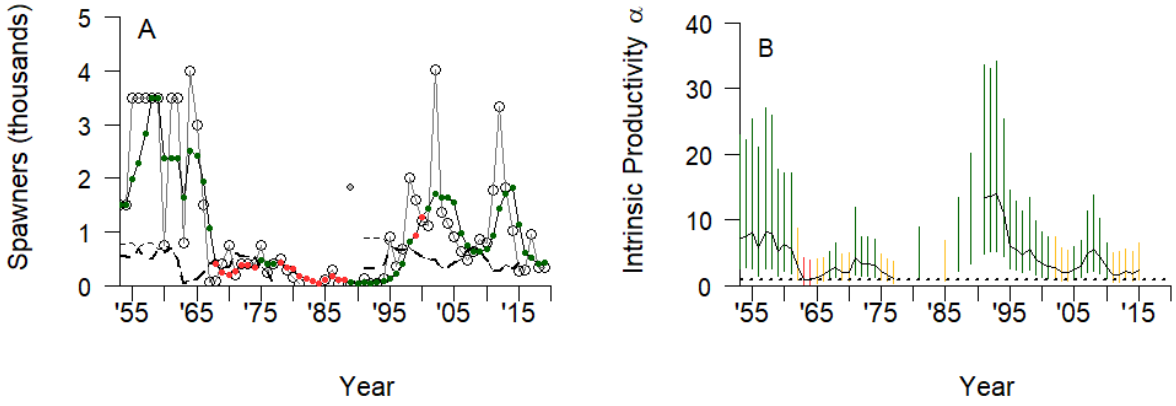




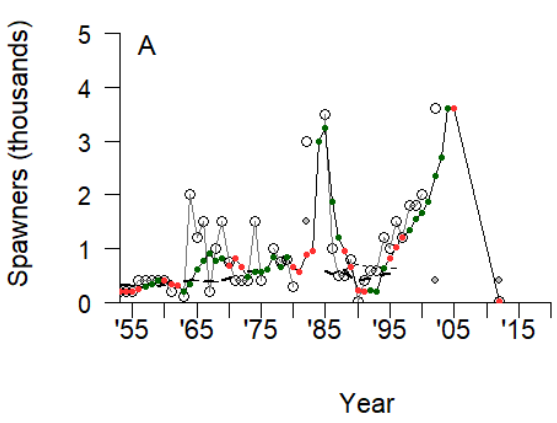
Lost Shoe Creek Coho

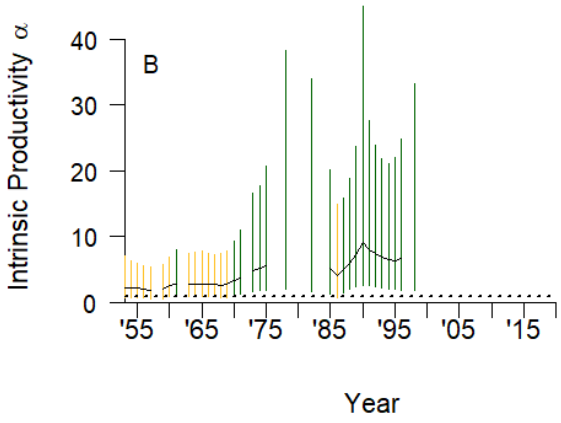


Megin River Coho

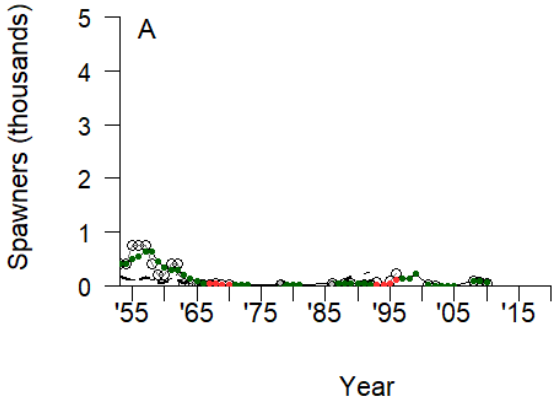


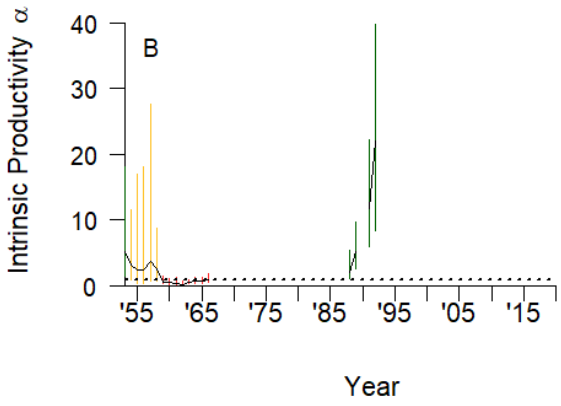
Kootowis Creek Coho



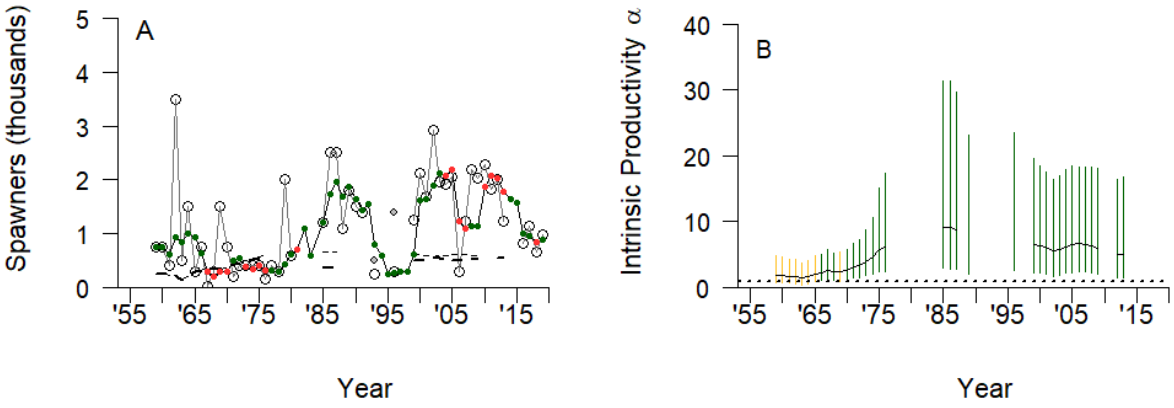


Ice River Coho

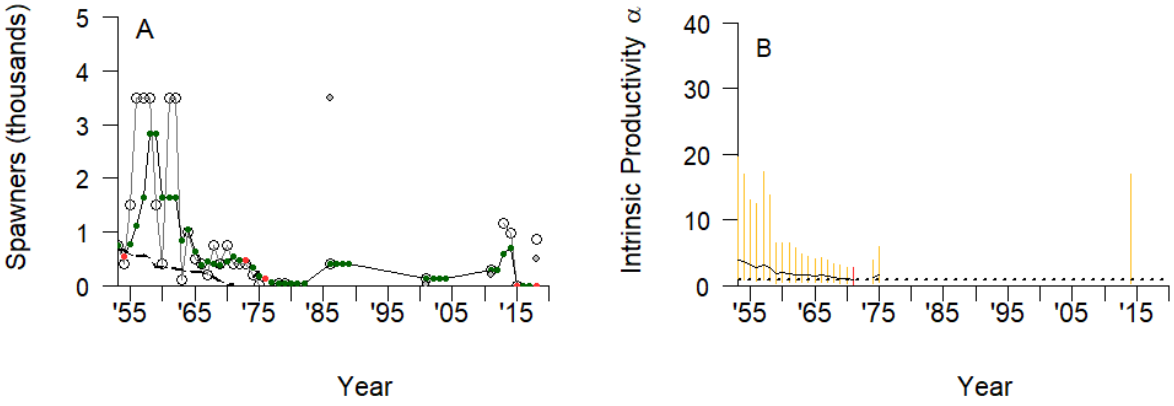




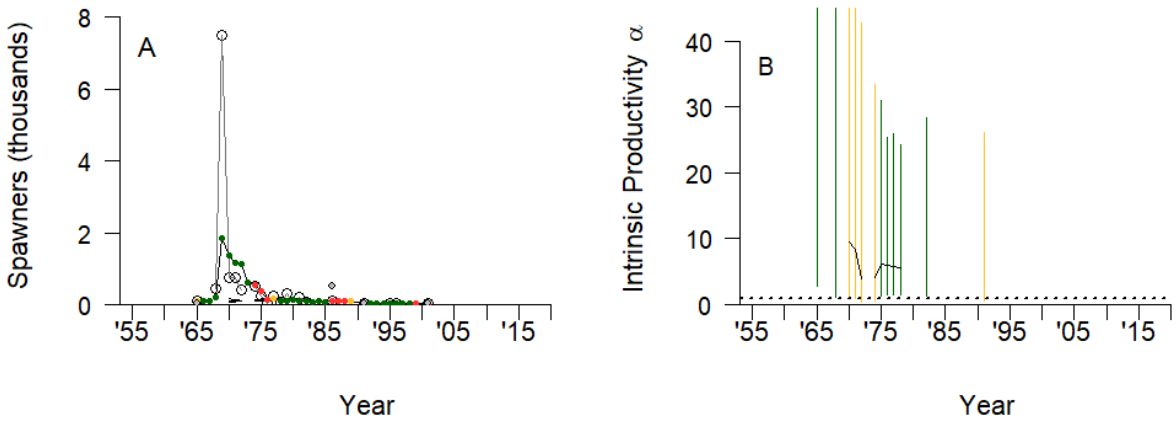
Kennedy River (Upper) Coho



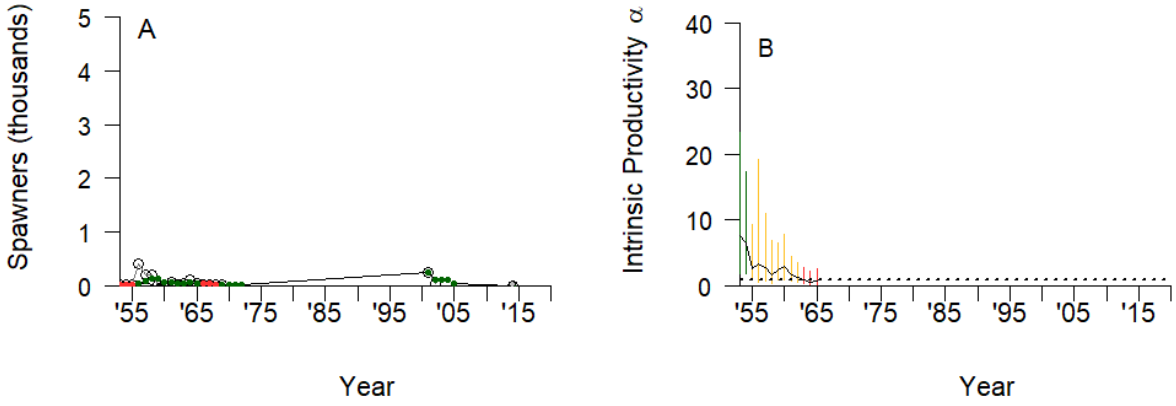
Hesquiat Lake Creek Coho



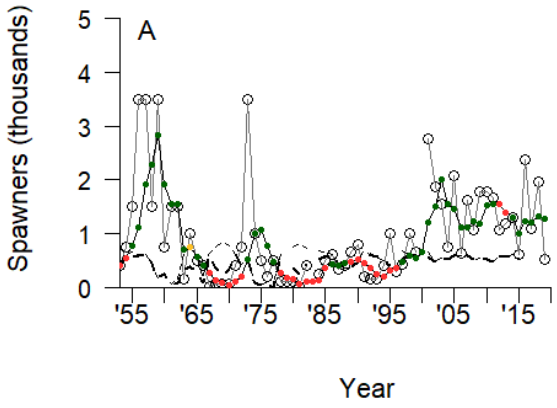
Hootla Kootla Creek Coho

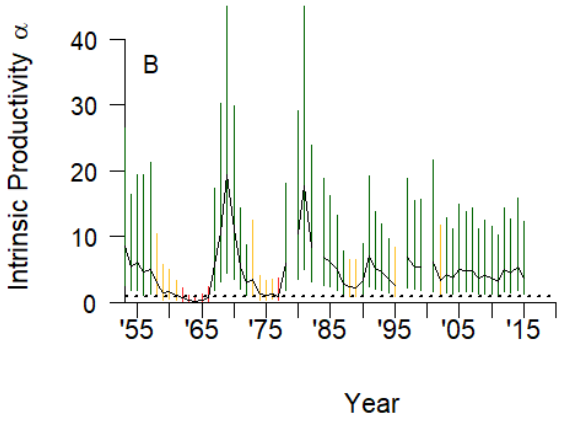


Hot Springs Cove Creek Coho

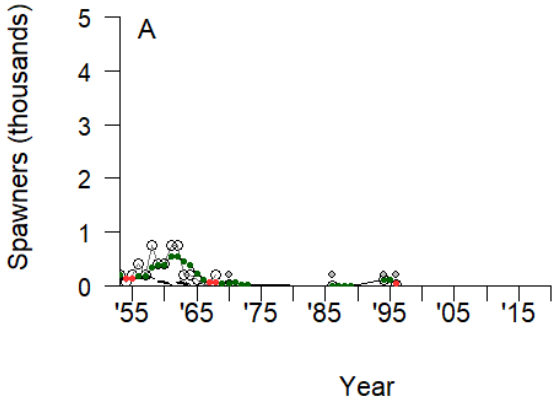


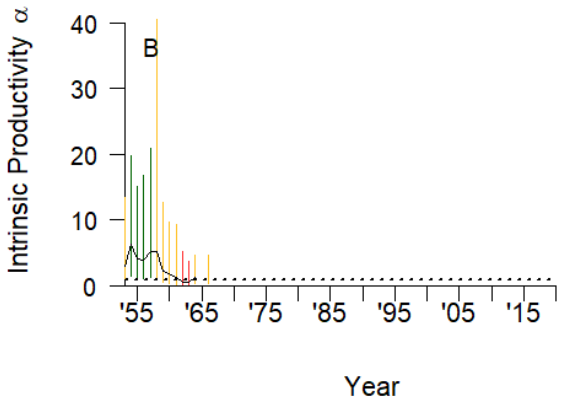
Cypre River Coho



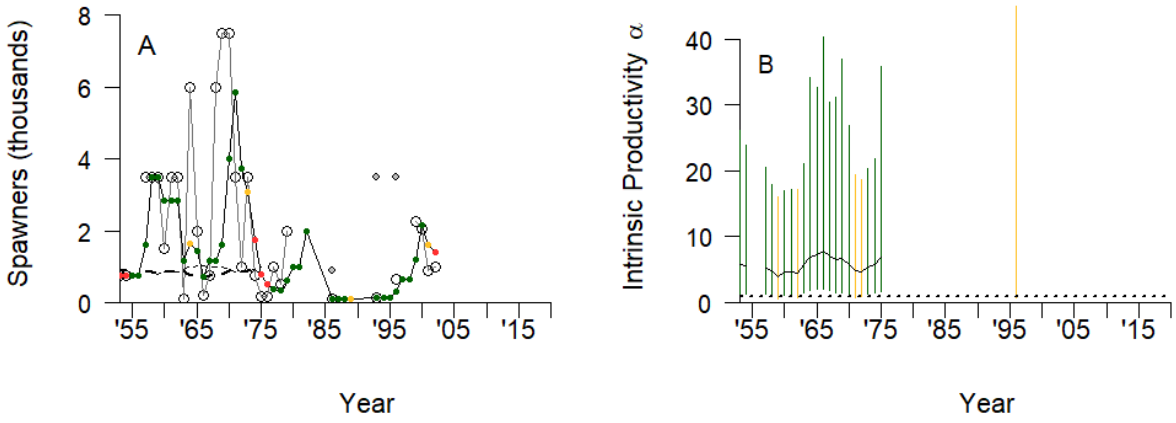


Cecilia Creek Coho

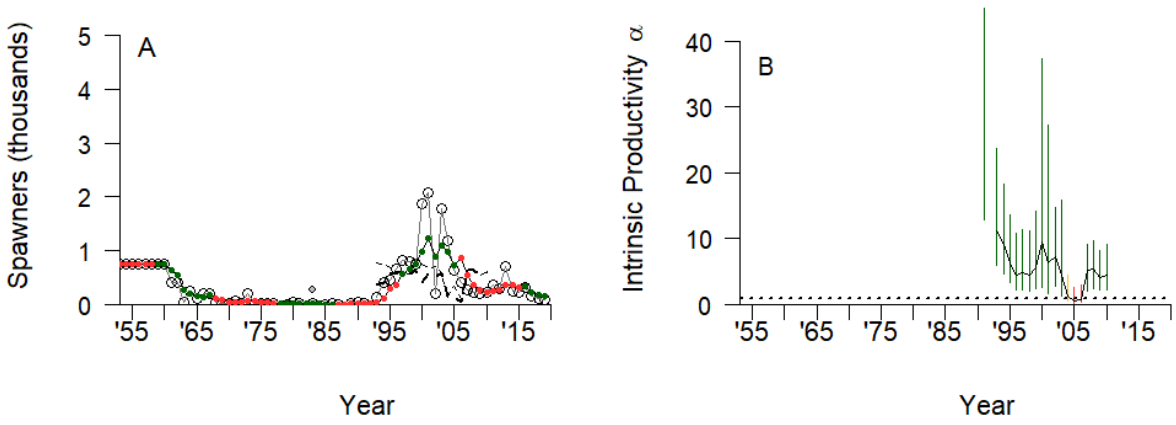




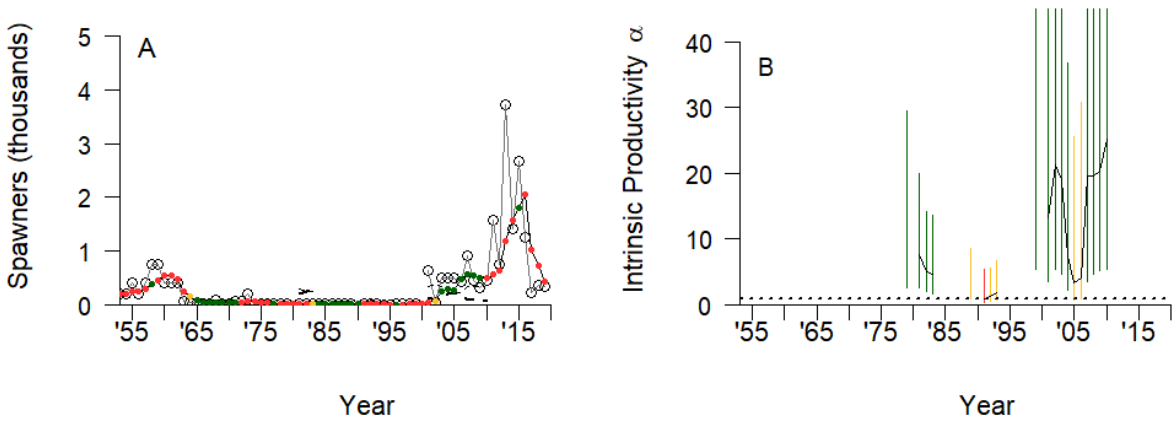
Clayoquot River (Upper) Coho



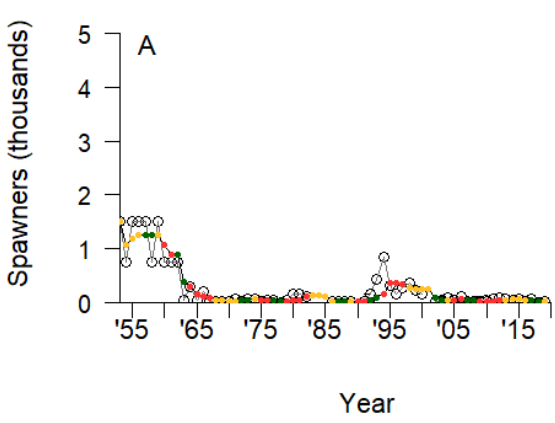
Tranquil Creek Chinook

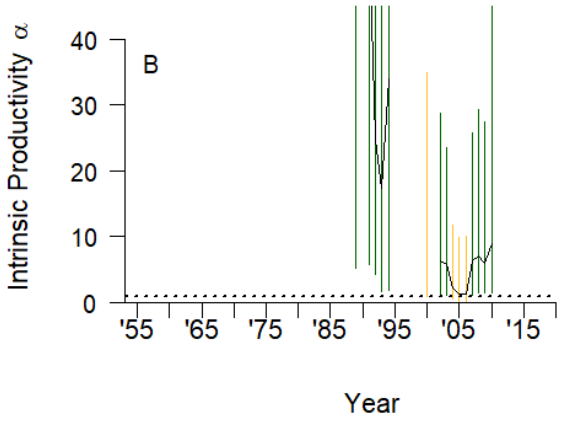


Cypre River Chinook

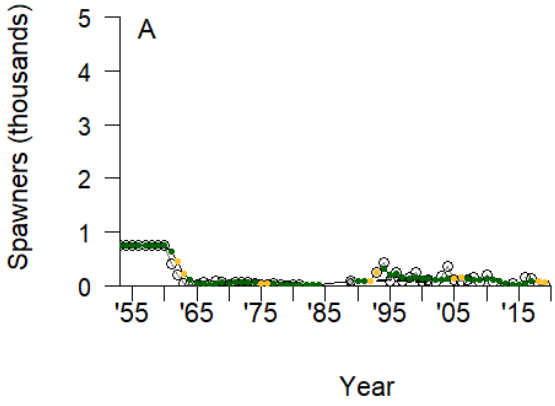


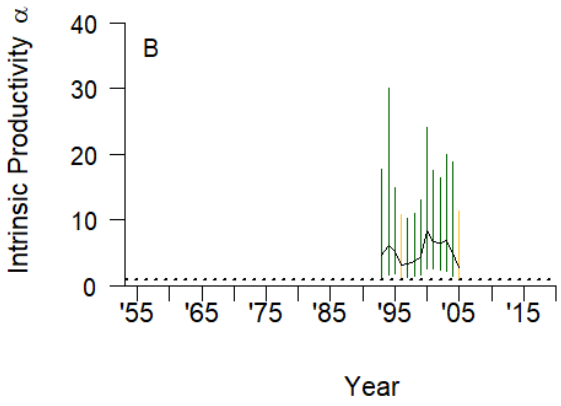
Megin River Chinook



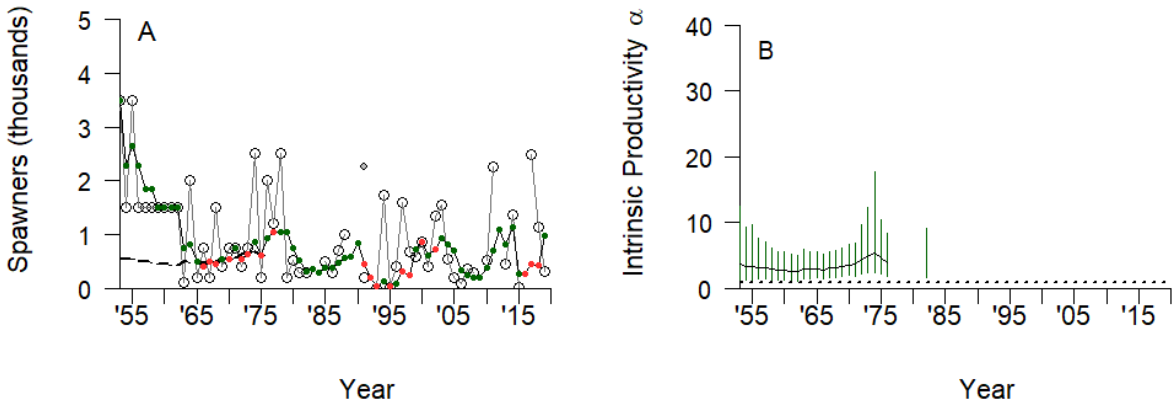


Moyeha River Chinook

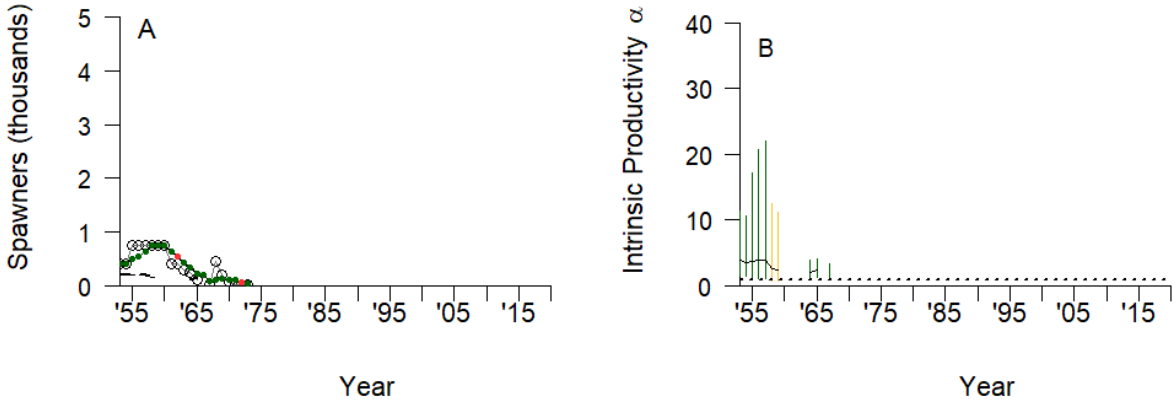




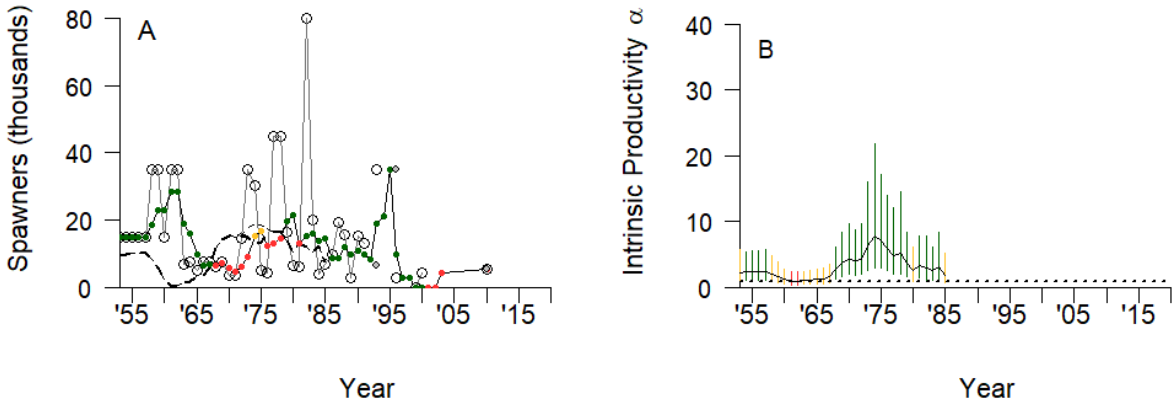
Megin River Sockeye



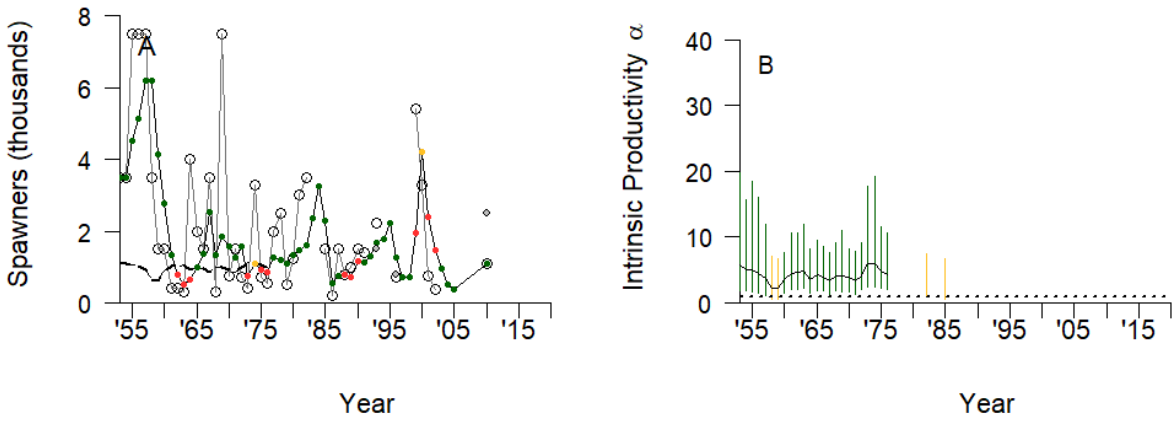
Cecilia Creek (Tofino) Sockeye Run 1



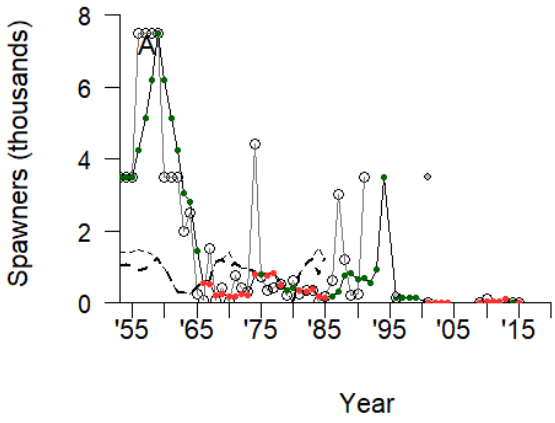
Clayoquot Arm Beaches Sockeye

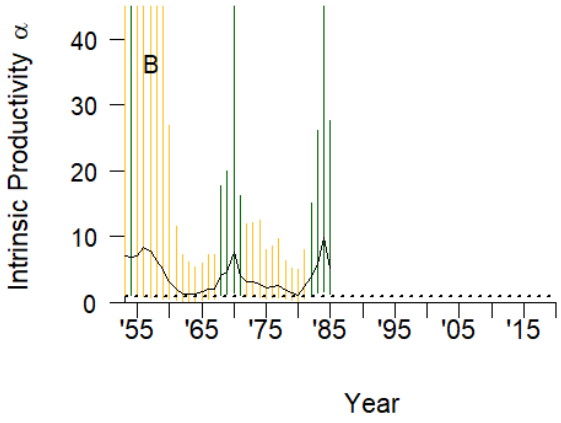


Clayoquot River (Upper) Sockeye

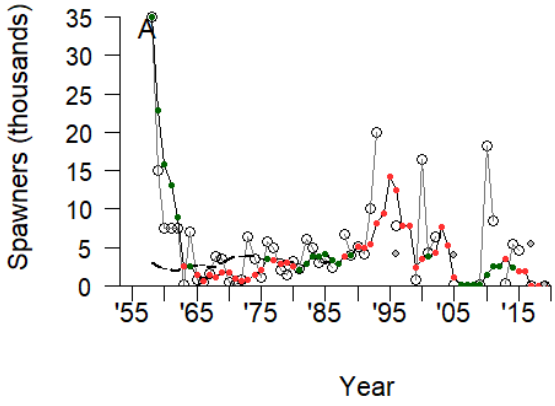


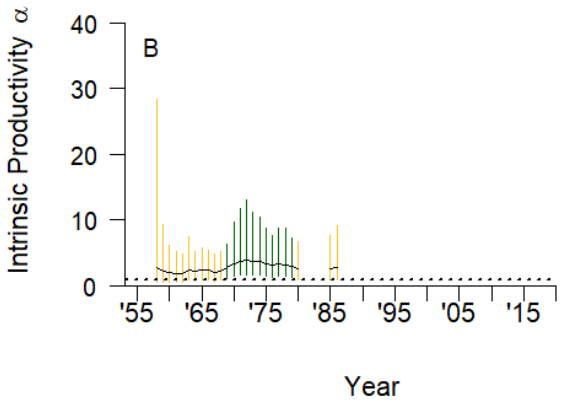
Cold Creek Sockeye



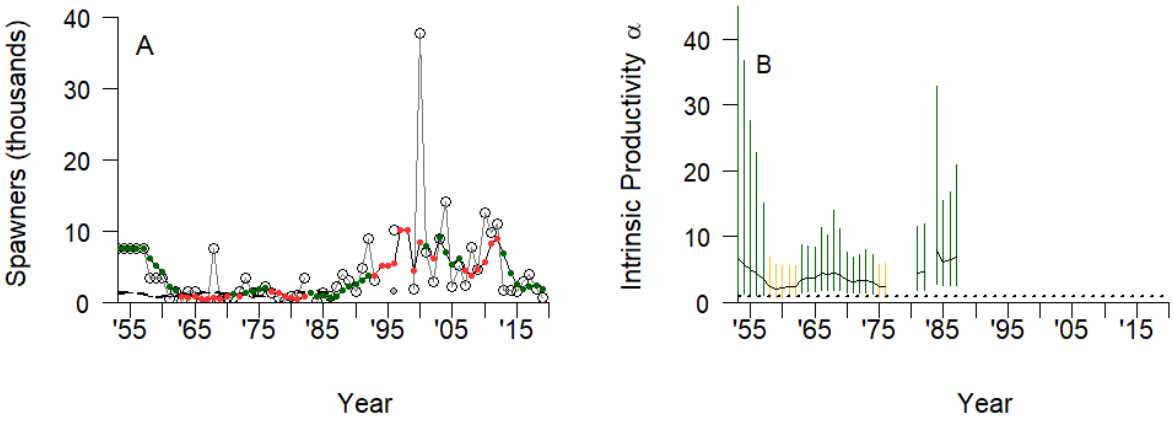


Kennedy Lake Sockeye

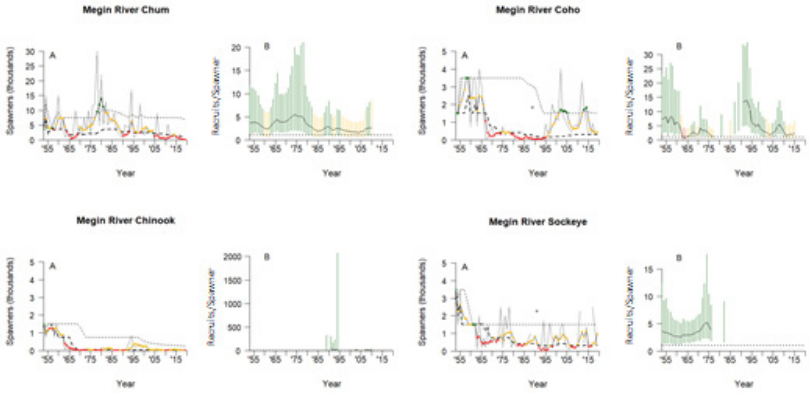




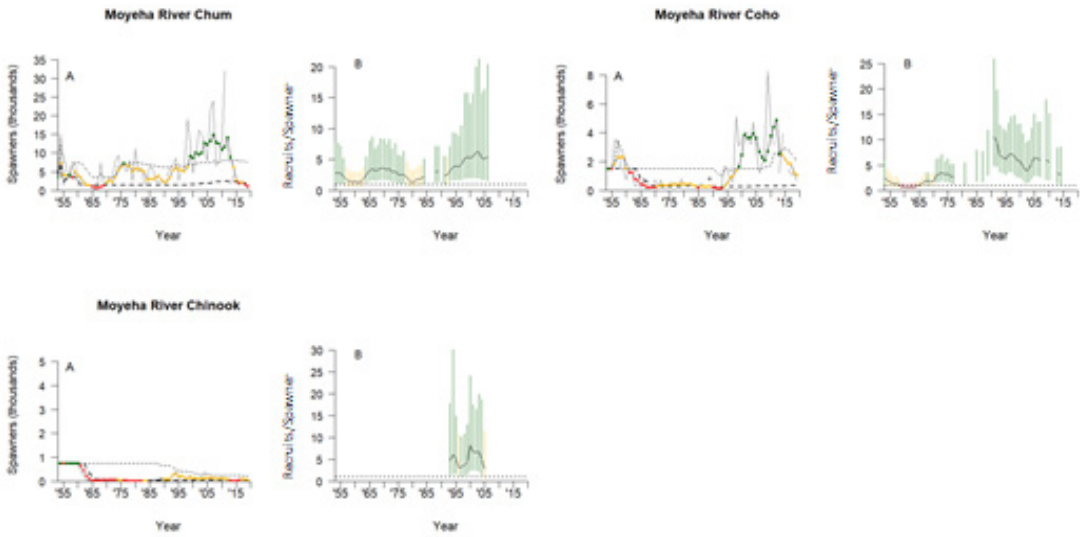
Kennedy River (Upper) Sockeye



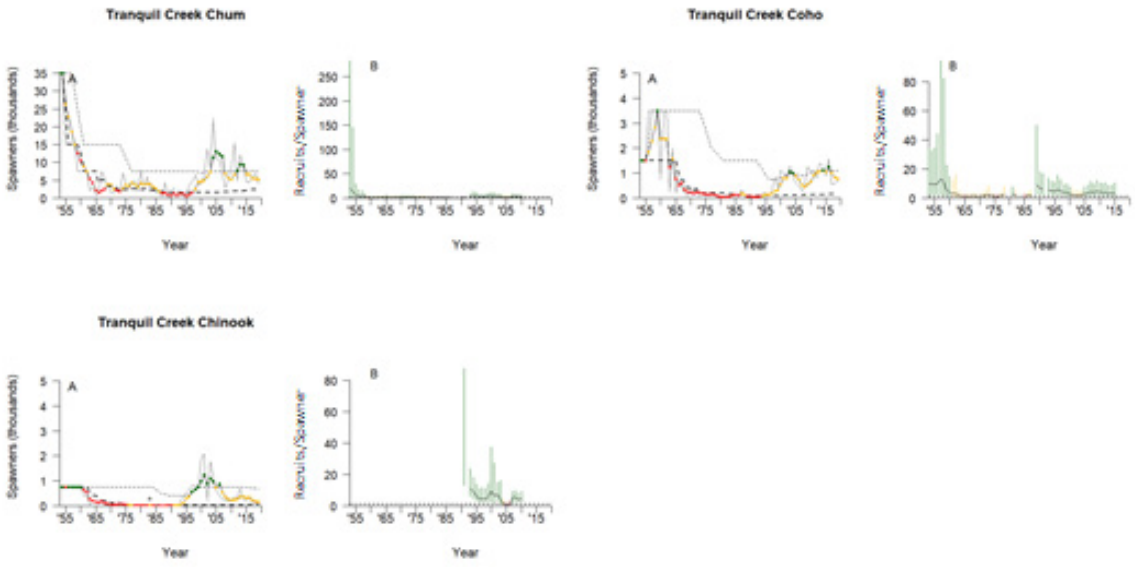
Appendix C
Comparisons



The most recent percentile statuses for Megin River salmon have been Amber and Red (A panels) and Green and Amber for resilience statuses (B panels). A bump in escapement for Megin Chinook and Megin Coho is seen in the 1990s which corresponds with peaks of high intrinsic productivity. The peak in Megin Chinook escapement and resilience has declined. Recent Megin Coho escapement is variable and so may be stable or following similar declining trends as Chum and Chinook counterparts. The most recent estimates for Megin Coho escapement seem to show similar levels as the beginning of the 1990s increase, and resilience has been steadily declining since the 1990s increase. The increase in Megin Chum escapement happens earlier than that of Megin Chinook and Megin Coho. The increase in Megin Chum escapement has since declined to recent estimates of 0 individuals. Despite this dramatic decline in Megin Chum escapement, resilience remains above replacement. Megin Sockeye escapement seems to have declined since the beginning of WCVI monitoring to a relatively stable state.

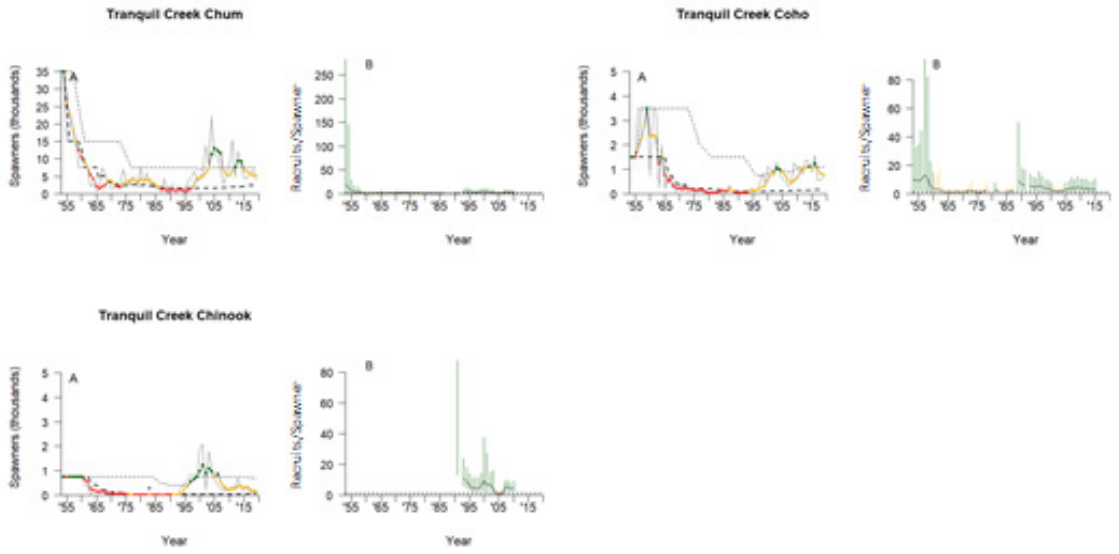


The most recent percentile statuses for Moyeha River salmon have been Amber and Red (A panels) and Green and Amber for resilience statuses (B panels). A bump in escapement for Moyeha populations is seen in the late 1990s, which corresponds with peaks of high intrinsic productivity. The peaks in Moyeha Chinook, Chum, and Coho escapement and resilience have declined. Moyeha Chinook and Chum have declined to similar low escapement estimates as were seen in the 1960s. Moyeha Coho seem to have a delayed decline relative to Moyeha Chum and Chinook.

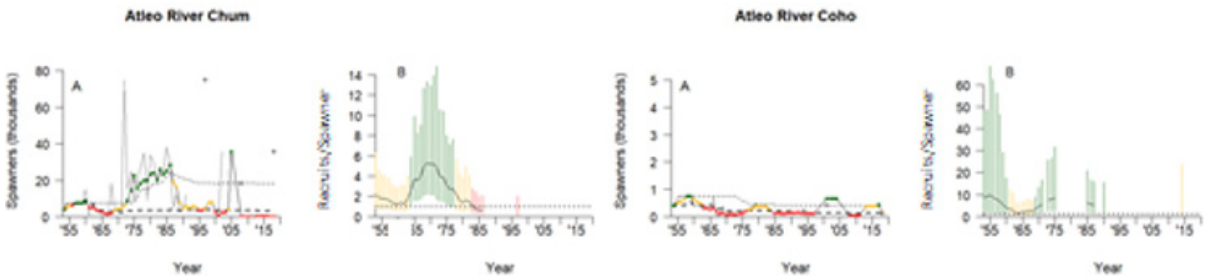


Cypre River salmon have had instances of relatively high intrinsic productivity (B panels). Cypre River Chinook have the highest recent productivity estimates despite having had the smallest overall escapement on Cypre River. Since the early 2000s, Cypre River Chinook have increased in escapement and productivity. Cypre River Chum have steadily decreased from being the major species in Cypre River in the 1950s. The latest escapement (A panels) and productivity (B panels)

for Cypre River Chum are at their lowest points for the stock. Cypre River Coho have increased since a stretch of low escapement in the 1970s and 1980s to a relatively stable escapement and productivity that is closer to escapement at the beginning of monitoring on WCVI.



Tranquil Creek salmon declined dramatically in escapement and productivity from the 1950s to the 1990s. Tranquil Chum, Coho, and Chinook salmon experienced a bump in escapement starting in the 1990s. For Tranquil Chum and Chinook the bump in escapement and productivity have since declined. However, Tranquil Chum, Coho, and Chinook have the capacity for high productivity. Tranquil Chum were one of the major Chum populations in Clayoquot Sound. Tranquil Coho seem to still have an increased escapement since the bump in the 1990s.



Atleo River Chum and Coho populations offer examples of “dead” populations, as they are locally known. Productivity for Atleo Chum is below replacement, and escapement has gone from historically, one of the greatest returns in Clayoquot Sound, to recent estimates of 0 individuals.