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Robert Ireland for the degree of Master of Science in Marine Resource Management November 23, 2010.

Title: The distribution and aggregation of Chinook salmon stocks on the Oregon Shelf as indicated by the commercial catch and genetics

Abstract approved:

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Project CROOS, Collaborative Research on Oregon Ocean Salmon, is a unique partnership of scientists and commercial fishermen that combines catch location data with stock assignments obtained from genetic micro-satellite analysis to investigate the distribution of Oregon Chinook across multiple spatial scales. Using catch data collected by collaborating Oregon troll fishermen, we investigated the distribution of individual populations of Chinook salmon along the nearshore regions of the Oregon Coast. The study focused on two distinct spatial scales: 1) the coast-wide, latitudinal distribution of the 13 most abundant stocks that contributed to the Oregon catch in 2007, and 2) stock-based patterns of Chinook aggregation on spatial scales as low as tens to hundreds of meters. The description of spatial distribution was performed over time periods as short as two days and in season-long summaries.

Based on 2007 catch data, we report three separate patterns in the coastal distribution of Oregon-caught Chinook. Stocks from the Sacramento River, Mid-

Oregon Coast and Upper Columbia basin were distributed coast-wide in the Oregon catch. Chinook salmon that originated from northern California and southern Oregon were found to be more abundant south of 44° North – the approximate latitude of the coastal town of Florence, Oregon. Stocks from the north Oregon coast and the lower Columbia basin were primarily taken north of 44° North. We describe in-season and annual changes in the relative contribution of discrete stocks and in the age-structure of these stocks. Using distance-based metrics compared to random permutations, we found evidence from the ocean catch that Chinook salmon were sometimes closely proximate to river cohorts at sea. However, these discreet stocks were generally intermingled with other stocks in mixed-stock aggregations.

The distribution and aggregation of Chinook salmon stocks on the Oregon Shelf as indicated by the commercial catch and genetics

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APPROVED:

Major Professor, representing Marine Resource Management

Dean of the College of Oceanic and Atmospheric Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Robert Ireland, Author

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CONTRIBUTIONS OF AUTHORS

Renee Bellinger performed genetic stock analysis. Stock composition and age structure are adapted from the 2006 Project CROOS report. Lisa Borgerson interpreted scale samples for age analysis. Dr. Lorenzo Ciannelli assisted with nearest neighbor analysis. Dr. Doug Reese assisted with multivariate analysis.

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Introduction

Salmon trollers in the nearshore waters of Oregon, pursue Chinook salmon in a mixed-stock ocean fishery. Management of the fishery requires a consideration of the population status and relative contribution of the individual stocks that comprise the total harvest. Consequently, a thorough understanding of the ocean distribution of the component stocks is a prerequisite to manage the fishery and for designing effective strategies to maintain or recover individual populations of Chinook salmon. In a collaborative effort to investigate the distribution of discreet adult Chinook stocks, scientist, managers and fishermen combined to create Project CROOS (Collaborative Research on Oregon Ocean Salmon). The partnership with Oregon fishermen has facilitated the collection of Chinook catch data at spatial and temporal resolutions unique to the project. Using this data, we investigated the distribution of individual populations of Chinook salmon on both coastal and local scales. Fishery restrictions put in place for the 2006 Chinook fishery closed much of the Oregon coast to commercial fishing. As a result, fishing activity in 2006 was concentrated on the Oregon Shelf in the area offshore of Newport, Oregon. In 2007, the Oregon fishery was prosecuted coastwide. Analysis, therefore, differed between the two years. For 2007, we described the coastal range of the important stocks that contributed to the fishery. Three separate patterns of coastal distribution were identified. Individual stocks were assigned to a categorical group based on a common distribution. In 2006, short duration time periods with a high overall catch were examined to determine whether Chinook salmon formed aggregations with breeding population cohorts. In-season and between-season trends in the relative contribution of individual stocks and age-class structure were also examined. The use of DNA microsatellite analysis allowed each Chinook caught by participating fishermen to be genetically identified whether it was a wild or hatchery reared fish. Sample sizes were sufficiently large to investigate stock-specific ocean aggregations at spatial resolutions as low as 10s of meters. Time sensitive fishery data regarding aggregation and stock composition has the potential to provide a finer granularity to the management decisions that regulate this economically important fishery.

The remainder of this introduction will describe the species of interest, the relationship to the communities of the Pacific Northwest, and the fishery concerns that motivated this study. Next, relevant aspects of Chinook life history and the salmon terminology used within this study are introduced. A review of past research on ocean distribution and stock-specific aggregation of salmon is provided to place this study in context with previous findings. The introduction concludes by highlighting the unique data set, the research objectives, the timely relevance of this study, and its potential to further advance our the understanding of the ocean behavior and distribution Chinook salmon.

Chinook salmon: fish, people and the fishery

On the west coast of North America, Chinook salmon are widely distributed from Central California to the Bering Sea. Naturally spawning populations are found in major rivers and in small coastal streams. The five species of Pacific salmon native to North America have existed for at least the last 6 million years – their range alternately expanding and contracting as ice sheets advanced and retreated with each recurring glacial episode. Chinook salmon colonized their current range during the past 10,000 years following the retreat of the last glacial maximum. They are believed to have radiated from two ice-free refugia – a Bering Sea refuge in the north and a southern refuge in the Columbia River basin (Beacham et al. 2006). In North America, a close relationship between salmon and people has existed for the last 10,000 years (Butler and O'Connor 2004). Today, there is perhaps no species more closely integrated into the cultural conscience of a region than that of salmon to the communities of the Pacific Northwest.

The ocean abundance of salmon and their freshwater migration patterns affect planning and development throughout the region. Considerable time, effort and dollars are expended to design land use policies and management strategies that protect salmon without compromising the resource demands of an expanding regional economy and a growing population (Lackey 2003). It’s a difficult balance at any time, but one compounded by short and long-term climate variations that can affect marine and freshwater survival. Stocks at the southern extent of the salmon’s range, and consequently the livelihoods they support, may be especially vulnerable.

Throughout much of their range on the west coast of North America, salmon numbers are currently at historic lows. At least 106 distinct populations have been extirpated. In California, Oregon, Washington and Idaho, salmon are now absent from 40% of their historic range. Many of the extant populations are threatened or endangered, and while some populations appear stable, others are unquestionably in decline (Nehlsen et al. 1991; NRC 1996). South of the Canadian border, wild spawning populations of west coast salmon are estimated to be in the range of 0.1% to 27% of their historical abundance (Good et al. 2007). The construction of dams in the Columbia River basin has resulted in a reliance on hatchery production. In addition to the genetic diversity lost due to population declines and extinction, as much as 80% of the Columbia River runs are hatchery spawned (Williams et al. 1999). Hatcheries are believed to produce less robust individuals that decrease overall reproductive success when they crossbreed with wild counterparts (Araki et al. 2007). In addition, direct competition with hatchery fish has been found to inhibit the recovery of wild populations (Levin et al. 2001). Fisheries managers face a conundrum: supplementation of fish numbers to counteract human-modified river system while simultaneously recovering and protecting threatened wild populations. A further complicating factor is the tendency for salmon numbers to exhibit year-to-year, and decadal fluctuations. River to river variations in the abundance of individual stocks affects the regional composition of mixed-stock ocean fisheries. Projected salmon returns at specific rivers sometimes fail to materialize leading fisheries managers to severely curtail or eliminate commercial and recreational fishing in response to the decline of a single stock. In the Pacific Northwest, salmon fishing is a deeply embedded regional pursuit with historic significance, both traditionally and economically. The closure of a fishery creates economic hardship and lost opportunities for recreation.

Salmon fisheries are managed to ensure the long-term viability of independent runs of salmon that originate from distinct freshwater spawning grounds. Fisheries managers are required to prevent the over harvest of weak stocks that co-occur with abundant stocks in the mixed-stock, ocean fishery. The decline or collapse of a single important stock can force restrictions or the regional closure of the entire ocean fishery. Two recent events illustrate this point. Preseason projections of a poor 2006 escapement on the Klamath River forced the PFMC to adopt fishery restrictions in Oregon and California (PFMC 2006). Ocean fishing between Florence, Oregon and Horse Mountain, California was closed. A limited season was allowed in Oregon north of Florence and in California south of Horse Mountain. Oregon salmon fishing resumed coastwide for the 2007 season. However, the dramatic decline of Sacramento River fall Chinook that began with the 2007 escapement forced the complete closure of all Chinook fishing throughout California and Oregon in both 2008 and 2009 (PFMC 2008; PFMC 2009). In the southern portion of their range, year-to-year uncertainty in the abundance of salmon has become routine in the Chinook fishery. Annual variability is reflected in the 30-year record of Chinook landings in Oregon (Figure 1). Perhaps no group has been more deeply affected by population declines then ocean fishermen. A shared interest in the conservation of salmon and a way of life has brought about the collaboration of Oregon salmon trollers and scientists in an investigation of the stock-specific distribution of Chinook salmon in the coastal waters of Oregon.

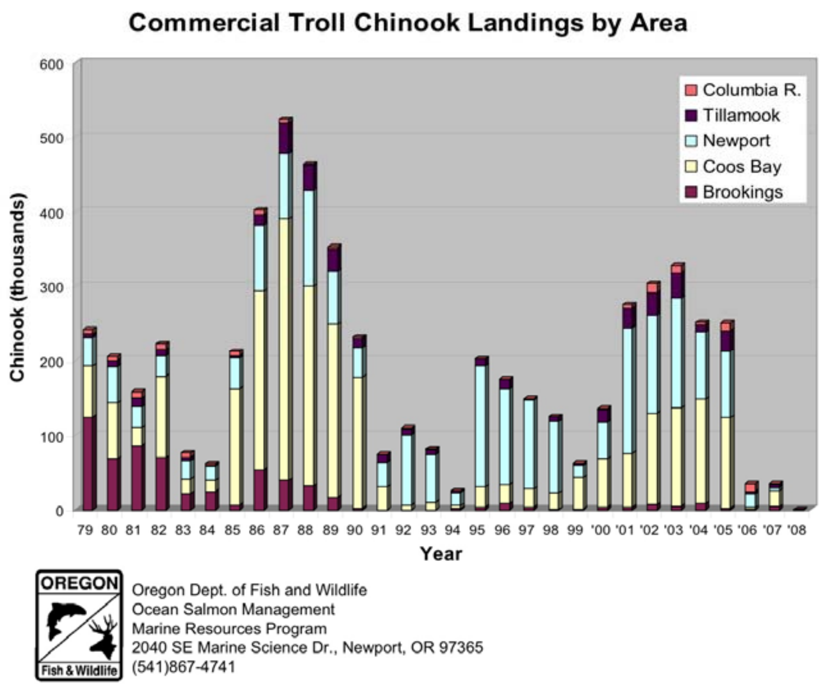


Figure 1. Oregon Chinook salmon landings for the period 1979 to 2008. The decline of Sacramento River Fall Chinook forced the Oregon fishery to be closed south of Cape Falcon in both 2008 and 2009. Fishing resumed on the Oregon coast in 2010.

Ocean conditions are known to play a significant role in salmon survival (Pearcy 1992; Logerwell et al. 2003; Brodeur et al. 2003; Lindley et al. 2009). Conditions that influence survival operate on basin-wide scales that affect salmon throughout the eastern Pacific and on local scales that affect individual stocks in a specific region (Mantua et al. 1997; Hare et al. 1999; Tucker et al. 2009). The combined effect of a warming climate with normal background cycles has the potential to amplify variations in ocean conditions that impact salmon productivity. As a counter to increased ocean variability, some researchers have argued for a greater emphasis on the maintenance of salmon diversity and conservative fisheries (Bisbal and McConnaha 1998; Francis 1999; Hilborn et al. 2003). In this environment it’s prudent to explore new management options. A description of ocean migration and distribution at improved levels of spatial and temporal accuracy is a sensible objective. Chittenden et al. (2009) specifically identified a need for fisheries data at increased levels of precision. Increased precision could allow a more comprehensive assessment of individual salmon stocks that leads to finely crafted fishery practices benefitting salmon conservation and the salmon fishery.

Some aspects of Salmon life history

Chinook salmon eggs hatch in freshwater streams within gravel beds. The beds, called redds, are excavated by females. Males simultaneously fertilize the eggs while a female deposits her roe. Newly hatched fry, termed alevins, remain in the gravel until the yolk sac is absorbed. Alvins emerge from the gravel camouflaged in vertical brown or olive colored bars – parr marks. Juvenile salmon at this stage are called fry or parr (Figure 2).

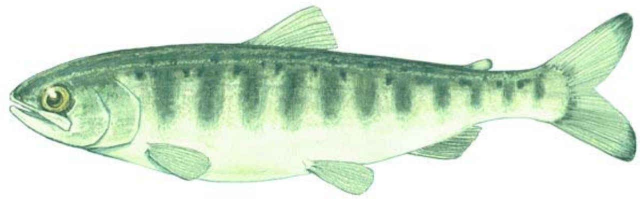


Figure 2. Chinook Parr (© *Idaho Fish And Game)*

During their downstream migration toward the estuaries and coastal ocean, parr undergo a physiological transition affecting their appearance and osmoregulatory system. Parr marks fade and the juveniles take on the silvery sheen of ocean salmon (Figure 3). At the transition stage from freshwater to the ocean phase, salmon are referred to as smolts. Young salmon feeding at sea are variously called smolts, juveniles, subyearlings, yearlings, or immatures depending on their age or the length of time they've been at sea. There is generally no absolute point in time that distinguishes one phase from another. In this document, the terms juvenile and adult are most frequently used to describe salmon during the first year and subsequent years at sea. Chinook salmon are typically three years old before they have grown to a legal size to be targeted by ocean fisheries. In California and Oregon, maturing Chinook return to freshwater to spawn at 3 to 4 years of age – less frequently as 5 or 6-year-olds. A discernable latitudinal cline exists for the age of maturity; older maturing salmon are generally found farther north.

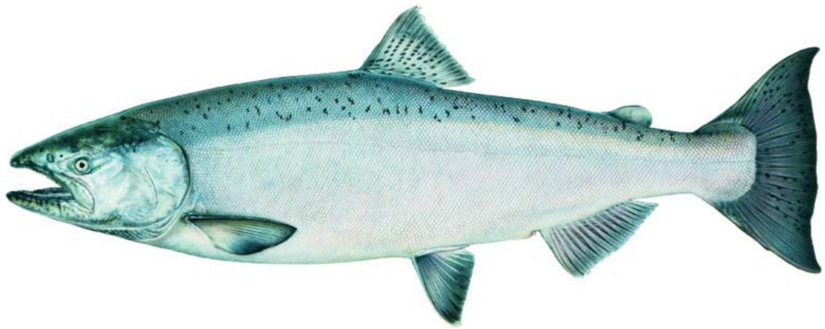


Figure 3. Chinook Adult (© *Idaho Fish And Game)*

Strong fidelity to a home stream, with minimal straying, results in segregated populations adapted to the locally encountered flow and temperature regimes. Variations in the optimal timing of spawning runs, fresh water rearing times, and downstream migration patterns manifest as a diverse collection of genetic and behavioral life history traits unique to specific rivers and specific populations within those rivers.

Chinook are classified by the timing of their spawning run and the length of time they rear in freshwater. Ocean-type Chinook migrate to the sea or estuaries shortly after emerging from the gravel. Stream-type Chinook spend a year or more in fresh water before migrating to sea. Maturing Chinook return to freshwater to begin their upstream spawning migration during almost any month of the year, though there are generally two main peaks. Spring-run Chinook enter freshwater between March and June where they hold in freshwater pools before spawning in the fall. Fall-run Chinook enter their river systems between September and November then begin spawning shortly afterwards. Spring-run Chinook frequently have a stream-type life history whereas fall-run Chinook usually follow an ocean-type strategy. In the northern portion of their range only a single spawning-run peak may occur. Almost all Chinook north of the Columbia River follow a stream-type life history. South of the Columbia most Chinook are ocean-type populations, while the Columbia River has both stream-type and ocean-type Chinook (Groot and Margolis 1991; Quinn 2005).

The stock concept

The conclusion that salmon from different rivers and tributaries comprise separate, reproductively isolated population units with a unique set of heritable traits forms the basis of the stock concept. Ricker (1972) reviewed research on many aspects of salmon life history, homing fidelity, and phenotypic traits to establish that salmon are comprised of isolated stocks native to a specific stream or lake. He defined a stock as “fish that spawn in a particular river system (or portion of it) at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season.” Ricker’s precise definition culminated years of accumulating evidence that individual river systems are comprised of spawning populations of Pacific salmon unique to their locale. In his breakthrough study of sockeye salmon, Charles Henry Gilbert (1914-1925, as cited in Pearcy and McKinnell (2007)) demonstrated that salmon from adjacent rivers in British Columbia had their own river-specific life histories with differences in freshwater rearing patterns and the age-group structure of returning spawners. McGregor (1923) reported that Klamath River Chinook could be distinguished from Sacramento River Chinook based on ova counts and the number of pyloric caeca.

Stock-based differences have also been demonstrated for Atlantic salmon. The mean age at which migrating adults first return to their natal stream to spawn has been shown to differ between river systems (Schaffer and Elson 1975). Atlantic salmon that faced a long or otherwise difficult upstream migration to their spawning grounds returned at an older mean age than salmon from rivers with shorter and easier freshwater migrations. Nehlsen (1991), Quinn (1999; 2005), and Peary and McKinnell (2007) have each summarized different aspects of the stock concept and its origins. Some of the traits shown to differ among populations are age at maturity, spawning time, growth rate, timing of both upstream and downstream migration, orientation of fry to water currents, disease and parasite resistance, fat content upon reentering freshwater, size and number of eggs produced, and the temperature tolerances of embryos. Because salmon are uniquely adapted to a home stream, most attempts to transplant salmon outside their native streams have been unsuccessful. There are a few notable exceptions – for example, the establishment of a self-sustaining population of pink salmon in the Great Lakes of North America and the successful transplant of California Chinook in the rivers of New Zealand’s South Island. Quinn (2005) noted the interesting fact that it has proved to be more difficult to establish anadromous populations of salmonids than nonanadromous. Despite the propensity of salmon to evolve adaptations to their natal streams, it nonetheless appears that accommodating a foreign ocean environment is the main impediment to successfully establishing anadromous populations. For stocks that have been successfully transplanted within their native range, survival of the transplants is usually lower (Unwin et al. 2003) and the newly established populations tend to retain ancestral traits, including ocean migration patterns (Brannon and Hershberger 1984; Nicholas and Hankin 1988).

The stock concept has been used to identify current and historical populations of Pacific salmon. Nehlsen et al. (1991) identified 214 at risk stocks of Pacific Salmon, steelhead and sea-run cutthroat in California, Oregon, Idaho and Washington. Lawson et al. (2007) identified 56 historical populations of coho salmon that potentially existed in the Oregon Coast ESU south of the Columbia River based on two rules that described the degree of isolation. They further categorized these populations as “functionally independent,” “potentially dependent” or “dependent” as a measure of their degree of isolation and persistence. Dependent populations require in-migration to maintain population viability. Functionally independent populations are self-sustaining without in-migration. These categories addressed Ricker’s requirement that a unique stock does not interbreed to a “substantial degree” with any other group.

Stock-specific heritable traits maintained by isolation and local selective pressures manifest as a distinguishing genetic signature, which can be exploited to identify ocean-caught salmon using genetic analysis. The Genetic Analysis of Pacific

Salmonids (GAPS) consortium developed a baseline database of 13 microsatellite locations for 166 unique stocks of Chinook salmon (Seeb et al. 2007). Genetic analysis in this study used the GAPS database for stock identification of ocean-caught Chinook.

Stock-specific Marine Migration patterns

Early research on salmon recruitment and conservation frequently focused primarily on components of their freshwater life history – homing, freshwater migration, and the development of fry and smolts. However, recognition of the connection between marine survival and salmon productivity, especially during the crucial first year at sea (Fisher and Pearcy 1988; Pearcy 1992; Fisher and Pearcy 1995; Logerwell et al. 2003; Lindley et al. 2009) has helped motivate a growing interest in marine research over the past two decades (Quinn 2005; Pearcy and McKinnell 2007; Brodeur et al. 2003). The anadromous life cycle of salmon compels researchers to scrutinize salmon ecology throughout all the habitats where they are found – freshwater, estuarine and marine. Just as isolated populations develop unique adaptations to the prevailing hydrological conditions of their natal stream, research has likewise demonstrated stock-specific patterns in marine distribution and migration patterns.

Coded wire tags (CWT) and genetic stock identification (GSI) have been used to investigate the ocean distribution of discrete stocks. Weitkamp and Neely (2002) described the recovery locations from 1979-1993 of 1.77 million ocean-caught coho with embedded CWTs – 1 mm sections of stainless steel wire injected into the snout of juvenile salmon etched with a unique code that identifies their release site. Using 21 separate recovery zones from Monterey Bay, California to Cook Inlet, Alaska, 12 distinct coho recovery patterns were identified. They found that coho salmon from a common river system share a common pattern of at-sea recovery locations that are geographically distinct in comparison to coho from a different river system. Weitkamp (2010) also used the CWT database to investigate Chinook recoveries from southern California to the Bering Sea spanning the years 1979 through 2004. As with coho, Chinook from a common region of origin were found to share a common marine distribution. Furthermore, differences in the overall range of specific stocks were noted – some ranged widely while others exhibited a more limited range that kept them closer to their region of origin. The results also confirmed Healey’s (1983; 1991) assessment that spring-run salmon travel greater distances from their river of origin than fall-run. However, CWT recoveries of juvenile Chinook do not appear to consistently follow Healey’s characteristic pattern of stream-type and ocean-type migratory behavior. Trudel et al. (2009) found that after exiting the mouth of the Columbia River, juvenile spring Chinook migrate rapidly northward and disperse widely as is typical of a stream-type life history, while spring-run juveniles from coastal Oregon streams have a period of residence near their river of origin. Coastal populations may remain within 200 km of their home stream until 2 or 3 years of age. The significance of this discussion is not that Chinook were somewhat variable adhering to overarching rules; it's the recurring theme that ocean distribution is a characteristic trait of individual stocks.

Evidence suggests that ocean distribution is an inherited trait with a genetic basis. Brannon and Hershberger (1984) reported that Elwha River Chinook reared at the University of Washington Hatchery differed in their marine distribution compared to the local UW hatchery population. Elwha River Chinook reared and released at the UW hatchery continued the same migration pattern after ocean entry that is observed at their native river on the Olympic Peninsula. The authors suggest that Elwha Chinook have an innate directional preference and a specific pattern of distribution presumed to be a population-specific adaptation to the circumstances of their native habitat. Furthermore, the marine distribution of hybrids created by crossing the Elwha stock with the University of Washington stock showed an intermediate distribution in Puget Sound between the two stocks.

Nicholas and Hankin (1988) assessed the status and life history traits of Chinook populations endemic to Oregon's coastal rivers. They identified north migrating stocks and south migrating stocks with a sharp break at the Elk River near Cape Blanco. Based on CWTs, three basic patterns of marine recovery were identified. Stocks from the Elk River and northward migrated to the north after entering the ocean. A second group of coastal populations, those from the Rogue River and southward, migrated to the south. The third group, consisting solely of Umpqua River spring Chinook, was notable in that it had both north and south migrating components. The study also summarized several transplant experiments.

Fall-run stocks from the Rogue River and Chetco River transplanted to the lower Columbia River contributed primarily to the Chinook harvest in Oregon. Hence, southern stocks reared and released north of their home river had a marine distribution that shifted slightly northward, but they continued their stock-specific trait to migrate southward in contrast to the indigenous north migrating Columbia River stocks. The authors surmised that the “direction and distance” of ocean migration was an inherited trait. In a study of juvenile salmonids in coastal Oregon, Brodeur et al. (2004) noted a pattern similar to that described by Nicholas and Hankin. Juveniles from the area north of Cape Blanco, which are made up of the northward migrating stocks of Nicholas and Hankin, contributed 54% to early June surface trawl samples, but were nearly absent by August indicating that they had moved out of the area, presumably northward. Juvenile Chinook from the rivers south of Cape Blanco, the southward migrants of Nicholas and Hankin, were found throughout the summer. They contributed 53% to the overall catch in the sample transects south of Cape Blanco.

Stock-specific differences in marine migration behavior appear to be ubiquitous in salmonids. Tucker et al. (2009) report that the majority of Fraser River Sockeye migrate northward to sea through the Queen Charlotte strait, however sockeye from the Harrison River, a tributary of the Fraser, appear to migrate to the open shelf by going southward through the Strait of Juan de Fuca. Atlantic salmon in the Baltic Sea have also been shown to exhibit stock-specific ocean distributions. Kalio-Nyberg and Ikonen (1992) reported different migration patterns depending on the river of origin. Salmon from the River Iijoki migrated greater distances than salmon from the River Neva and utilized different feeding areas. The differences in migration distance noted between the two stocks were unaffected by their release points.

The large Columbia River system supports a correspondingly large number of salmon populations. Trudel et al. (2009) reported a diversity of stock-specific differences in migratory behavior within the river system based on CWT recoveries of juvenile Chinook. Columbia River spring Chinook smolts migrated rapidly northward to British Columbia and Southeast Alaska after ocean entry and appeared to leave the continental shelf by late summer or fall. In contrast, Columbia River fall Chinook also migrate north, but were seldom recovered north of Vancouver Island and tended to remain resident on the continental shelf into their second year at sea. They also reported that, contrary to the predominant northward migration of Columbia River Chinook, a small percentage actively migrated south after leaving the river. The propensity to migrate southward varied among basins with the majority of southern migrants made up of Cowlitz River spring-run Chinook and Snake River fall-run. Teel (2004) described two separate ecotypes of fall-run Columbia basin Chinook distinguished by genetics and life history differences. Juvenile “brights” were mostly caught in southern sampling locations in Oregon or in the vicinity of the Columbia River, while “tules” were more frequently caught further north in the Washington area. Historically, upriver brights originated from the Columbia River and Snake River above Celilo Falls, the current location of the Dalles Dam (river kilometer 309). Conversely, tules were a geographically separate group found below the barrier of the falls (Myers et al. 1998). Considering the total number of unique populations, the variations are extensive and complex. This is a key obstacle to overcome for salmon fisheries to be managed on a per stock basis. There is a requirement for detailed population-specific data and a necessity to reduce the complexity to something manageable.

While ocean distribution appears to be a stock-specific trait, the overall range of unique salmon stocks nevertheless overlaps widely at sea. In the ocean areas where they are found, Pacific salmon intermingle in mixed-stock and quite often mixed-species assemblages (Neave 1964; Jaenicke and Celewycz 1994). Stock composition analyses identify the stocks found in a specific area and calculate the percent contribution of each stock to the combined mixture. McGregor (1923) attempted some of the first calculations of the relative contribution of individual stocks to a mixed-stock fishery. He analyzed a sample of California troll-caught Chinook from the waters near Fort Bragg and a limited number of samples taken in Monterey Bay. Based on physiological differences, he estimated a stock mixture of 70% to 80% Klamath River and 20% to 30% Sacramento River Chinook in the Fort Bragg sample area. Conversely, the Monterey catch indicated a stock mixture of 86% Sacramento and 14% Klamath Chinook. Furthermore, McGregor also noted that the stock percentage changed over the two-month study – Sacramento River Chinook disappeared altogether from the Fort Bragg catch by August. Tucker et al. (2009) used genetic markers to describe stock-specific differences in migration pathways of juvenile sockeye sampled from the coastal Washington to the Alaska Peninsula. They noted seasonal changes in the stock composition in each region sampled. Seeb et al. (2004) investigated the spatial and temporal distribution of chum salmon stocks in the Bering Sea and along migration corridors south of the Alaska Peninsula and Kamchatka Peninsula. They observed that the contribution of individual stocks to the overall stock mixture change significantly through time. The assemblage and contribution level of individual stocks to a mixed-stock fishery varies by geographic region sampled. In addition, at any fixed location temporal changes in the stock mixture manifest as different stocks move through the area according to their own specific origins, migration rates and pathways. Both spatial and temporal parameters are important considerations to successfully design ocean fisheries that satisfy the dual management goal of preserving the abundance of individual stocks while maintaining stock diversity (Anderson and Beer 2009; Doctor et al. 2010).

Genetic predisposition appears to largely determine stock-specific trends of ocean distribution, however, additional factors may impart seasonal and annual variations. Brodeur et al. (2003) suggest that juvenile coho from Oregon and Washington may make more extensive northward migrations during years of unfavorable ocean conditions. The degree of flexibility in the distribution of individual stocks has not been thoroughly studied. A full catalogue of the factors that contribute to ocean distribution of salmon has not been described, nor is it known if these factors express uniformly throughout all populations or in all individuals of a single population. Weitkamp el al. (2002) cited earlier studies that reported size differences between Oregon Coast coho and Washington Coast coho during the 1983 El Niño year. Returning Oregon coho were exceptionally small that year while the Washington coho showed no change. Differences in their ocean distribution presumably exposed them to a different set of ocean conditions that produced differing rates of growth. The ocean distribution pattern of Chinook stocks has been shown to exhibit remarkable year-to-year stability, however, even during El Niño years (Weitkamp 2010). Hinke et al. (2005) reported that Chinook salmon from California and Oregon demonstrated a preference for seawater temperatures in the range of 8° to 12°C. They used archival tags to show that in 2003, Chinook changed their vertical distribution to use deeper, cooler water as sea surface temperatures warmed. The extent to which salmon can modify their horizontal distribution in response to ocean conditions, however, has not been extensively studied.

Aggregation with population conspecifics

Observed stock-based similarities of spatial and temporal distributions combined with a synchronized return migration to natal spawning grounds naturally raises questions regarding the cohesiveness of stock-specific aggregations. McKinnell et al. (1997) reported several incidences of steelhead caught together on the high seas up to three years after their same-day release from a common hatchery. Since steelhead released from the same hatchery can also be caught large distances from one another, they found no basis to conclude that discrete populations form a single, loosely schooled aggregation. However, the evidence did support the notion that steelhead might travel intermittently in many smaller, stock-specific groupings. Emlen et al. (1990) examined Cruise Reports for 1981 through 1985 on the Studies of Juvenile Salmonids off the Oregon and Washington Coast (Wakefield et al. 1981; Fisher et al. 1983; Fisher et al. 1984; Fisher and Pearcy 1985a; Fisher and Pearcy 1985b). Individual tows in which two or more marked juveniles were recovered indicated that individual stocks tend to be segregated with less than 10 percent mixing. Fraser et al. (2005) used genetic analysis of migratory arctic char in a freshwater lake to argue that most, but not all schools, were largely composed of aggregations from the same breeding-population. While these studies suggest the possibility of stock-specific aggregations, the evidence that Pacific salmon associate with population conspecifics during their ocean phase is not conclusive. Palm et al. (2008) in a two-year study of kin associations found only weak evidence during a single year that unrelated Atlantic salmon from the same population occur together. The possibility that stock-based associations might intermittently form and disband in different locations creates a challenging data collection problem requiring the accurate identification of stock origin, precise positional coordinates, and a sufficient sample size.

Study objectives

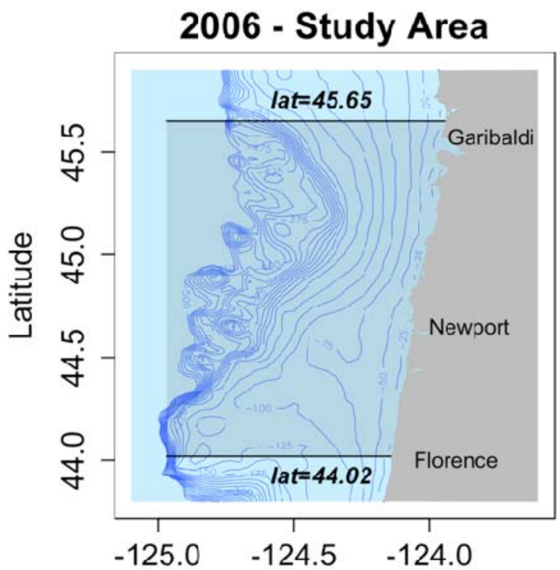
This study combines commercial fishery catch data with genetic stock identification (GSI) to investigate the stock-specific spatial distribution of Chinook salmon on the Oregon shelf for 2006 and 2007. We identify the important stocks that contribute to the Oregon fishery and temporal changes in the relative contribution level. We demonstrate in-season and between season changes in the age structure of discrete stocks. Precise capture coordinates provided by fishermen allow analysis of stock distribution from scales of hundreds of kilometers down to tens of meters – a degree of precision that distinguishes this study. There are three main objectives: 1) describe the stock-specific distribution of Chinook salmon on the Oregon Coast by comparing the coastal range of important stocks from the 2007 commercial catch; 2) describe year-to-year and in-season changes to stock-composition and the age structure of select Chinook stocks; 3) on the scale of a few meters to several thousand meters, examine the 2006 mixed-stock salmon aggregations for evidence that Chinook tend to be found closer to their breeding population cohorts than would be predicted for randomly intermingled mixed-stock aggregations. The study's comprehensive goal is to demonstrate the effectiveness of the collaboration of fishermen and scientist and the use of GSI techniques to acquire high-volume catch data at previously unobtainable scales of accuracy. Furthermore, we demonstrate how this data can be used to describe stock-specific patterns of Chinook ocean distribution at improved scales of spatial and temporal resolution and we describe the merits of this study in relation to the management of west coast salmon fisheries.

Methods and Materials

Project CROOS is a unique partnership of fishermen, fisheries managers and scientist comprising research, public outreach and a program to explore and develop marketing opportunities for wild-caught Oregon Chinook. The study was conceived and designed to serve the diverse interests of the principle salmon stakeholders. Oregon salmon trollers provided essential support for Project CROOS – they were active researchers that collected all field data. Using catch data supplied by collaborating fishermen, this study investigated the distribution of individual populations of Chinook salmon along the nearshore regions of the Oregon Coast. In 2007, the study focused on the 13 most abundant stocks to explore population-specific patterns in their coastal extent in Oregon waters. For 2006 and 2007, the study investigated stock-based patterns of Chinook aggregation on spatial scales as low as tens to hundreds of meters. Analysis of stock-specific spatial distribution and aggregation required precise catch coordinates and a stock assignment for each individual fish. The home river, or in some cases home region, of each Chinook salmon was determined using genetic stock identification. Collaborating Oregon salmon trollers record salmon catch coordinates and other biological and physical data collected during their normal fishing activity. It was assumed that the observed catch distribution reflected the actual ocean distribution of Chinook over the duration of this study. The 2006 season was a demonstration year for Project CROOS. Data collection protocols developed prior to the 2006 were field tested in 2006. Research findings were shared with fishermen, fisheries managers and the general public through a project website (www.pacificfishtrax.org) and a wild-caught Oregon salmon marketing program.

Study Area and the period of study

The Oregon Coast stretches approximately 470 km from its southern border with California to the Columbia River in the north. Fishing restrictions enacted in 2006 season closed much of the commercial Oregon Chinook fishery along the Oregon Coast. In 2006, the study area (Figure 4) covered a 181 km section of the coast from the south jetty of Florence northward encompassing a latitudinal range from 44.02°N to 45.65°N and an 80 kilometer east to west expanse of the Oregon shelf from west longitude –123.96° to –124.97°. The 2006 sample period began June 4 and ended October 31. In this time period there was a total of 50 days at sea with a catch of one or more Chinook. In the 2007 season, Project CROOS fishermen collected data from 42°N to 45.72°N and from west longitude –123.96° to –124.93° (Figure 5), an area approximately 413 km north to south by 77 km east to west. Sample dates for the 2007 season ran from May 1 to November 20, a total of 133 days at sea with 97 separate days of fishing with a catch of one or more Chinook salmon. Coverage of the most northern portions of the coast was limited. Sample days during each season took place according to the commercial Chinook regulations for opened and closed periods.



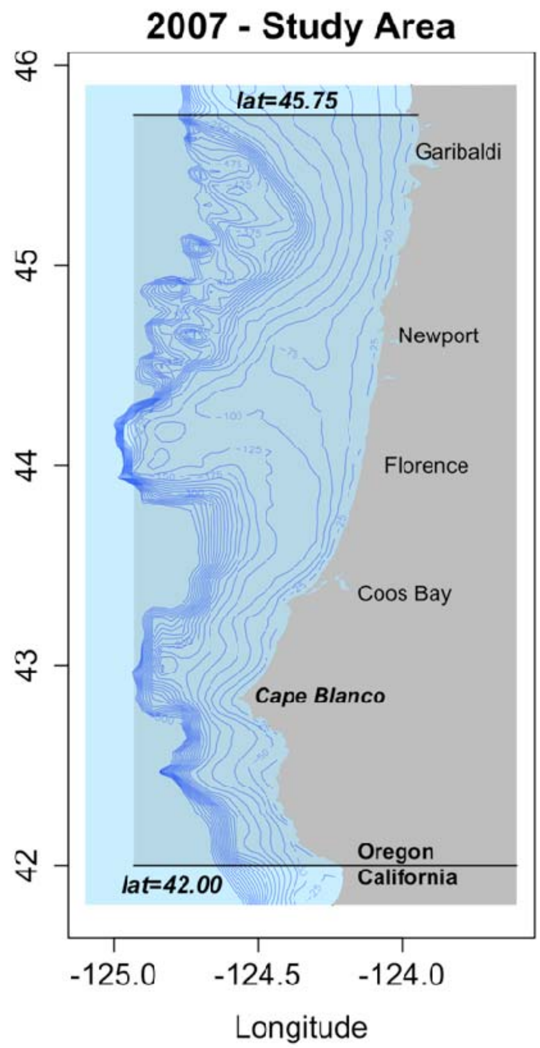


Figure 4 (above) indicates the 2006 study area. Chinook were caught between latitude 44.02° N to 45.65° N, a span of 181 km.

Figure 5 (right) shows the bounds of the 2007 sampling season. Chinook were caught over a 413 km segment of the Oregon Coast from latitude 42° N to 45.75° N.

Data Collection

Data collection methodology and genetic analysis procedures have been fully described in Bellinger and Banks (2008) – a summary of data collection and genetic procedures follows. Fishermen were supplied with a collection kit and a hand-held GPS unit. They attended a training session given by a port liaison to become familiar with the data collection protocol used by Project CROOS. While actively fishing, the

GPS unit updated the current position of the fishing vessel at five-minute intervals. The five-minute waypoints were stored automatically in local memory on the GPS unit producing a track log used to calculate fishing effort. GPS equipment that was deployed to automate the calculation of fishing effort was not widely available in the 2006 season. For each Chinook salmon brought aboard, a metal tag printed with a unique barcode was attached to the jaw of the fish. Fishermen recorded latitude and longitude coordinates for the catch using the waypoint feature of the GPS unit. Accompanying the metal barcode tag were envelopes pre-printed with a matching identity code. From each salmon, scale samples were taken to estimate age and a tissue sample was collected from the fin for genetic stock identification. Samples were stored in the envelopes. Vessel name, fork length in inches, depth of capture in fathoms, and a catch location waypoint number were recorded for each fish. Also the presence of a hatchery mark was noted (usually an adipose fin removed at the hatchery). Envelopes were quickly stored in a dry area to prevent sample degradation. Catch coordinates were obtained from onboard navigation equipment for vessels that did not have a hand-held GPS unit. Information on each individual salmon supplied by fisherman was entered into a Microsoft Access database. Personnel at the Oregon Department of Fish and Wildlife analyzed scale samples for age determination. The database was later updated to include age information for each successfully aged fish.

Genetic identification

Genetic analysis to determine stock identification was performed by the Marine Fisheries Genetics Laboratory at the Hatfield Marine Science Center of Oregon State University. DNA was extracted from fin clip samples in 2006 using Qiagen® DNeasy™ kits following manufacturer protocols. Silica fiber Pall plates were used for DNA extraction in 2007. Also in 2007, the Conservation Genetics Laboratory at the National Marine Fisheries Service, Northwest Fisheries Science Center, genotyped 885 of the samples. In order to verify the agreement of stock assignment results, a small subset of the 2007 samples were processed by both laboratories. Stock assignments used the GAPS (Genetic Analysis of Pacific Salmonids) baseline v2 (Seeb et al. 2007). Probability estimates were provided that accompanied the assignment results of individual Chinook. After genetic analysis was complete, the database record for each fish, identified by its barcode ID, was updated to include stock assignment information.

Catch data

During 2006 and 2007, a total of 8,145 Chinook samples were collected. Fish that had data recording errors were discarded. The most frequent data errors were missing catch coordinates or subsequent genotyping errors. Data errors were more common during the 2006 season. Of the initial 8,145 fish sampled during the 2-year study, 1,746 were excluded from the analysis because of missing data fields – 1,650 in 2006, 202 in 2007 – leaving a total sample size of 6,399. In addition, when analyzing characteristics of an individual stock, such as its coastal range or proximity of river cohorts, a stock assignment probability of 90% or greater was required. A combined total of 4,932 individual stock assignments met the 90% probability requirement – 2,210 in 2006 and 2,722 in 2007. Stock composition calculations that determined the relative contribution of individual stocks to the overall stock mixture did not require an assignment probability greater than 90% – all genotyped Chinook, regardless of individual assignment probability, were included in composition analysis. Table 1 summarizes the Chinook data for 2006 and 2007 showing the total catch categorized by stock origin, individual stock assignments of 90% or greater, number of fish that were aged by scale analysis, and the age class structure of each stock. Fishing effort north of Depoe Bay was limited for each of the two seasons. Of the Chinook salmon that met the 90% assignment probability for the two sample seasons, a combined total of 62 specimens were collected north of 44.8°N – 24 in 2006 and 38 in 2007. In an effort to limit the spatial area used when describing 2006 stock composition changes over time, these few individuals were omitted. They were included in the 2007 coastal range descriptions.

Table 1. Summary of the 2006 and 2007 catch data. Catch is the total number of Chinook from each stock, p>=.9 is the total that assigned to the stock with a probability 90 percent or greater. Aged is the number of fish for which scale analysis successfully estimated age, 3yrs – 6yrs is the number of Chinook in each age class.

	2006								2007							
Stock Name	**Catch**	**Percent**	**p>=.9**	**Aged**	**3 yrs**	**4 yrs**	**5 yrs**	**6 yrs**	**Catch**	**Percent**	**p>=.9**	**Aged**	**3 yrs**	**4 yrs**	**5 yrs**	**6 yrs**
California Coast	60	0.0223	52	47	26	17	4	0	205	0.0552	188	184	90	75	17	2
Central BC Coast	0	0	0	0	0	0	0	0	4	0.0011	1	1	0	1	0	0
Central Valley (Fall/Fea spr)	1614	0.6011	1540	1378	893	469	15	1	290	0.0781	149	143	38	93	12	0
Central Valley (spring)	36	0.0134	24	22	18	3	0	0	175	0.0471	75	72	18	49	5	0
Central Valley (winter)	0	0	0	0	0	0	0	0	1	0.0003	1	1	1	0	0	0
Deschutes R. (Fall)	14	0.0052	5	3	1	2	0	0	26	0.007	15	14	3	10	1	0
East Vancouver Is.	2	0.0007	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hood Canal	22	0.0082	6	5	3	2	0	0	11	0.003	5	2	1	1	0	0
Klamath R.	172	0.0641	151	135	79	55	1	0	1420	0.3823	1279	1234	893	319	20	1
Lower Columbia R. (Fall)	45	0.0168	22	16	2	11	3	0	35	0.0094	25	23	8	11	4	0
Lower Columbia (spring)	16	0.006	5	4	1	3	0	0	17	0.0046	7	6	2	3	1	0
Lower Fraser	28	0.0104	23	20	14	6	0	0	5	0.0013	5	5	2	3	0	0
Lower Skeena R.	1	0.0004	0	0	0	0	0	0	4	0.0011	4	3	0	1	2	0
Mid/Upper Columbia (spring)	0	0	0	0	0	0	0	0	1	0.0003	1	1	0	1	0	0
Mid Columbia-Tule	26	0.0097	22	20	13	6	1	0	40	0.0108	36	35	23	11	1	0
Mid Fraser R.	5	0.0019	4	2	0	2	0	0	6	0.0016	6	6	0	0	6	0
Mid Oregon Coast	172	0.0641	87	65	18	31	11	5	422	0.1136	260	226	67	119	34	6
N. California/S. Oregon Coast	60	0.0223	43	39	11	22	5	1	249	0.067	199	176	66	77	33	0
N. Gulf Coast Alsek R.	1	0.0004	1	1	0	1	0	0	0	0	0	0	0	0	0	0
North Oregon Coast	44	0.0164	20	18	1	7	9	1	55	0.0148	38	30	3	7	16	4
N. Puget Sound	14	0.0052	4	0	0	0	0	0	20	0.0054	4	2	1	1	0	0
N. Thompson R.	1	0.0004	0	0	0	0	0	0	1	0.0003	1	0	0	0	0	0
NSE Alaska-Chilkat R.	1	0.0004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rogue R.	195	0.0726	114	99	51	45	3	0	552	0.1486	313	274	134	116	24	0
S. Puget Sound	42	0.0156	19	18	13	5	0	0	28	0.0075	23	19	9	10	0	0
S. Thompson R.	12	0.0045	7	4	0	3	1	0	11	0.003	8	5	1	1	3	0
Snake River (Fall)	8	0.003	3	2	1	1	0	0	18	0.0048	8	7	4	2	1	0
SSE. Alaska	4	0.0015	2	1	1	0	0	0	1	0.0003	1	0	0	0	0	0
SSE Alaska-Stikine R.	0	0	0	0	0	0	0	0	2	0.0005	1	1	0	0	1	0
Taku R.	0	0	0	0	0	0	0	0	1	0.0003	0	0	0	0	0	0
Upper Columbia (sum/Fall)	74	0.0276	48	17	0	6	11	0	100	0.0269	60	50	7	20	22	1
Upper Fraser R.	2	0.0007	2	2	0	2	0	0	3	0.0008	3	3	0	1	2	0
Upper Skeena R.	2	0.0007	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Stikine	0	0	0	0	0	0	0	0	2	0.0005	1	1	0	1	0	0
West Vancouver Is.	2	0.0007	1	0	0	0	0	0	1	0.0003	1	1	0	1	0	0
Washington Coast	6	0.0022	2	0	0	0	0	0	7	0.0019	3	2	0	0	1	0
Willamette R.	4	0.0015	3	2	0	2	0	0	1	0.0003	1	1	0	0	1	0
Totals	**2685**	**1**	**2210**	**1920**	**1146**	**701**	**64**	**8**	**3714**	**1**	**2722**	**2528**	**1371**	**934**	**207**	**14**

Distribution of Stocks on the Oregon Shelf

With a study area that spanned most of the Oregon Coast (Figure 5), the 2007 season compared the coastal distribution of the catch to investigate stock-based patterns of ocean distribution. The study area was partitioned into 15 separate 0.25° bins of latitude from 42°N to 45.75°N (Figure 6). To assure their range was sufficiently represented, only stocks with a reasonable number of captures were included. A minimum catch of 15 Chinook with a stock assignment probability of 90% or greater was set as the cutoff – a requirement that included the 13 most abundant stocks (the 13 stocks are identified in Table 2; see Figure 7 and Figure 8 for the home regions). These 13 stocks accounted for 2,660 of the 2,772 Chinook caught in 2007 that had a stock assignment probability of 90% or greater.

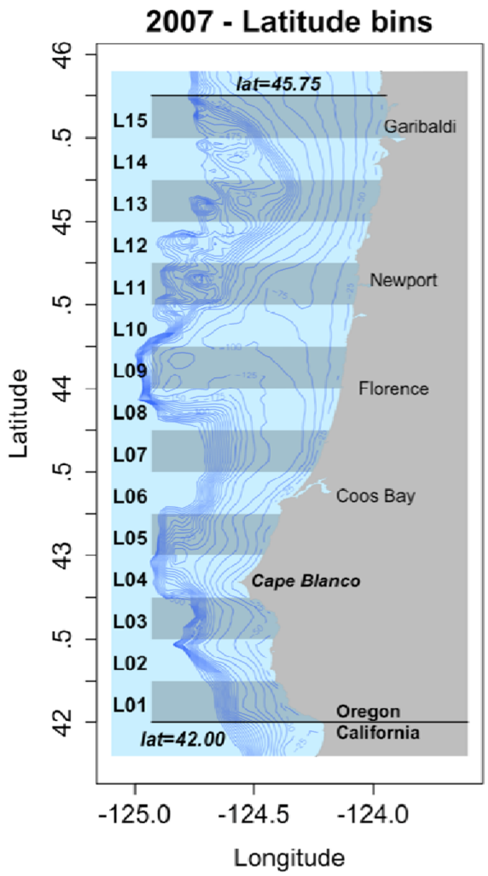


Figure 6. CPUE for the 13 most abundant 2007 stocks was calculated in 15 separate 0.25° latitudinal bins, L01-L15. Results were used to group stocks with a common distribution pattern.

Catch per unit effort was calculated for each of the 13 stocks by latitude bin. The CPUE value for any given stock i in latitude bin j was calculated as fish per hour using the formula,

$$CPUE_{ij} = \frac{\sum n_{ij}}{\sum w_j \left(\frac{5}{60}\right)}$$

where n_{ij} indentifies the number of Chinook of stock i in latitude bin j, and w_j is the number of 5-minute track-log waypoints in latitude bin j. CPUE was converted to number of fish per hour by multiplying the number of 5-minute waypoints by $^{5}/_{60}$. The absolute CPUE values for individual stocks varied widely with the relative abundance of each stock. Therefore, CPUE was standardized as a percentage of an individual stock's CPUE in each bin of latitude. This allowed distribution trends between stocks with vastly different absolute CPUE values to be easily compared on a common scale. $CPUE\%$ of stock i in bin j was calculated as

$$CPUE\%_{ij} = \frac{CPUE_{ij}}{\sum_{j=1}^{15} CPUE_{ij}} \; (100)$$

where $CPUE_{ij}$ is the CPUE of stock i in bin j. For the 13 most abundant stocks from 2007, bar graphs were combined with catch plots to graphically display capture locations and CPUE percentage by latitudinal increment.

To investigate whether individual stocks could be grouped according to similar distributions, three separate analyses were used – two multivariate techniques and a pairwise t-test. The multivariate techniques were applied to investigate similarities in the percent of CPUE in 0.25° bins of latitude. An ANOVA and pairwise-t compared the mean latitude of capture for individual stocks. Multivariate analysis was performed using PC-ORD v4.41. The standardized CPUE was used to construct a 15 by 13 matrix (Table 2) of CPUE values corresponding to latitude bin and stock. Bin 14 was excluded from the multivariate analysis since the $CPUE\%$ was zero for all stocks. The first multivariate technique employed hierarchical agglomerative cluster analysis using Sorensen distances (Bray-Curtis) and a flexible beta linkage ($\beta = -0.6$) to construct a tree dendrogram that grouped Chinook stocks by the similarity of their latitudinal distribution across bins. The tree dendrogram was cut to retain group homogeneity while also attempting to minimize the number of groups.

The cut point selected for the tree dendrogram maximized group homogeneity, but also left 3 stocks orphaned. Following the cluster analysis, the mean catch latitude for each of the 13 stocks was compared to refine stock groups selected by the cluster analysis. A one-way ANOVA was used to test for differences in the mean catch latitude of the 13 separate stocks. After verifying that the means differed, a pairwise t-test with a Holm-Bonferroni adjustment for multiple comparisons was used to iteratively compare the mean latitude of each of the 13 stocks against one another. The output from the pairwise t-test produced a table of p-values for the individual t-tests. These results were used to assign stocks that were left orphaned by the dendrogram cut. The mean latitude for each stock represented the observed 2007 mean relative to the distribution of fishing effort. Effort was not

Table 2. Matrix of CPUE percent by latitudinal bin and stock ID. Each cell reports the percentage of the total CPUE for an individual stock in a corresponding bin of latitude. Total CPUE is calculated by summing the CPUE values in the 15 bins then dividing by the number of bins (15). For the California Coast stock, the absolute CPUE of latitude bin 1 was 29% of the sum of bin1 to bin 15.

			Stock ID												
			Ca Cst	C Val F	C Val Sp	Deschu F	Klamath	L Col F	Md Col Tu	Md Or Cst	N Ca S Or	N Or Cst	Rogue	S Pug Snd	U Col SuF
0.25° latitude bin and starting latitude	L01	42	29.8	9.1	10.8	16.9	20.2	6.6	0	8.8	37.4	0	26	7.4	10.5
	L02	42.25	0	14.7	15.2	0	3.7	0	0	0	6	0	3.8	0	19.8
	L03	42.5	15.5	4.9	7.6	15.8	22.2	12.3	7.9	5.9	11	0	18.9	0	0
	L04	42.75	6.3	9.8	2	12.7	9	0	6.4	28.9	7.3	0	10.2	0	0
	L05	43	7	28.7	33.5	19	13.1	14.9	28.7	6.4	9.6	3.1	8.4	25.1	33.6
	L06	43.25	13.2	8	6.6	8.2	10	9.6	2.1	6.4	10.9	0.7	9.5	3.6	5.1
	L07	42.5	22.2	7.3	4.8	11.2	14.5	2.9	0	6.8	10.5	1.2	12.4	0	3.9
	L08	43.75	4.1	0	0	0	3.4	0	0	3.7	6.3	8	4	0	0
	L09	44	0	2.9	6	0	1.1	0	0	12.5	0	0	3	0	0
	L10	44.25	0	0	0	0	1.9	0	0	2.1	0	9.1	1.1	0	5.9
	L11	44.5	2	8.8	13.6	16.2	0.8	53.7	54.9	4.7	1	3.9	2.7	63.9	19.3
	L12	44.75	0	5.8	0	0	0	0	0	2.8	0	0	0	0	0
	L13	45	0	0	0	0	0	0	0	9.1	0	39.6	0	0	0
	L14	45.25	0	0	0	0	0	0	0	0	0	0	0	0	0
	L15	45.5	0	0	0	0	0.1	0	0	2.1	0	34.5	0	0	1.9
CPUE% Totals			100	100	100	100	100	100	100	100	100	100	100	100	100

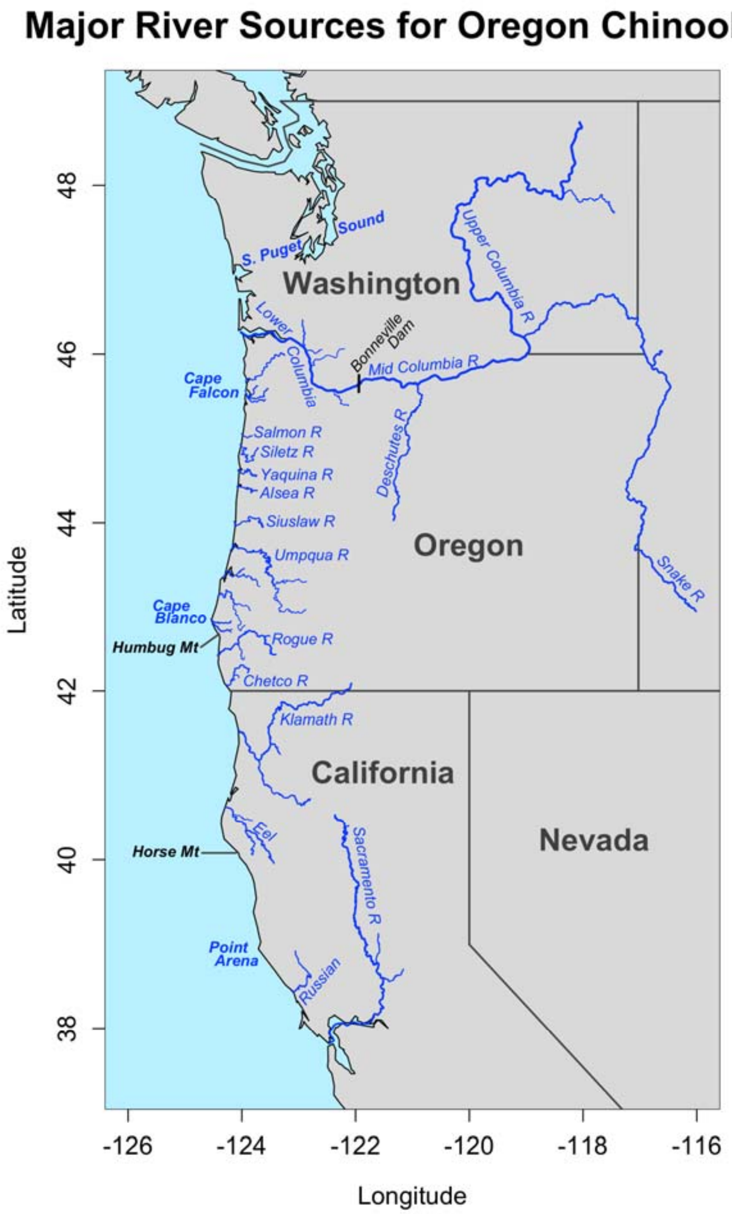


Figure 7. The major West Coast river sources that contributed to the 2007 coastal range study of Oregon ocean Chinook. Central Valley Chinook originated from the Sacramento River. The California Coast stock originated from the Eel and the Russian Rivers. All N. Cal / S. Oregon Chinook came from the Chetco River in southern Oregon. Lower Columbia River Chinook occurred below the Bonneville Dam. The Mid Columbia stock originated between the Bonneville Dam and the confluence the Columbia and the Snake. Upper Columbia River Chinook originated on the Columbia River above the confluence with the Snake River.

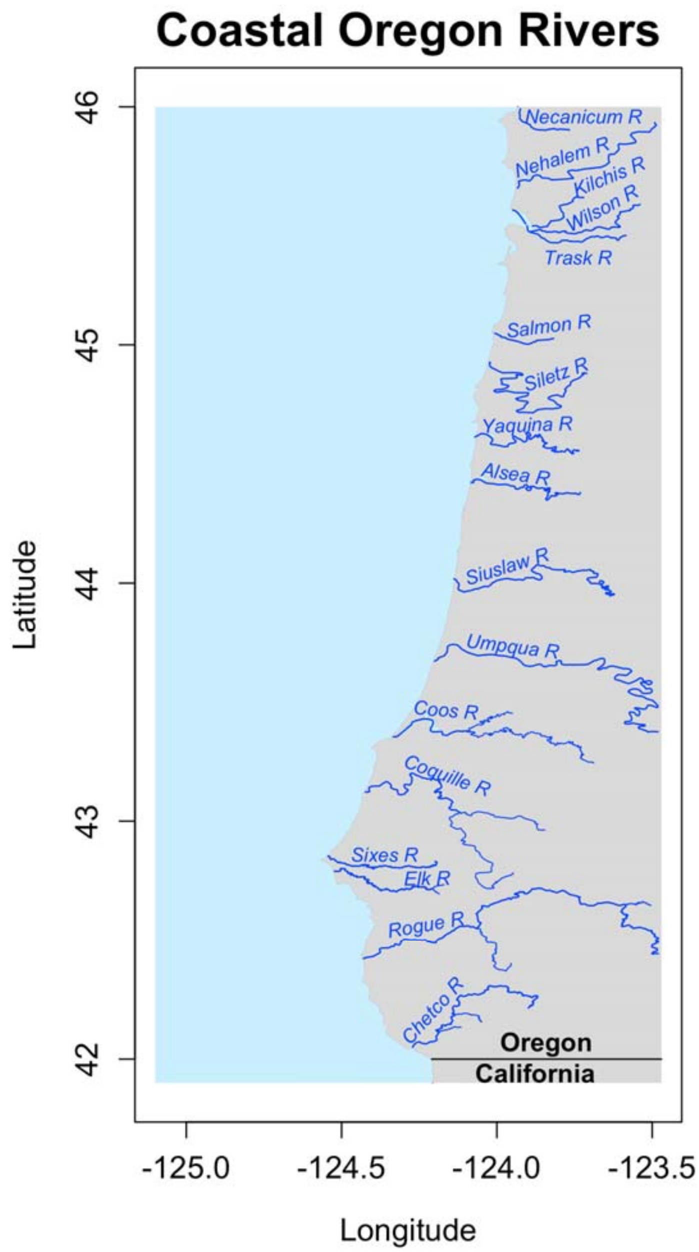


Figure 8. Important coastal Oregon rivers that contribute to Oregon ocean-caught Chinook. The Chetco River was the single source for the Northern California / Southern Oregon stock. Mid Oregon Coast Chinook originated from the Elk, Sixes Coquille, Coos Umpqua and Siuslaw river drainages. The Northern Oregon stock originated from the Alsea, Yaquina, Siletz, Salmon, Trask, Wilson, Kilchis, Nehalem and Necanicum river systems. Rogue River Chinook were distinct from the other coastal Oregon Chinook.

uniform throughout the study area. Therefore, the observed mean latitude of a given stock is not assumed to represent the actual mean latitude of that stock within the study area. However, all stocks were subjected to the same effort within the study area, thus, the comparison of means was assumed to reflect stock-based differences in Chinook distribution during the period of study.

After the group assignments were made, nonmetric multidimensional scaling (NMS) was used to ordinate Chinook stocks using *CPUE*% in 0.25° latitude bins. This step was intended to verify whether the groups selected from the previous two steps produced an acceptable explanation of ordination distances. The NMS ordination used Sorenson's distance measure. NMS is considered robust to non-normal data with a high number of zeros while Sorenson distances are less sensitive to outliers.

In-season Stock Composition and Age Structure

The contribution of individual stocks to the total fishery harvest reflects the relative abundance of discrete stock units to the overall mixed-stock assemblege. Among the factors that affect the contribution percentage of individual stocks is the spatial area where the ocean fishery is prosecuted and the temporal period of fishing activity. Changes in the mixed harvest composition across space and time provide evidence of stock-specific preferences for particular ocean locations, migration pathways, and the seasonal timing of ocean habitat use and migration routes. To investigate these stock-specific tendencies, the stock composition is calculated for specific locations throughout the course of the fishing season. The stock composition for the total catch in any given time period included all genotyped fish in the mixed-stock fishery regardless of assignment probability. The $Stock\%_i$ of each stock i of the total harvest was calculated as

$$Stock\%_i = \frac{n_i}{n}(100)$$

where n was the total number of fish genotyped and n_i was the total number of genotyped fish in stock i. In 2006, the stock composition and age structure were calculated for both an early season period (June 4 – Aug 3) and a late season period (Sep 12 – Oct 31). Changes in the stock composition during the season and changes in the age structure of individual stocks were assumed to suggest that population cohorts travel together with year-class and population groups of various sizes. For 2007, the stock composition and age structure was compared over three periods, an early season period (May 1 – July 17), a mid season period (July 18 – Sep 14) and a late season period (Sep 20 – Nov 20). Examining the age structure changes of individual stocks required a degree of certainty in the stock identification, therefore only those individuals that assigned with a greater than 90% probability were used. For both 2006 and 2007, the age structure was examined during each time period for the Central Valley Fall, Klamath River, Rogue River and Mid Oregon Coast stocks.

In addition to the early, mid (2007 only) and late season composition and age structure investigation, a more detailed examination over short duration time periods was conducted in 2006. Six separate time periods (see Table 9 in Results) with relatively high catch were used. In 3 of the time periods, the location of the catch was plotted along with the stock compositions to investigate the effect of catch location on stock composition.

A dramatic decline in the escapement of Sacramento River fall Chinook was reported in 2007. Sacramento River fall Chinook, a major contributor to the Oregon fishery, assign to the Central Valley fall / Feather River spring stock. To investigate whether this decline was observable during the 2007 fishery using GSI, the stock composition and age structure of Central Valley Fall Chinook was compared between 2006 and 2007. Any change noted in the abundance of the Oregon catch between 2006 and 2007 could be an early indication of falling numbers of Central Valley fall Chinook – a scenario that would advocate the future use of in-season genetic data to evaluate population status.

Analysis of stock-specific aggregations

In addition to identifying the important stocks and their coastal distribution, a major goal of this study was to determine whether stocks show a tendency to aggregate with population cohorts. Given the limited geographical extent of fishing activity during the 2006 season, analysis for that year concentrated on exploring stock aggregations. Two separate nearest neighbor techniques were applied: 1) frequency histograms were used to compare the observed mean nearest neighbor distance to mean distances obtained from Monte Carlo simulations; 2) the cumulative distribution of nearest neighbor distances were plotted as an additional aggregation test and to expose the spatial scale at which aggregations were observable.

A major assumption of the aggregation analysis was that stocks tended to remain in favorable ocean locations for up to 3 days at a time with little movement. While it was unknown how often actual events satisfied this condition, it was expected that significant movement of stocks during the 3-day window would result in a failure to detect a stock-based aggregation rather than falsely implying an aggregation. The mean nearest neighbor distance was calculated by measuring the distance from each fish of a given stock to the closest neighboring fish from the same stock using the formula,

$$\overline{NN}_i = \frac{\sum_{j=2}^{n_{ij}} NN_{ij}}{n_i - 1}$$

where $\overline{NN}_i$ is the average nearest neighbor distance for stock i, n_i is the number of fish in stock i, n_{ij} denotes a single fish from stock i and NN_{ij} is the distance to the nearest neighbor of fish n_{ij} in stock i. The observed nearest neighbor distances for important stocks were compared to those obtained from a 1,000-permutation simulation. For the simulation, the observed catch locations were held fixed. Each fish from the observed catch was then randomly assigned to one of the fixed locations – a reshuffling of stocks at the fixed locations. Reported p-values represent the fraction of permutations with average nearest neighbor distances less than those calculated for the observed catch (Figure 9). Low p-values indicate that the observed catch is more closely aggregated than a high proportion, 1 – p, of the simulations.

Comparison of the observed mean nearest neighbor distances to Monte Carlo simulations can identify aggregated stocks, but cannot detect the scale at which the aggregations occur. Outliers, especially with low sample sizes, adversely affect the mean nearest neighbor distance. Therefore, cumulative nearest neighbor distributions were plotted to investigate the spatial scale at which aggregations were observed. As with the average distance between nearest neighbors, the observed cumulative distribution of nearest neighbors was compared to a Monte Carlo simulation at fixed catch locations. Figure 10a – 10h illustrates the results of cumulative distribution plots for specific spatial patterns. The process is effective at detecting three types of spatial patterns – a random distribution (Figure 10c and 10d), an aggregated distribution (Figure 10e and 10f) and a regular distribution (Figure 10g and 10h).

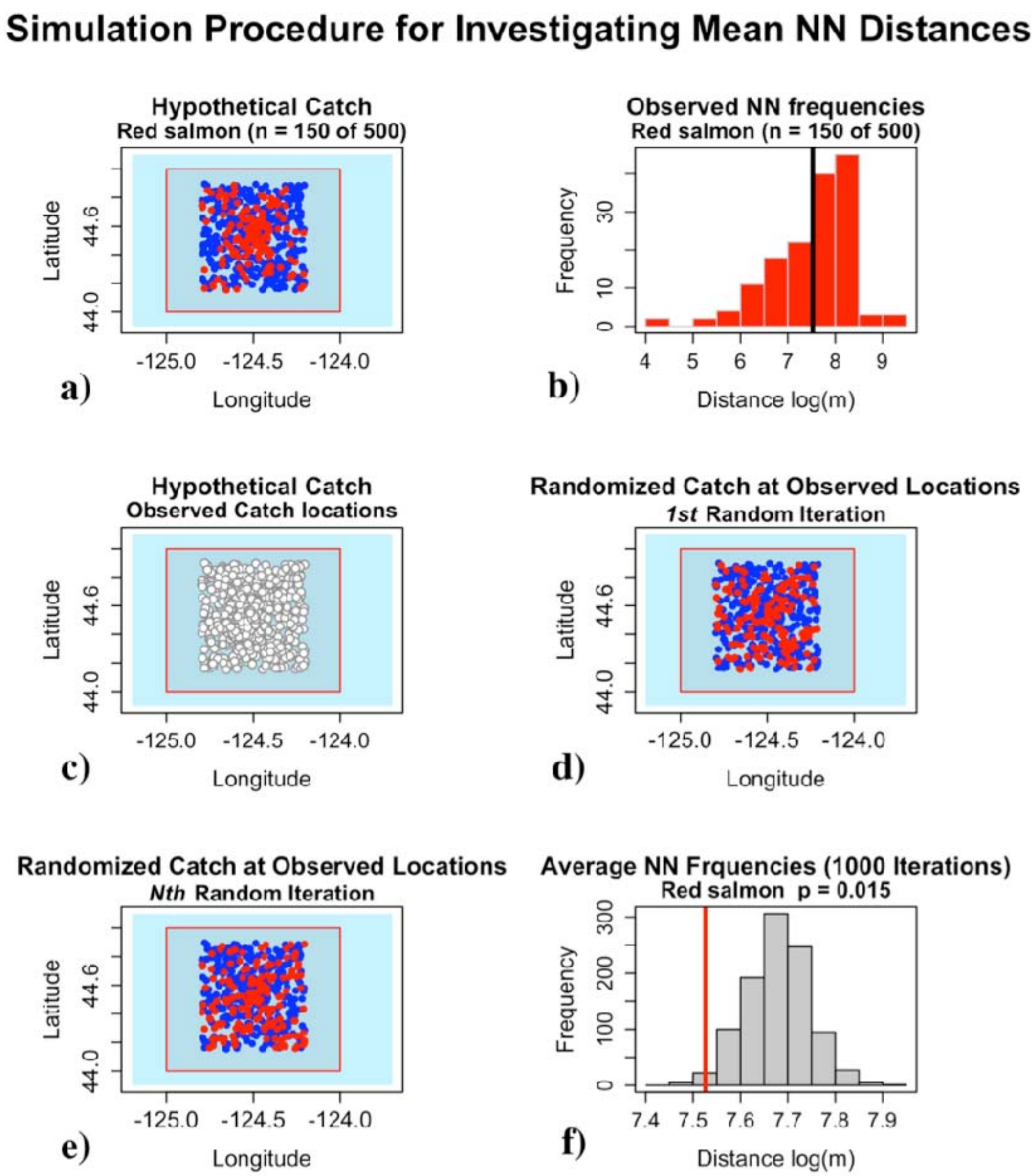


Figure 9. Randomization methodology used to investigate stock aggregation. The objective is to identify a stock aggregation within a mixed-stock cluster of salmon **a)** Observed catch locations for stocks of salmon (350 blue, 150, red). **b)** Frequency histogram of nearest neighbor (NN) distances for the catch of 150 red salmon, the black vertical bar in the mean NN distance. **c)** Observed catch locations from Figure 6a. These are the catch locations used for the Monte Carlo simulation. **d)** The first iteration of a random assignment of 350 blue salmon and 150 red salmon to the fixed catch locations in Figure 6c. **e)** The *n*th iteration of the randomization process. **f)** Frequency histogram of 1000 permutations of the randomization process showing the average NN distance, the red vertical bar is the observed mean NN distance in Figure 6b.

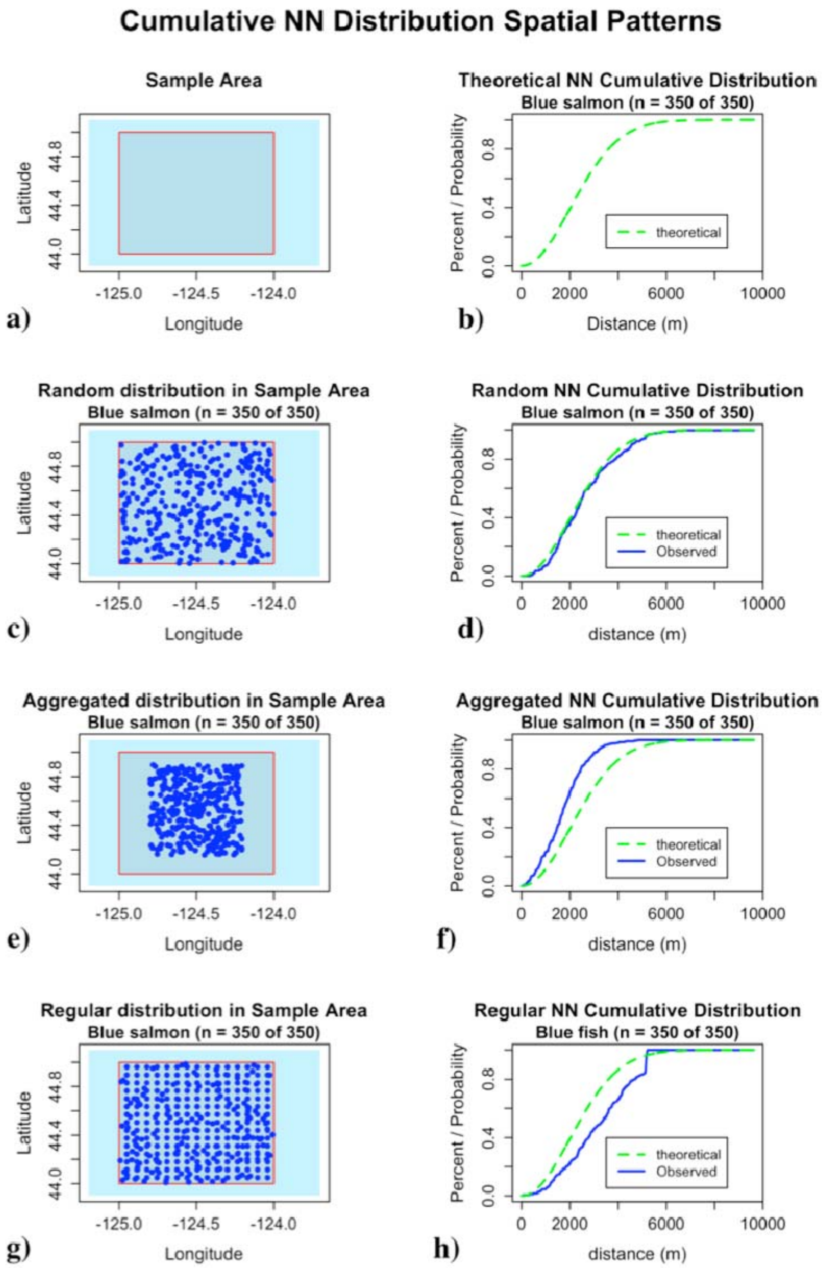


Figure 10. Examples of spatial patterns that can be detected by cumulative nearest neighbor distribution plots using spatstat library in R. **a)** Hypothetical ocean location that includes a small a rectangular sample area (red box) where fishing occurs. **b)** Theoretical Poisson distribution within the sample area of 350 blue salmon. **c)** 350 random points generated in sample area. **d)** Observed cumulative distribution (CD) of random points matches theoretical CD. **e)** Example of an aggregation within a larger sample area. **f)** CD of aggregated points compared to theoretical CD. **g)** A regular distribution where fish tend to distribute evenly. **h)** CD of a regular distribution compared to the theoretical CD.

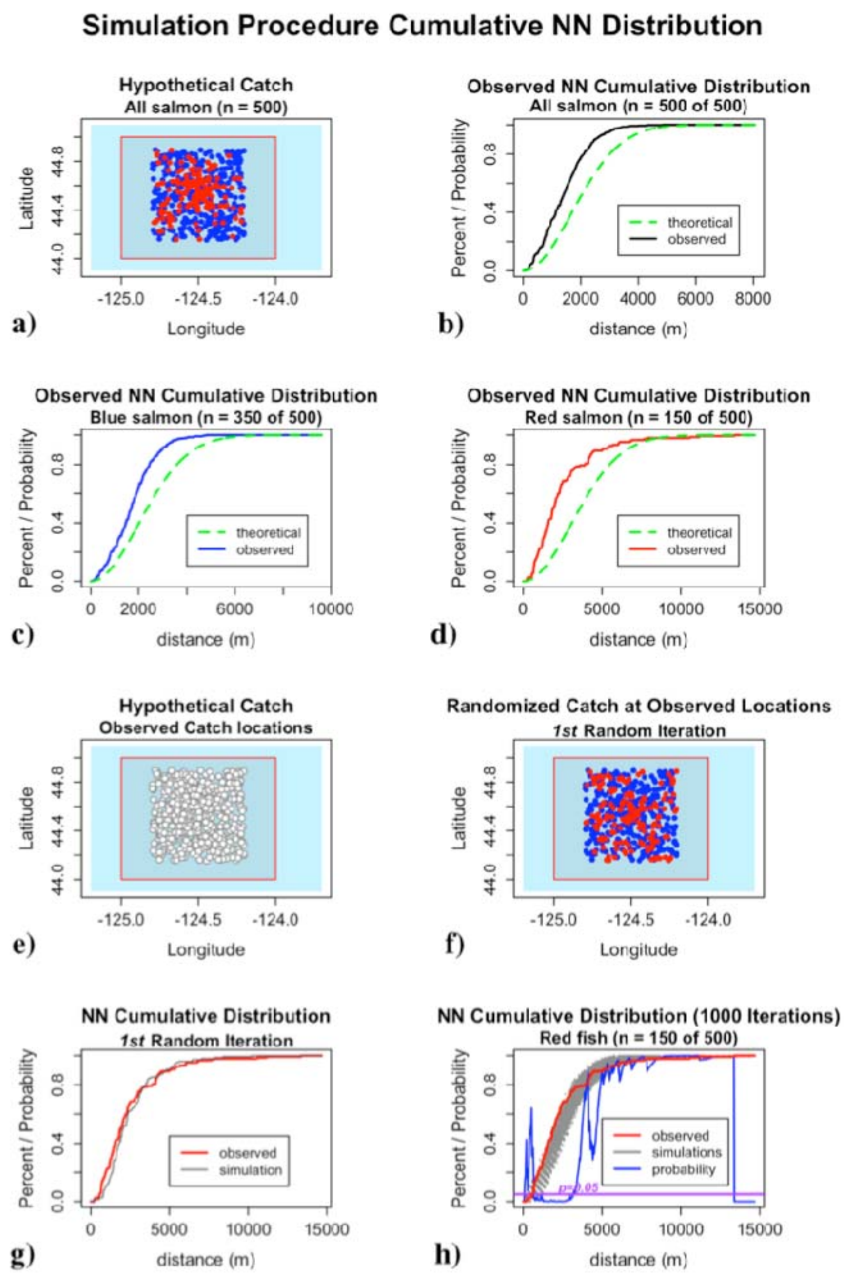


Figure 11. Methodology for comparing observed cumulative distribution (CD) to random shuffling of observed catch at fixed catch locations. **a)** Hypothetical catch of 350 blue salmon and 150 red salmon in sample area. **b)** CD indicating an aggregated catch. **c)** CD of blue salmon. **d)** CD of red salmon. **e)** Fixed catch locations of red and blue salmon in 8a **f)** Random assignment of 350 blue salmon and 150 red salmon to the fixed catch locations. **g)** CD of observed catch of red salmon (red) with 1 iteration of randomized catch at fixed locations (gray). **h)** CD of observed catch (red) and 1,000 iterations of simulation (gray). Blue line is the percent of the simulations that have NN distributions less aggregated than the observed for a given distance on the x-axis. Purple line indicates 0.05 percent/probability.

Detecting stock-based aggregations at sea presents a challenge. Figure 11a through 11h demonstrate the methodology used to detect stock-based aggregations within a larger mixed-stock shoal. For a hypothetical aggregation of two salmon stocks (Figure 11a) within a study area (bounded by red rectangle), the cumulative distribution is plotted in Figure 11b. The plot indicates that the salmon are clustered within the study area. It is therefore not surprising that Figures 11c and 11d indicate that both the red salmon and the blue salmon are clustered. To detect whether the red salmon are more closely aggregated within the study area than expected, the observed cumulative nearest neighbor distribution of red salmon is compared to other possible configurations of 350 blue salmon and 150 red salmon at the observed catch locations. This is done by randomly assigning the 500 salmon to one of the fixed catch locations in Figure 11e. Figure 11f shows the first iteration of the randomized permutation procedure. Figure 11g shows the cumulative distribution of red salmon obtained from the first iteration (gray) plotted with the cumulative distribution obtained from the observed catch in Figure11a (red). As can be seen from Figure 11g, a single randomized iteration did not generate a cumulative distribution substantially different from the observed distribution. However, repeating the simulation for 1,000 iterations (Figure 11h) indicates that between 500m and 4000m the observed cumulative distribution of nearest neighbors were more closely aggregated than 95% of the simulations.

This study assumes that all Chinook stocks were equally susceptible to commercial troll gear and that the distribution of these stocks observed in the fishery represented the actual distribution of Chinook in Oregon waters. Unless otherwise noted, all maps, plots and statistical analysis were done using “R: A Language and Environment for statistical Computing” version 2.12.0. Nearest neighbor distribution plots used the SPATSTAT library for spatial statistics version 1.20–5.

Results

This study identified the major stocks of Chinook salmon that contributed to the commercial catch in Oregon coastal waters. Based on catch data supplied by fishermen, the study described the stock composition observed in 2006 and 2007. Following a summary of each season’s catch, results on three major aspects of Chinook distribution are presented: 1) On a scale that encompassed the breadth of the Oregon Coast, the latitudinal range of the major stocks that contributed to the 2007 Oregon fishery were examined. The results were used to demonstrate stock-specific patterns of coastal distribution; 2) The study described both year-to-year and in-season changes to the overall stock-composition and the age structure of select Chinook stocks throughout the period of study; 3) Ocean areas with a high Chinook catch were investigated to describe the spatial proximity of river cohorts within mixed-stock shoals.

Season summary for 2006 and 2007

Microsatellite analysis identified Chinook from 31 separate reporting regions in the 2006 commercial season. Catch locations for each Chinook sampled in 2006 are shown in Figure 12 – stocks are color-coded by region of origin. Central Valley Fall / Feather River Spring Chinook, hereafter referred to as Central Valley Fall, made up slightly more than 60 percent of the 2006 catch. Rogue River, Klamath River and Mid Oregon Coast stocks contributed 7.3%, 6.4% and 6.4% respectively (Figure 14). Other notable contributors to the 2006 catch included Upper Columbia

River Summer/Fall (2.8%), California Coast (2.2%), and Northern California / Southern Oregon (2.2%), The remaining 24 stocks each accounted for less than 2% of the total catch on an individual basis. Collectively, stocks from the Columbia River basin made up 7% of the 2006 catch (Table 3). The Upper Columbia River Fall Chinook stock was the single largest contributor from the Columbia River. Figure 13 shows the catch locations for Chinook salmon sampled in the 2007 season. Chinook from 33 reporting regions were identified in the catch. The stock composition for the 2007 catch differed markedly from the previous sampling year (Figure 15). Central

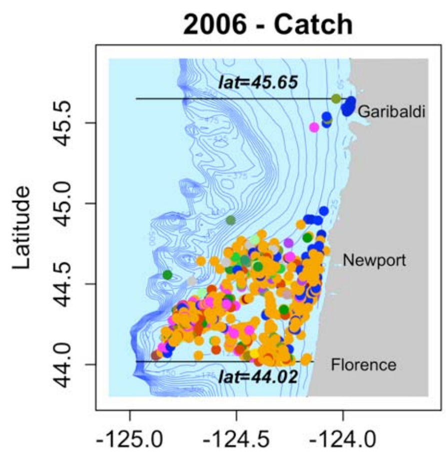


Figure 12 (above) 2006 Chinook catch locations. Colors represent unique stocks. Fishing was closed south of the Newport Jetty.

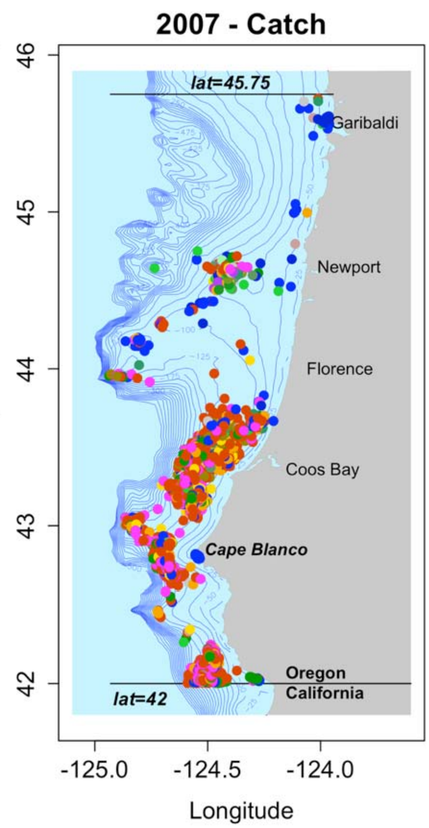


Figure 13 (right) 2007 Chinook catch locations. Analysis examined coastal distribution and stock-specific aggregations. The entire Oregon coast was open to fishing.

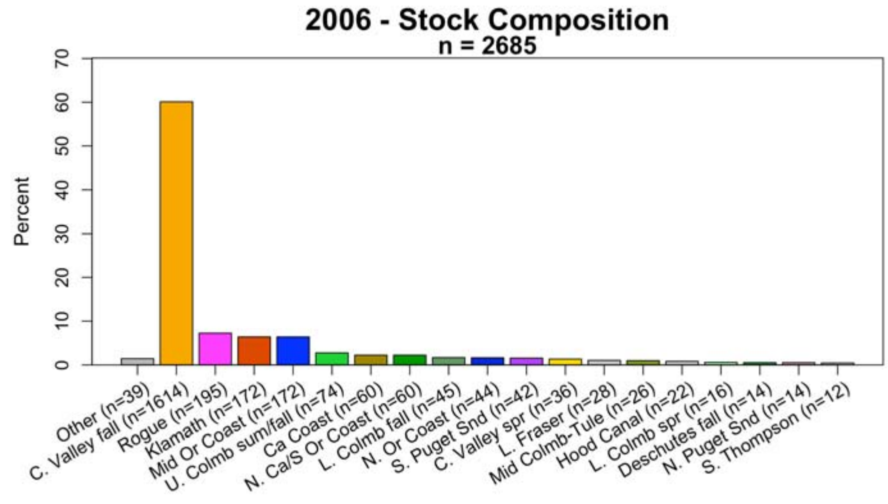


Figure 14 Stock composition of the 2006 catch. Chinook stocks with less than 10 fish were grouped in the 'Other' category. Fishing was closed south of Florence in 2006.

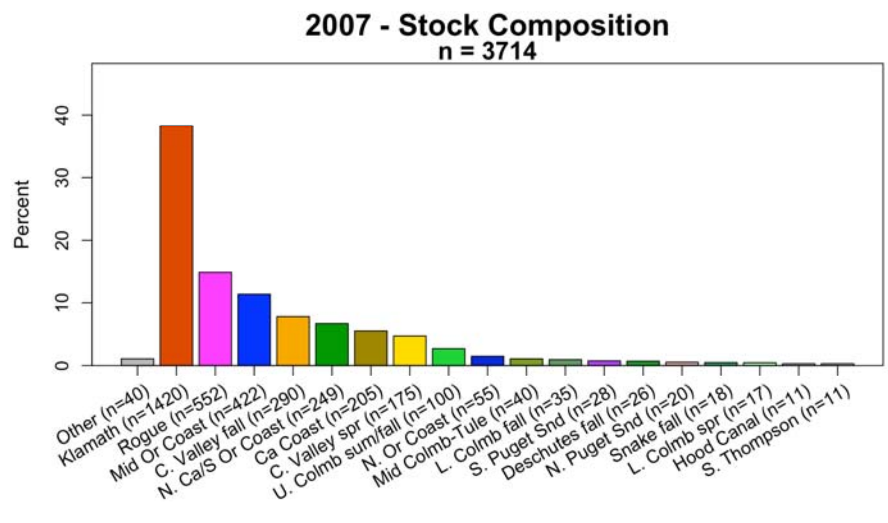


Figure 15 Stock composition of the 2007 catch. Fishing took place coastwide during the 2007 season.

Valley Fall Chinook, which made up 60% of the 2006 catch, dropped to 7.8% of the catch in 2007. Conversely, the Klamath River contribution increased from 6.4% in 2006 to 38% in 2007. Rogue River Chinook increased from 7.3% to 14.9% year over year. Mid Oregon Coast salmon also increased, climbing from 6.4% to 11.4%. Other notable increases from 2006 to 2007 were observed for the California Coast stock, 2.2% to 5.5%, and the northern California / Southern Oregon Coast stock, 2.2% to 6.7%. Gains in the percent contribution of each of these stocks were a result of an increased catch (Table 1); gains were not an exclusive an artifact of the sharp decline in the contribution level of Central Valley Fall Chinook. As will be shown shortly, year over year changes in the stock mixture were partially attributable to a large 2007 catch along the south Oregon Coast in areas that were closed to fishing in 2006.

Stock contributions from the Columbia River in 2007 were similar to those observed in 2006. The combined contribution of stocks from the Columbia River basin in 2007 was 6.4% (Table 3). Upper Columbia Fall Chinook were again the single largest stock contributor from the Columbia River at 2.7%. Fall-run Chinook from the lower Columbia River decreased from 1.7% of catch in 2006 to 0.9% of the total catch in 2007. The consistency of the combined contribution over the two-year study and the moderately stable relative abundance of individual populations was a notable feature of the Columbia River stocks.

Table 3. Contribution of Columbia River basin Chinook stocks to the 2006 and 2007 Oregon ocean Chinook fishery.

	2006		2007	
Stock Name	**Catch**	**Percent**	**Catch**	**Percent**
Upper Columbia	74	0.0276	100	0.0269
Lower Columbia R. (Fall)	45	0.0168	35	0.0094
Mid Columbia-Tule	26	0.0097	40	0.0108
Lower Columbia (spring)	16	0.0060	17	0.0046
Deschutes R. (Fall)	14	0.0052	26	0.0070
Snake River (Fall)	8	0.0030	18	0.0048
Willamette R.	4	0.0015	1	0.0003
Mid/Upper Columbia	0	0.0000	1	0.0003
Totals	**187**	**0.0698**	**238**	**0.0641**

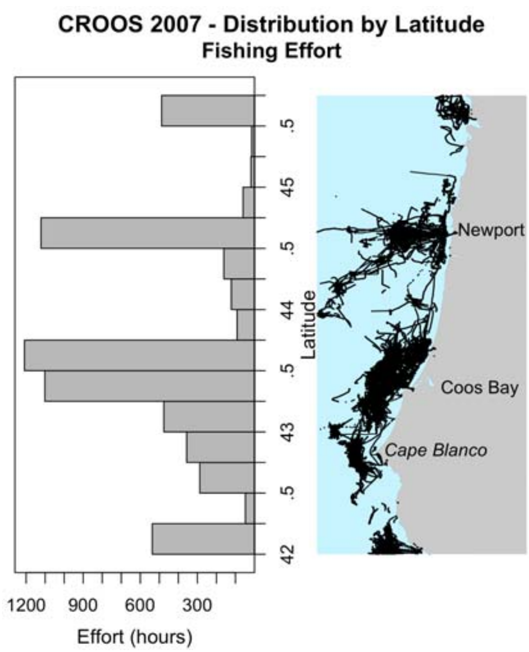
Scale analysis determined the age for 1,920 Chinook in 2006 and 2,528 in 2007. The age structure for the 2006 and 2007 season was roughly similar (Table 4). From 2006 to 2007, the percentage of 3-year-olds decreased slightly from 58.5% percent to 54.2%, while the percentage of 5-year-olds doubled, increasing from 3.8% to 8.2%. The percentage of 4-year-olds was largely unchanged from 2006 to 2007. Further analysis of age class structure is offered in subsequent sections.

Table 4. Age class structure of 2006 and 2007 Chinook catch. The totals include catch regardless of stock assignment probability.

	2006		2007	
Age	**Total**	**Percent**	**Total**	**Percent**
3	1195	58.52	1371	54.23
4	759	37.17	934	36.95
5	78	3.82	207	8.19
6	9	0.44	14	0.55
Totals	**2041**	**100**	**2526**	**100**

2007 Ocean Distribution of Oregon Chinook Stocks

Coast-wide fishing in 2007 provided an opportunity to examine the coastal range of the abundant Chinook stocks for 2007. By utilizing vessel track logs, catch per unit effort was calculated in 0.25° increments of coastal latitude. Vessel waypoints plotted in Figure 16 were used to calculate the total fishing effort for 2007. Effort is indicated by hours fished in 0.25° latitude increments.



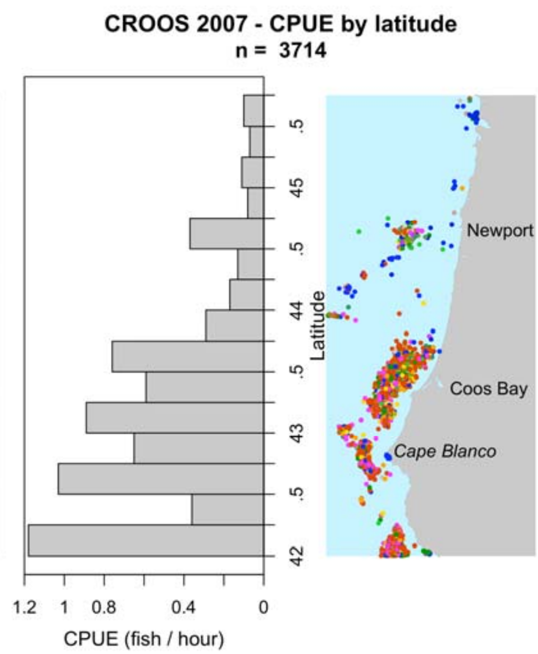


Figure 16 (left). Track log that shows fishing vessel location in 5 minute intervals for the 2007 Chinook season. The track log is grouped in 0.25° intervals of latitude. Fishing effort in hours fished is plotted for each latitude increment.

Figure 17 (right). Distribution of the 2007 catch by CPUE in 0.25° latitudinal bins. The highest CPUE values were recorded in the south and decreased from south to north.

Figure 17 shows the coastal distribution of the 2007 catch. Horizontal bars on the left of the plot indicate the 2007 CPUE in each 0.25° increment of latitude. Catch locations on the Oregon shelf are plotted on the right side of Figure 17. The Central Valley Fall stock exhibited a 2007 coastal range (Figure 18) that was somewhat evenly distributed across coastal Oregon. CPUE was standardized as a percent to allow for comparison between abundant and less abundant stocks on an identical scale. CPUE percent values are directly proportional to absolute CPUE values. While the CPUE for Central Valley Chinook had a peak between 43.00°N and 43.25°N, its abundance was widely spread from the California border to northern Oregon. Conversely, Mid-Columbia Tule CPUE (Figure 19) was skewed to the northern coast, particularly in the area offshore of Newport that had a CPUE value that was nearly double that of any other latitude bin. These figures were indicative of three basic patterns observed in the coastal range of Oregon ocean-caught Chinook: 1) a northern group of stocks (Figure 20) with higher CPUE values observed in the northern portion of the 2007 study area; 2) a southern group of stocks (Figure 21) with higher CPUE values found along the south Oregon Coast and a decreasing trend from south to north; and 3) a coastwide group of stocks (Figure 22) with an abundance spread somewhat evenly throughout coastal Oregon.

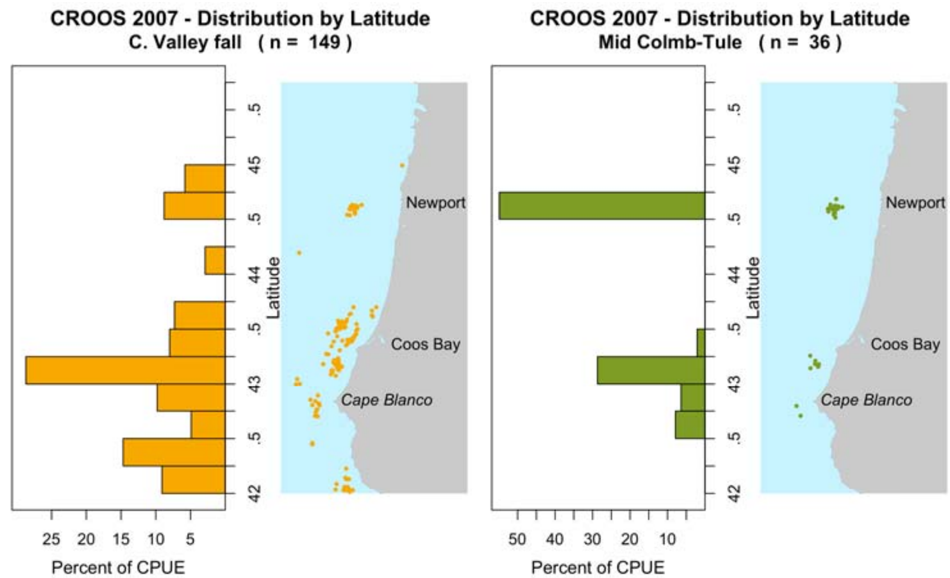


Figure 18 (left). Coastal range of Central Valley Fall Chinook by CPUE. The highest CPUE for the stock occurs just north of Cape Blanco between 43° N and 42.25° N. CPUE values were similar in other latitude bins and showed a near even coastal distribution in 2007.

Figure 19 (right). The distribution of Mid Columbia-Tule Chinook was more heavily weighted along the north coast in 2007. With the exception of the area north of Cape Blanco, the stock was not abundant along the southern coast.

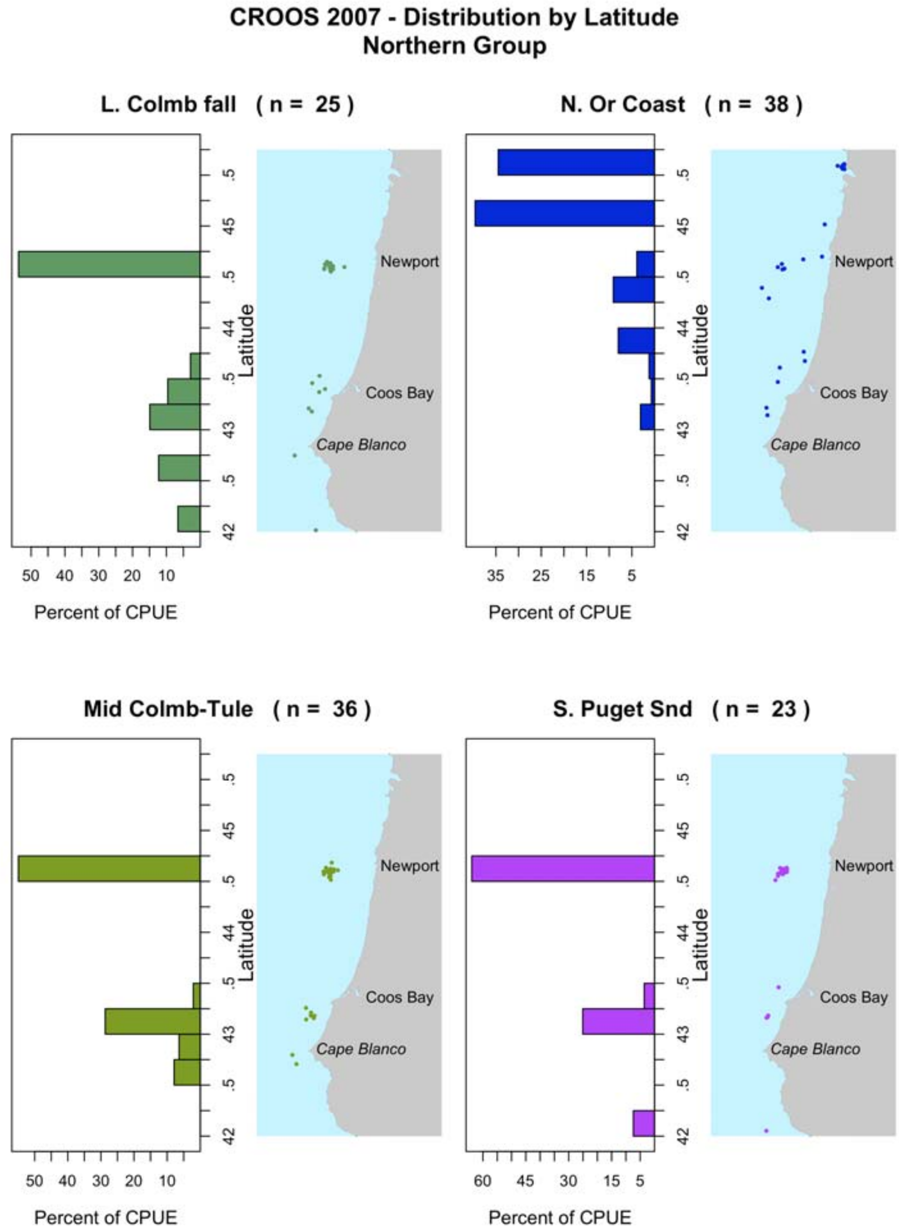


Figure 20. Chinook stocks from 2007 that displayed a coastal range with CPUE values highest in the north. The N. Oregon coast stock was the most dissimilar of the group and exhibited the most northern distribution pattern.

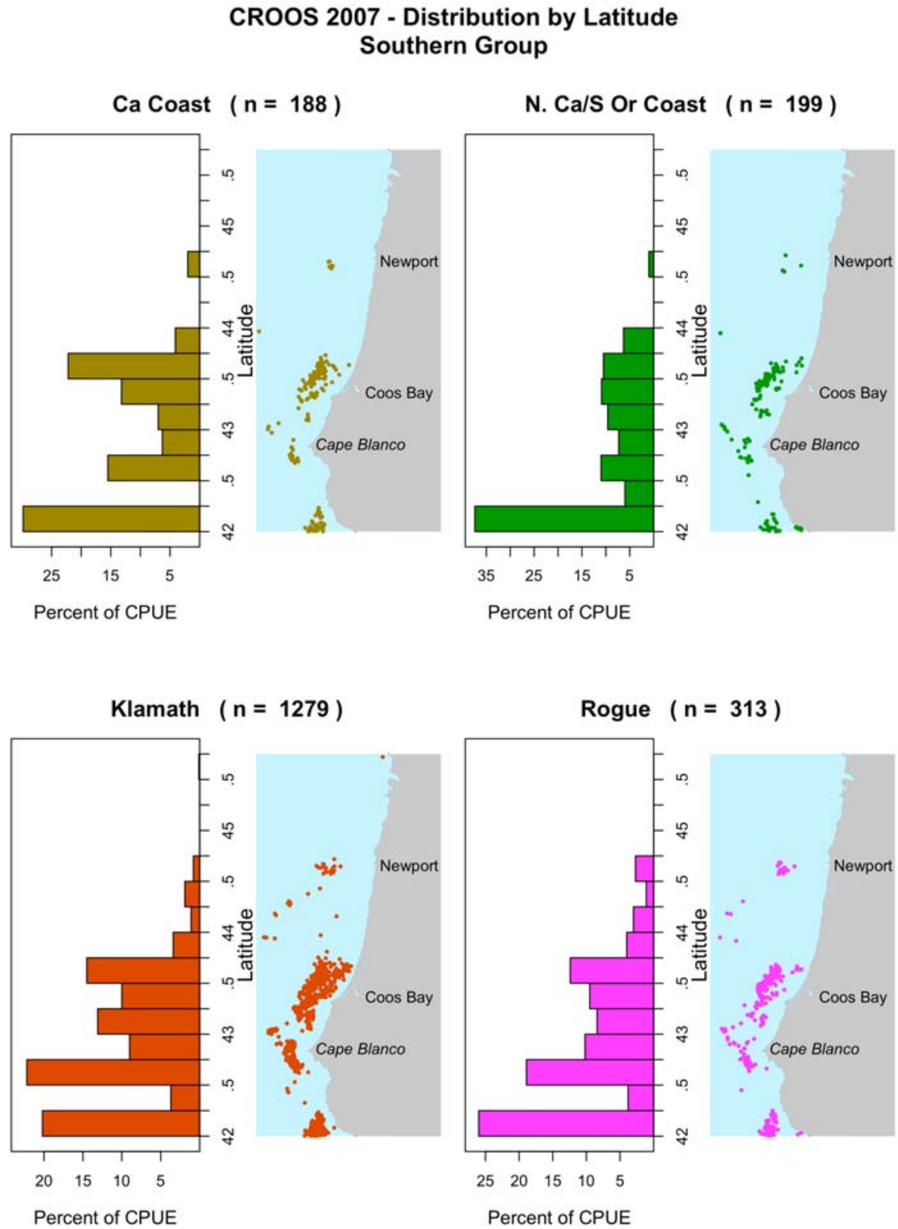


Figure 21. Chinook stocks from 2007 that displayed a coastal range with CPUE observed to be highest along the southern coast of Oregon. Peak CPUE was observed south of Cape Blanco for these stocks.

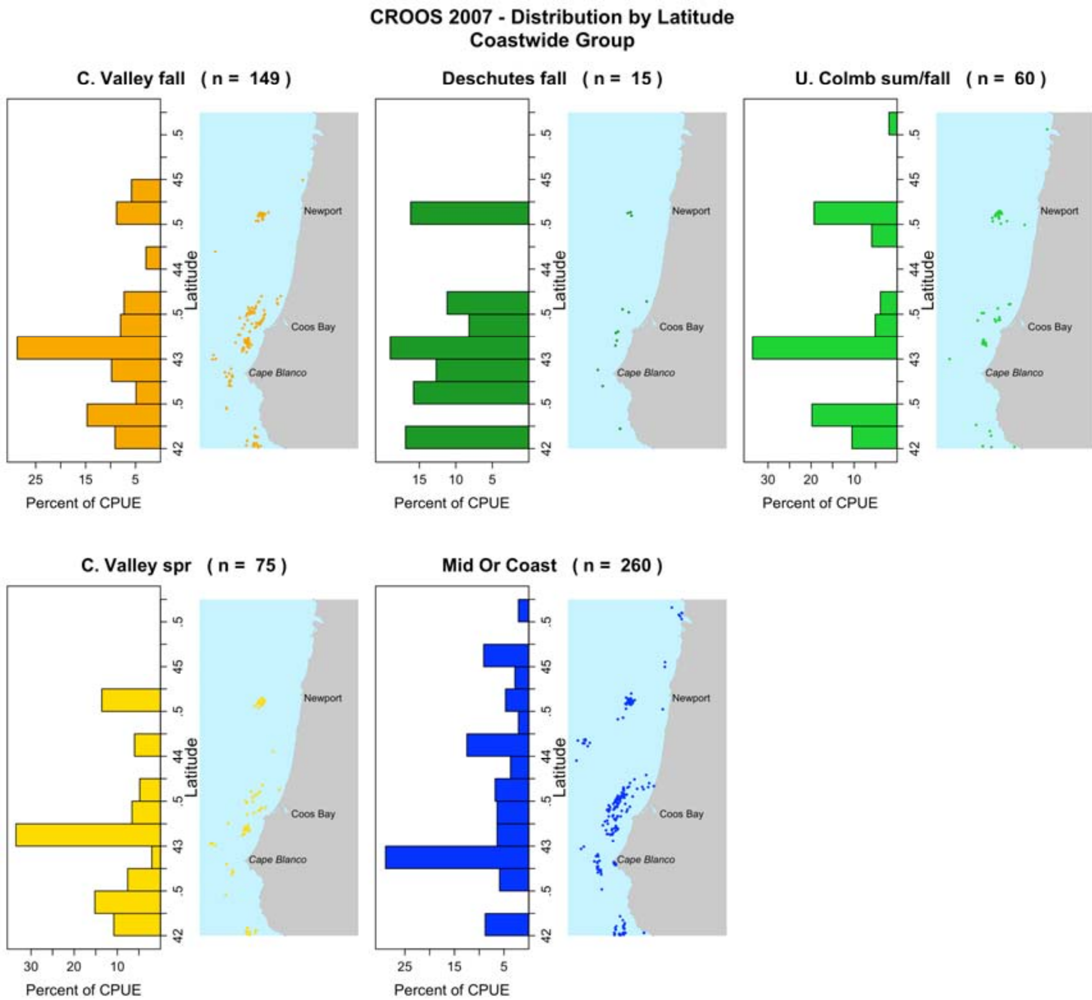


Figure 22. Chinook stocks from the 2007 season that were widely distributed north to south. Peak CPUE values were generally found north of Cape Blanco.

Cluster analysis performed on a matrix of the 13 most abundant stocks (Table 2) and corresponding CPUE percentages by latitude bin provided a tree dendrogram with a meaningful cutoff that yielded 3 groups with 3 additional stand-alone stocks (Figure 23). While the dedrogram placed Deschutes River Fall, Mid Oregon Coast and North Oregon Coast stocks in the same group with Rogue River Chinook, the selected tree cut isolated these three stocks as orphan, single-stock cluster groups. The cut point maximized the homogeneity of the stocks that clustered most strongly. Results of the cluster analysis gave a value for percent chaining of 4.88%, well below the 25% value considered extreme. Low values for percent chaining indicate that cluster groups are relatively distinct.

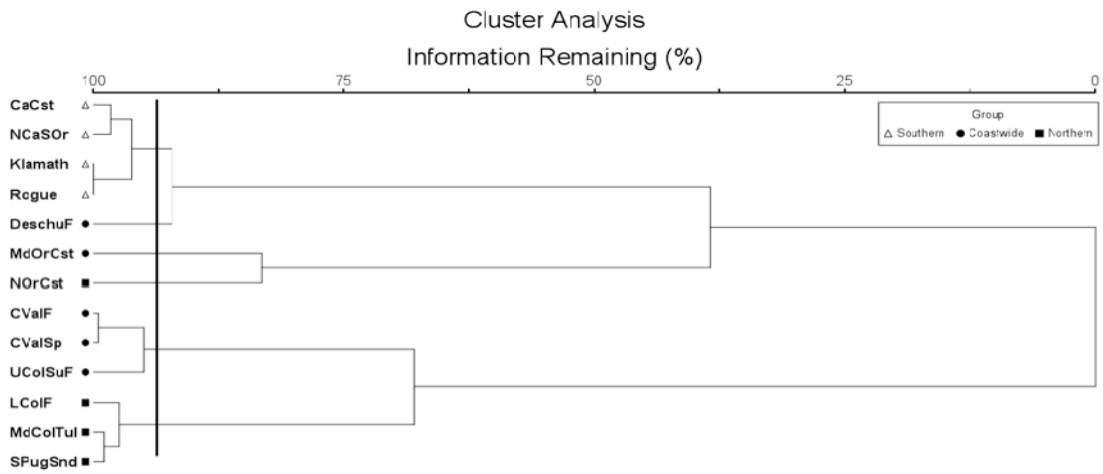


Figure 23. Dendrogram of important Oregon stocks obtained from an agglomerative cluster analysis of CPUE percentage across 15 separate latitude bins. Vertical bar cuts the dendrogram into 6 cluster groups, 3 of the cluster groups contain a single stock.

Orphaned stock units were assigned to a group by performing an additional test. The mean latitude of capture for each stock was calculated. A one-way ANOVA rejected the null hypothesis of equal means F=51.47, p< $2.2e^{-16}$. With a pairwise t-test, the mean latitude of each stock was individually compared to all other stocks (Table 5). Comparisons that yielded a p-value greater than 0.05 could not reject equal means, however, p-values approaching 1 were considered an indication of nearly identical mean latitudes. Orphan stocks were placed with the group that compared most favorably (highest p-values) to the individual group members. This best-fit approach resolved cases in which a stock could theoretically be assigned to two separate groups. For example, results of the pairwise t-test to compare the mean latitude of Deschutes River Chinook to all other stocks failed to reject equal means for 3 of the 4 southern stocks, Rogue River stock (p=.42), Klamath River (p=.43) and California Coast (p=.89). However, the comparison to the remaining southern stock, N.Cal / S. Ore, rejected an equal mean (p=.04). Furthermore, comparison of the Deschutes stock to the members of the coast-wide group generated a p-value of 1 in all cases. See circled values in Table 5 for all comparison combinations of Mid Oregon Coast and Deschutes River stocks.

Nonmetric multidimensional scaling (NMS; Kruskal, 1964) was used as a final method to test the preferred group assignments obtained from the cluster analysis and the pairwise t-test. With the exception of the North Oregon Coast stock, it confirmed the group assignments obtained from the previous tests. Results from a 2-dimensional NMS transposed solution generated a cumulative R-square value of 0.87 for the correlation between the ordination distance and the original distance. Synthetic axes 1 and 2 explained 65% and 22% of the correlation respectively (stress=6.6). Three distinct groups were noted on the ordination (Figure 24) that corresponded to the a-priori group selections. The southern group and the northern group clustered strongly, while the coastwide group showed more variation. The North Oregon Coast stock did not cluster with any of the other groupings. Table 6 shows the members of each distribution group. Although the North Oregon Coast Chinook did not appear statistically similar to other stocks, they were assigned to the northern group based on the high CPUE values found in the northern-most latitude bins.

Table 5. Pairwise t-test that compared the mean latitude of abundant 2007 stocks based on point of capture. The test used a Holm-Bonferonni correction for multiple comparisons. Stock comparisons that yielded a p-value approaching 1 were considered to be the most similar with regards to mean latitude. Large p-values in bold represent group comparisons where the null hypothesis of equal means could not be rejected. Values in bold italics cannot reject equal means, but stock was placed in a better fitting group (with a larger p-value). Values in italics were marginally significant, but equal means were rejected and the stock was placed in a better fitting group. The p-values circled in red show the results for comparison of Deschutes and Mid Oregon Coast stocks to other stocks in the coastwide group. The mean latitude for the North Oregon Coast stock rejects the hypothesis of equal means for all stock comparisons.

	California_Coast	Central_Valley_fa_fsp	Central_Valley_Sp	Deschutes_R._fa	Klamath_R.	L_Columbia_R.fa	Mid_Columbia_R._tule	Mid_Oregon_Coast	N_California.S_Oregon_Coast	N_Oregon_Coast	Rogue_R.	S_Puget_Sound
Central_Valley_fa_fsp	0.007											
Central_Valley_Sp	0.003	**1**										
Deschutes_R._fa	***0.891***	**1**	**1**									
Klamath_R.	**1**	<0.001	<0.001	***0.428***								
L_Columbia_R.fa	<0.001	<0.001	0.003	*0.078*	<0.001							
Mid_Columbia_R._tule	<0.001	<0.001	<0.001	0.012	<0.001	**1**						
Mid_Oregon_Coast	0.018	**1**	**1**	**1**	<0.001	<0.001	<0.001					
N_California/S_Oregon_Coast	0.022	<0.001	<0.001	0.036	0.013	<0.001	<0.001	<0.001				
N_Oregon_Coast	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Rogue_R.	**1**	<0.001	<0.001	***0.423***	**1**	<0.001	<0.001	<0.001	**0.11**	<0.001		
S_Puget_Sound	<0.001	<0.001	<0.001	0.017	<0.001	**1**	**1**	<0.001	<0.001	0.001	<0.001	
U_ColumbiaR._su/fa	<0.001	**0.078**	**0.983**	**1**	<0.001	***0.211***	0.013	0.007	<0.001	<0.001	<0.001	0.031

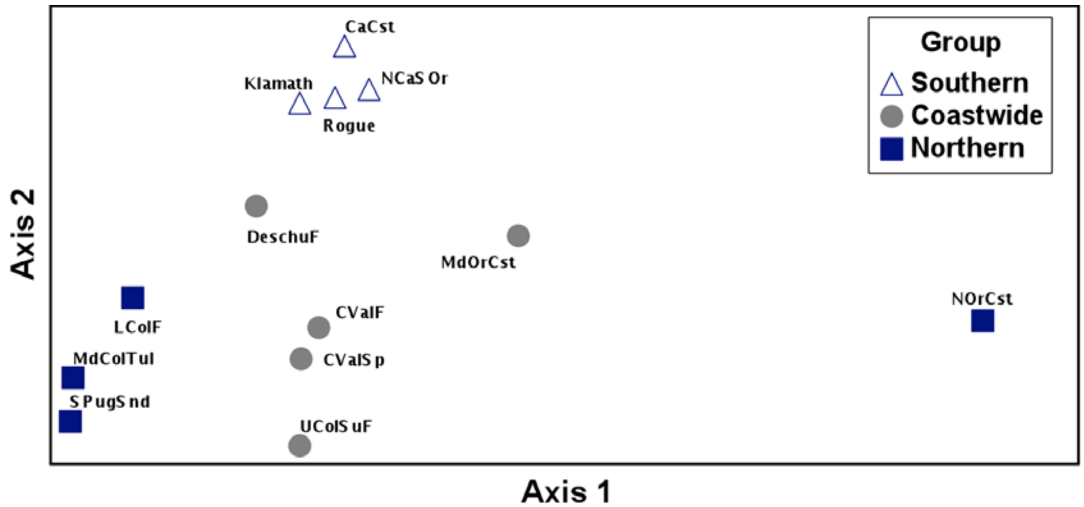


Figure 24. Two-dimensional solution for the ordination of Chinook stocks by CPUE across 15 latitudinal bins. Three distinct groups were identified that cluster stocks by a common distribution – southern stocks, northern stocks and coastwide stocks. Axes were rotated 25°.

Table 6. Three distinct patterns of coastal range were found for the most abundant stocks in the 2007 catch. The North Oregon Coast stock (*) was tentatively placed with the northern group.

Southern Group	Coastwide Group		Northern Group
Klamath River	Central Valley Fall	Deschutes River	S. Puget Sound
California Coast	Central Valley Spr	Upper Columbia	Lower Columbia
N. Cal / S. Oregon	Mid Oregon Coast		Mid Columbia Tule
Rogue River			* N. Oregon Coast

Chinook stock composition and age class structure

In 2006 and 2007, Chinook age class structure exhibited an in-season shift from a fishery take of predominantly 4-year-olds in the spring and early summer to a fishery dominated by 3-year-old salmon from mid-summer through fall. In 2006, 65% of the Chinook samples collected between June 4 and August 3 were 4-year-olds or older. Later in the season during the period from September 12 to October 31, 21% of the Chinook were age 4 or older while the percentage of 3-year-olds increased from 36% to 79% (Table 7). Commercial fishing took place in roughly the same ocean area during both periods. However, there were more Chinook taken inshore in the late season and the stock composition had also changed (Figure 25). Figure 25 also

Table 7. Age class structure of 2006 Chinook catch in early season and late season. There was no fishing during the period from August 4 to September 11.

2006	**June 4 – Aug 3**		**Sep 12 – Oct 31**	
	Total	**Percent**	**Total**	**Percent**
Catch	1386		1299	
Aged	976	70.42	1066	82.06
3-year-old	356	36.48	839	78.71
4-year-old	570	58.4	189	17.73
5-year-old	45	4.61	33	3.1
6-year-old	5	0.51	4	0.38

demonstrates a change in the overall stock composition between the early and late season. Chinook from the Central Valley were the major contributor to both the early and late season. The early season catch, however, was composed of a more diverse stock mixture. Also, the late season saw an increase in Chinook stocks that originated from the streams of northern California and southern Oregon. While there was a decided shift in age structure between early and late season, it was not a trend common to all Chinook stocks. Figure 26 compares the age structure of 4 stocks that were reasonably abundant in both the early and late season catch. The shift from predominantly 4-year-olds in the early season to 3-year-olds in the late season was a noteworthy trend for both Central Valley Fall Chinook and Klamath River Chinook. The Oregon stocks from the Mid Oregon Coast and the Rogue River did not decidedly shift from older to younger fish as the season progressed.

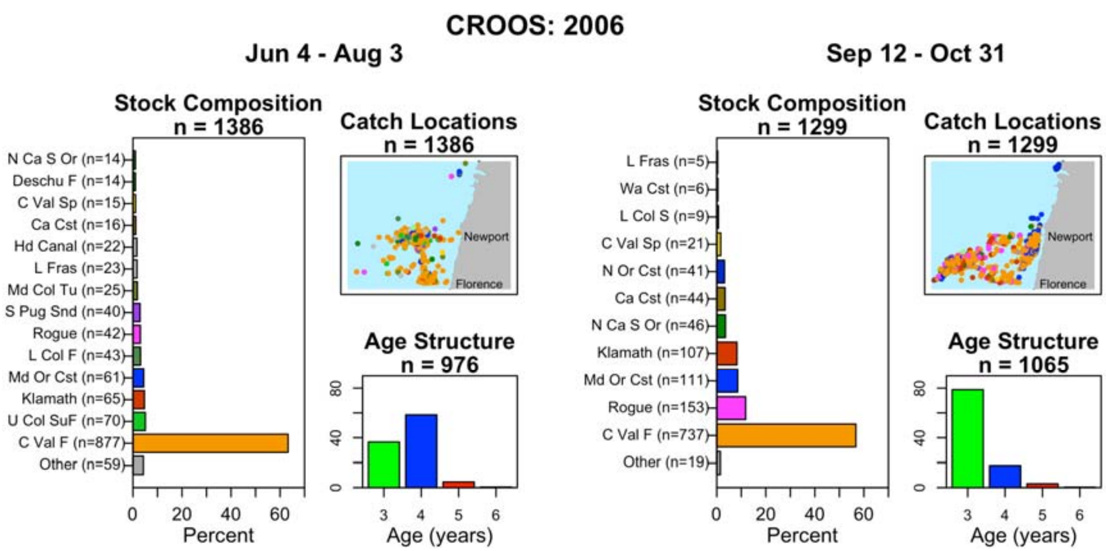


Figure 25. Stock composition, age structure and catch location of the early season and late season 2006 fishery. Age class 4 accounted for approximately 60% of the early season catch. By late season, the contribution of 4-year-olds fell to approximately 20% of the total catch while 3-year-olds accounted for more than 75%.

Many older salmon will have begun the final phase of their spawning migration by September, thus affecting the relative contributions of older age classes. However, the significant catch increases of 3-year-olds combined with the concurrent decline of 4-year-olds suggest an influx of 3-year-old salmon. Percent declines in the catch of 5 and 6-year-olds were not as large as decline of 4-year-olds (Table 7) – further supporting an influx of 3-year-olds. Effort data was not available to directly compare the abundance of age-class groups between the early and late season. Also, the commercial Chinook season was closed from August 4 through September 16. It was therefore not possible to more accurately identify a transition period in 2006 for the observed shift in age-class structure.

In 2007, the commercial fishing effort was more evenly distributed coastwide. However, stock composition of the total catch again showed an in-season change similar to that observed in 2006 (Figure 27). In 2007, it was again noted that Chinook salmon from the Columbia River and northward become rare in the Oregon catch as the season progressed. As in 2006, a shift of the age-class structure to younger fish was observed in 2007 (Table 8). However, in 2007, both the increased percentage of 3-year-olds and the decreased percentage of 4-year-olds were slightly less pronounced compared to 2006. Chinook of age 4 and older made up 64% of the catch during the period from May 1 to July 17. In comparison, the catch of Chinook age 4 and older dropped to 38% while the percentage of 3-year-olds increased from 36% to 62% during the mid-season period from July 18 to September 14. The summer

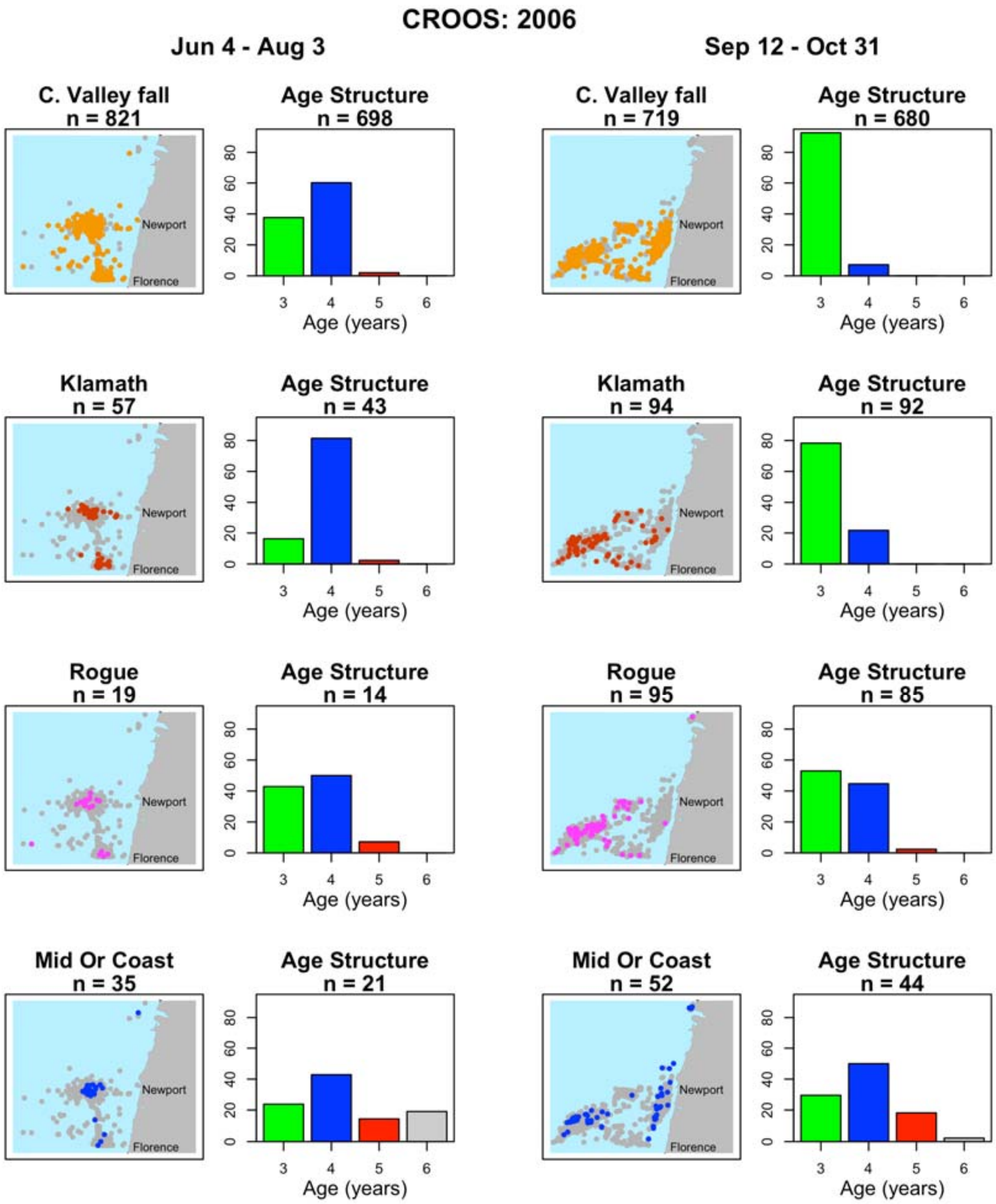


Figure 26. Stock composition, age structure and catch location of the early and late season 2006 fishery. By late in the season, Chinook from the Central Valley, Klamath River and California Coast all displayed a shift toward 3-year-old fish. The Rogue River and Mid Oregon Coast stocks appeared to maintain roughly the same age structure in both early and late season.

Table 8. Age class structure of the Chinook catch in three separate time periods during the 2007 season including catch per unit effort. CPUE values are in fish per hour.

2007	May 1 – July 17			July 18 – Sept 14			Sept 20 – Nov 20		
	Total	**Percent**	**CPUE**	**Total**	**Percent**	**CPUE**	**Total**	**Percent**	**CPUE**
Catch	982			2502			230		
Aged	599	61		1787	71.42		142	61.74	
3-yr-old	213	35.56	0.13	1115	62.4	0.32	43	30.28	0.04
4-yr-old	299	49.92	0.18	583	32.62	0.17	52	36.62	0.05
5-yr-old	84	14.02	0.05	83	4.64	0.02	40	28.17	0.04
6-yr-old	2	0.33	0.001	5	0.28	0.001	7	4.93	0.01

transition to a higher percentage of younger fish began in mid July. Late in the 2007 season, the Chinook catch reverted back to an age class structure that was more heavily weighted to older fish. From September 20 to November 20, Chinook age 4 and older accounted for 70% of the Chinook catch. While many stocks showed a slight trend toward younger fish from early to mid season, the change in age structure appeared to have been largely influenced by Klamath River Chinook in 2007 (Figure 28).

Much of the catch during the late period occurred near the mouth of rivers in both northern and southern Oregon (see right panel, Figure 27). Intercepting Chinook near the entry to their home streams could skew the observed age structure of the overall catch toward older, sexually maturing salmon. Many of the southern stocks that were present during the early periods were no longer abundant in the late season catch. Particularly noteworthy, the Klamath River stock that was a major contributor during the early and mid-season made up less than 10% of the late season catch. Klamath River fish largely influenced the overall age-class structure of the earlier periods. Table 8 showed a relatively constant CPUE for 4-year-olds in early and mid-season, while the CPUE for 3-year-olds nearly tripled from early to mid-season indicating a possible in-migration of younger fish as a group.

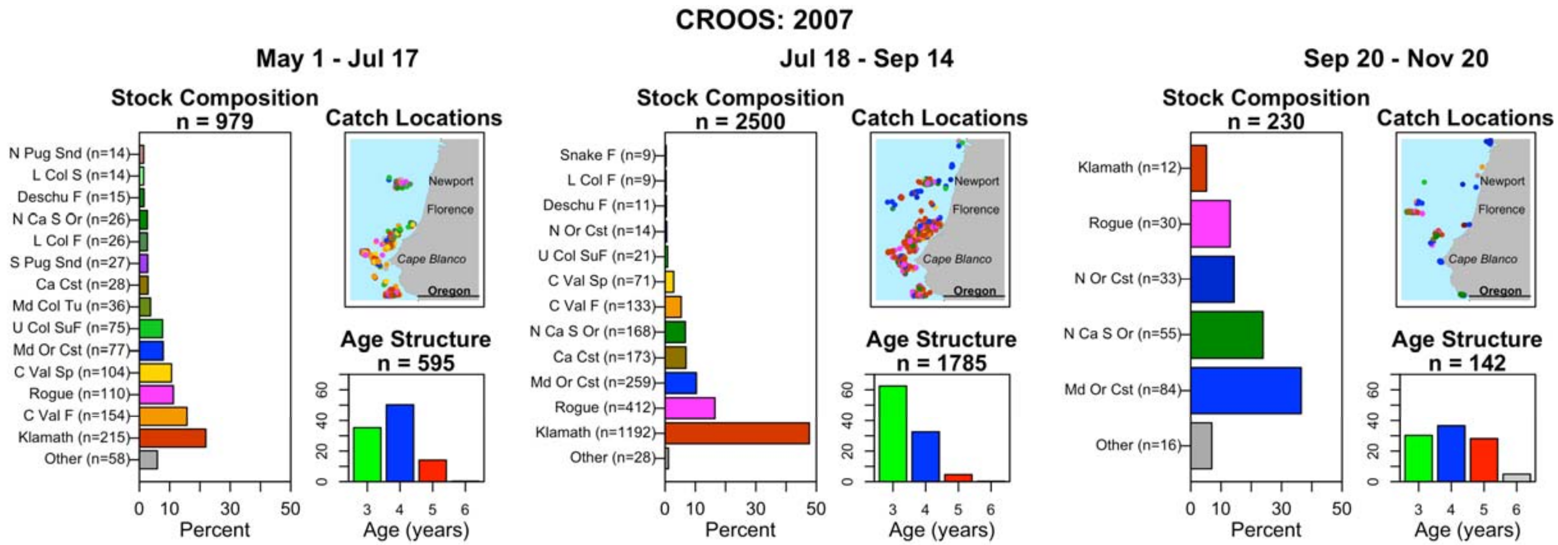


Figure 27. Stock composition, age structure and catch location of the early, mid and late season 2007 fishery. The mid season fishery indicated a shift to younger fish. Age class 4 accounted for more than 50% of the catch in the early season, but dropped to approximately 30% in the mid season. Age class 3 increased from approximately 30% to 60% from early to mid season. The late season catch showed a shift to older fish compared to the mid season age structure.

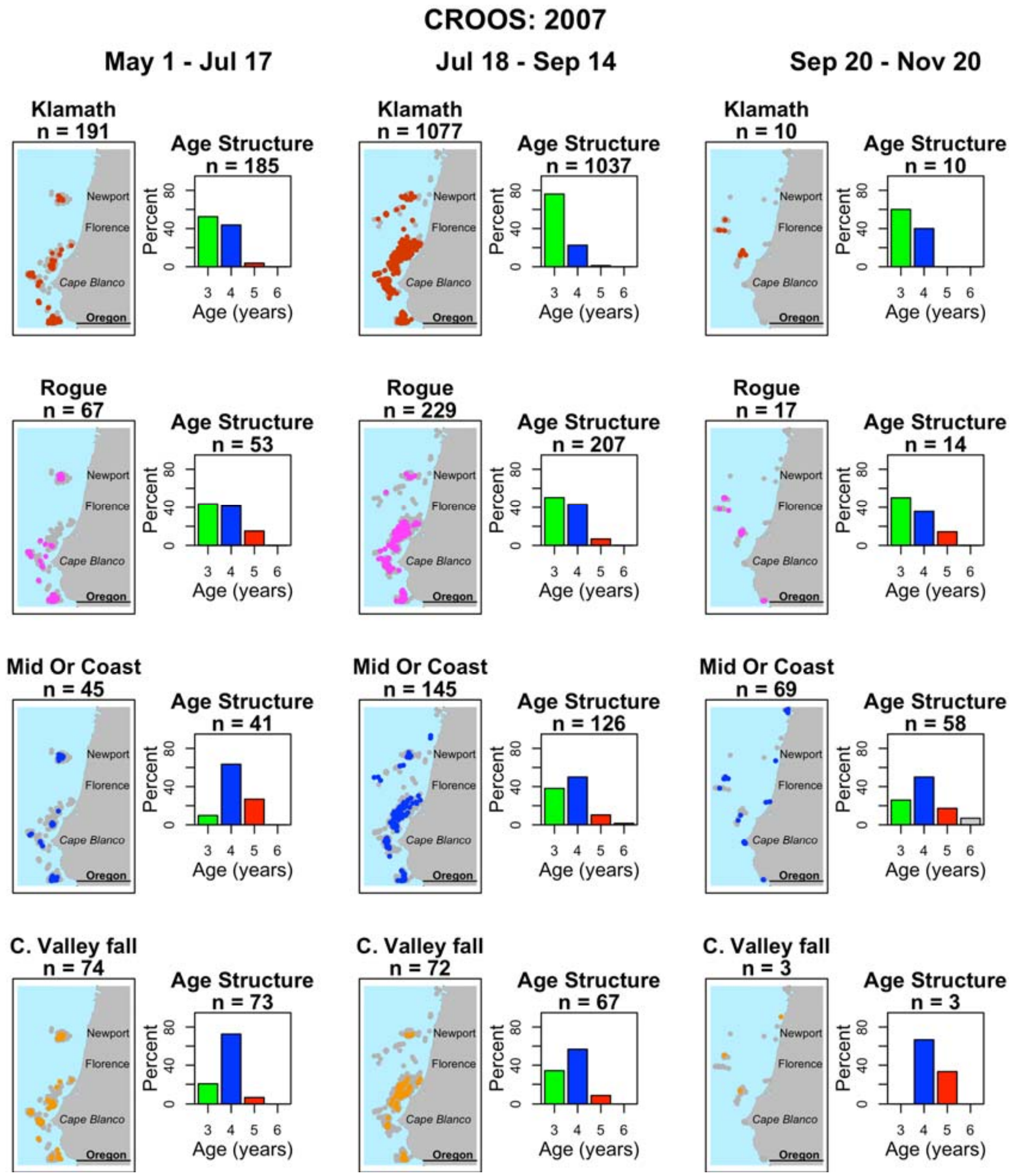


Figure 28 Stock composition, age structure and catch locations for the early, mid and late season 2007 fishery. Klamath River Chinook showed a decided shift to 3-year-old fish in the mid season. The Rogue River and Mid Oregon Coast stocks became younger, but roughly maintained the same age structure in both early and late season. Central Valley fall Chinook also showed a moderate shift to younger fish in the mid season; the late season catch was too low for a reliable age-class estimate.

A closer consideration of Stock Composition at finer temporal scales

Analysis of stock compositions during the 2006 and 2007 Chinook season demonstrated temporal changes in the mixture of stocks that make up the commercial harvest. In particular, differences were noted between the early and late season fishery. The spatial concentration of 2006 fishing effort in the offshore area near Newport, Oregon provided a localized area to follow changes in the stock mixture through time. Six separate periods of relatively good fishing from July 9 to October 31 (summarized in Table 9) demonstrated that Central Valley Chinook were consistently the dominant contributor to the catch. They contributed a minimum of 51% percent in each period and frequently contributed 60% to 70%. Other stocks show higher variability during the season.

Table 9. Stock mixture percentage of major contributors to the 2006 Chinook fishery during 6 periods of high catch. Dates for the periods are: 1) July 9-18; 2) July 23-25; 3) Aug 1-4; 4) Sep 17-21; 5) Sep 25-26; 6) Oct 26-31

Stock Name	**1**	**2**	**3**	**4**	**5**	**6**
Central Valley Fall / Fea Spr	60.8	65.3	70.7	51.3	70.3	51.8
California Coast	1.2	0.8	2.2	5.6	1.1	2.9
Klamath	4.2	6.9	4.4	11	4.7	9.6
Northern CA / Southern OR	0.7	1.5	1.7	6	1.9	2.1
Rogue	3.5	2.3	1.7	13.7	4.1	16.4
Mid Oregon Coast	4.9	5.3	4.4	8.3	8.8	8.9
North Oregon Coast	0	0.4	0	1	5.2	1.4
Lower Columbia R. (Fall)	4.5	1.1	2.2	0.4	0	0
Mid Columbia-Tule	1.7	0.8	2.2	0	0.3	0
Upper Columbia (sum/Fall)	4.3	4.2	3.5	0.4	0	0.7

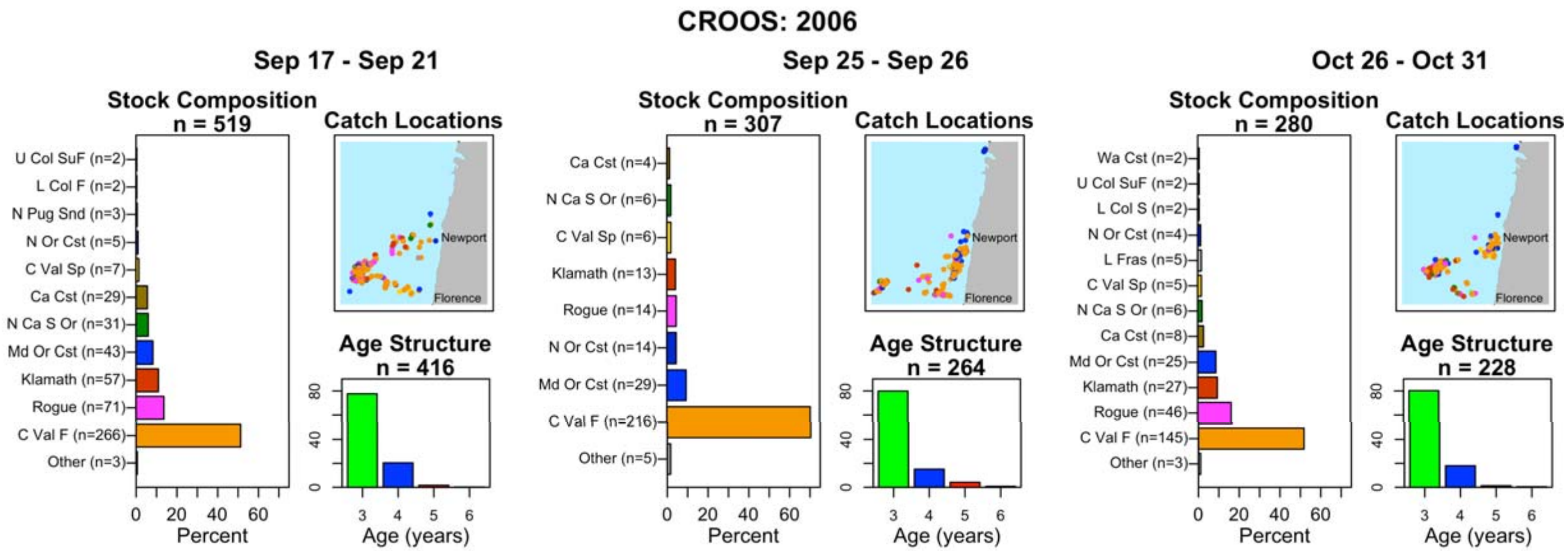


Figure 29. 2006 stock mixture, catch locations and age structure for Period 4 (left), 5 (middle), and 6 (right). A majority of the catch during Period 4 took place well offshore. In Period 5, much of the catch occurred inshore, while in Period 6 a large portion of the catch was again offshore. Stocks from the Southern group, most notably the Rogue River and Klamath River, decreased sharply in Period 5 when the catch was concentrated nearshore. The percentage of Mid Oregon Coast Chinook was stable through periods 4, 5 and 6. North Oregon Coast Chinook peaked in period 5 when the catch was inshore. The age structure remained approximately the same in all periods.

The three largest contributors from the Columbia River were observed to attain their highest percentage in the stock mixture during the July 9-18 period. By period 4 (Sep 17 – Sep 21), contributions from the Columbia River became negligible – largely in the range of 0% to 0.4%. Conversely, the stocks identified in 2007 as belonging to the Southern group generally reached a peak contribution level during period 4. Klamath River, Northern California / Southern Oregon and California Coast stocks contributed 11%, 6%, and 5.6% respectively during period 4 – in each case a seasonal high. Chinook from the Rouge River stock contributed 13.7% to period 4, but reached a maximum of 16.4% in the Oct 26-31 time period (Table 9).

Stock contributions from the southern group all decreased from period 4 to 5. Figure 29 shows that the commercial catch had shifted in-shore from period 4 to period 5 with a concomitant change in the stock mixture. The possible effect of the inshore shift on the stock mixture cannot be separated from any stock mixture variation that was a result of the temporal change. However, by period 6 (Oct 26-31), the catch was again predominantly located offshore similar to the observed catch locations in Period 4. Concurrent with the return to an offshore catch, the stock mixture returned to more closely resemble that observed in Period 4. The percent contribution of Mid Oregon Coast Chinook remained stable over Periods 4, 5 and 6. The North Oregon Coast stock reached its peak contribution percentage during period 5. In Period 6 from October 26 to October 31, the southern group was once again observed at relatively high contribution levels in the stock mixture. Rogue River Chinook reached their 2006 season maximum at 16.8% of the total catch. Klamath

River Chinook contributed 9.6%. The observed catch locations for salmon during period 6 were no longer concentrated in the near shore areas as they had been during period 5.

Overall, the age structure of the combined catch showed little or no change in periods 4 through 6. There was a noteworthy tendency, however, for Chinook from the small coastal streams of the North Oregon Coast and the Mid Oregon Coast to consistently exhibit an age structure composed predominantly of Chinook age 4 and older (see Table 1). North Oregon Coast Chinook salmon were consistently the oldest stock – only 4 of the 48 age-estimated North Oregon Coast Chinook were determined to be 3-year-olds over the two-year study.

The 2007 decline of Central Valley Chinook Fall Chinook

Central Valley Fall Chinook harvested in the Oregon fishery showed a dramatic decline during the two-year study from a total catch of 1,614 in 2006 to 290 in 2007 – a reduction of 83 percent (Table 10). During that same period the catch of Central Valley spring Chinook increased from 32 to 75, a 52% gain.

Table 10. Contribution of Central Valley Fall and Central Valley Spring Chinook to the total catch for 2006 and 2007.

Stock Name	**2006**		**2007**	
	Catch	**Percent**	**Catch**	**Percent**
Central Valley Fall/Fea Spr	1614	60	290	7.8
Central Valley (Spring)	36	1.3	175	4.7

Table 11. Age class structure of 2006 and 2007 Oregon catch of Central Valley fall and Spring Chinook.

Stock Name	2006			2007		
	3 yrs	4 yrs	5 yrs	3 yrs	4 yrs	5 yrs
CV Fall	893 (65%)	469 (34%)	15 (1%)	38 (27%)	93 (65%)	12 (8%)
CV Spr	18 (82%)	3 (14 %)	0 (0%)	18 (25%)	49 (68%)	5 (7%)

Analysis of scale samples indicated that the age structure of the Central Valley Chinook had also changed (Table 11). In 2006, Central Valley fall 3-year-olds made up 65 percent of the stock, 34 percent were 4-year-olds. The following year 65% of the fall run were 4-year-olds while 3-year-olds had decreased to 27 percent of the total. Central Valley Spring Chinook showed an even more striking shift to older fish from 2006 to 2007 despite the year-to-year increase in catch totals and stock contribution.

Stock specific aggregations of Oregon Chinook

The catch locations of Chinook salmon in 2007 demonstrated stock-specific patterns in the coastal range of Chinook caught on the Oregon shelf. Mixed stock analysis showed in-season changes in the relative contribution of individual stocks in a given area. There was some evidence for age-class cohesion, particularly in the most abundant stock groups. Precise catch coordinates obtained in the study allowed a detailed examination of the ocean proximity of population cohorts at spatial scales down to 10 meters. To investigate population-specific aggregations, the mean distance to the nearest neighbor was calculated and compared to mean nearest neighbor distances obtained from a 1,000 permutation Monte Carlo simulation. Six separate time periods for 2006 were investigated. Time periods were limited to 2-day or 3-day intervals to maximize sample size while also minimizing the effect of stock movement during the period. It was assumed that this tradeoff would allow for aggregations to be detected if the position of individual fish within a stock remained relatively constant over the time slice.

For the June 11 through June 13 time period, there was no evidence for stock-based aggregations (Figure 30). Upper Columbia and Lower Columbia River Chinook showed a strong signal that could indicate stock-based aggregations in the July 9 through July 11 period (Figure 31). Lower Columbia Fall continued to show evidence for a stock-based aggregation in the July 16 through July 18 catch (Figure 32). In the period from July 23 to July 25 (Figure 33), Central Valley fall and South Puget Sound Chinook appeared aggregated. See Figures 34 through 37 for additional time periods that showed evidence of stock-based aggregations.

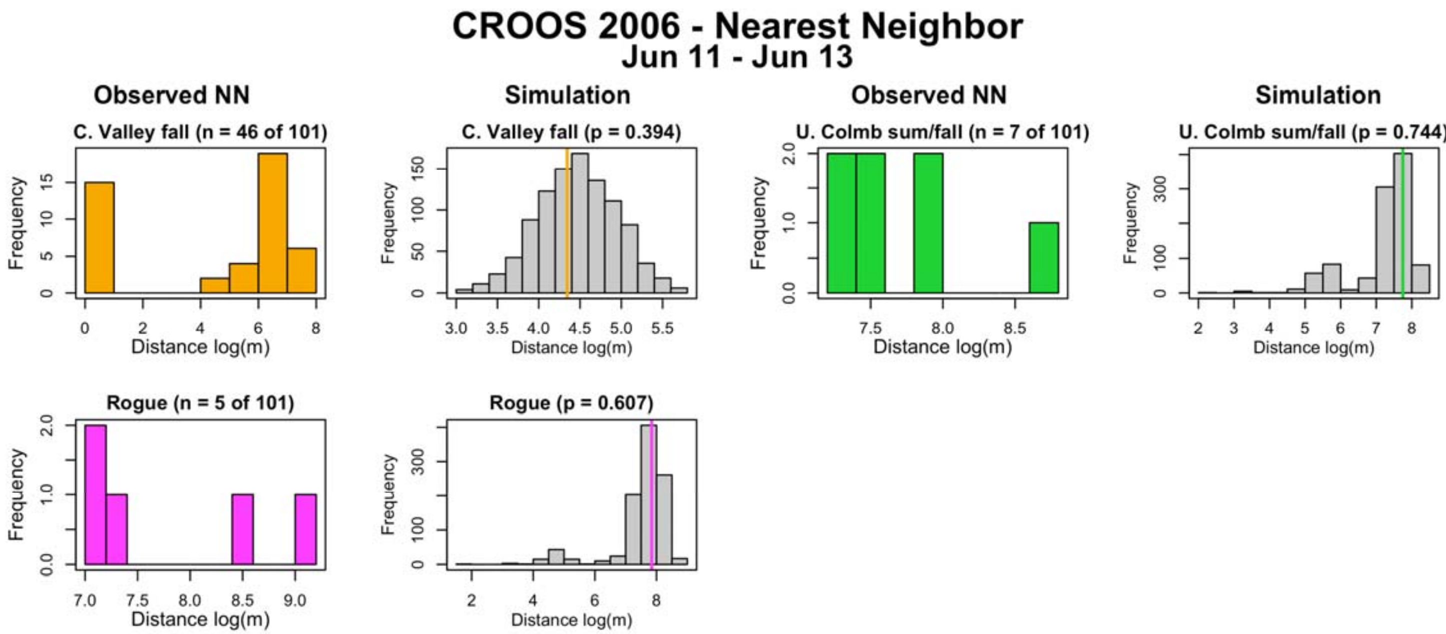


Figure 30. Observed nearest neighbor frequency histogram and the average frequency obtained from a 1,000 permutation Monte Carlo simulation. The simulation randomizes the observed catch at the fixed catch points. During the early season period from June 11 through June 13 there was no indication of cohort aggregation. The vertical bar on the simulation plots is the mean nearest neighbor distance from the observed plots. P-value is the percentage of random permutations that generated a mean nearest neighbor distance less than the observed mean.

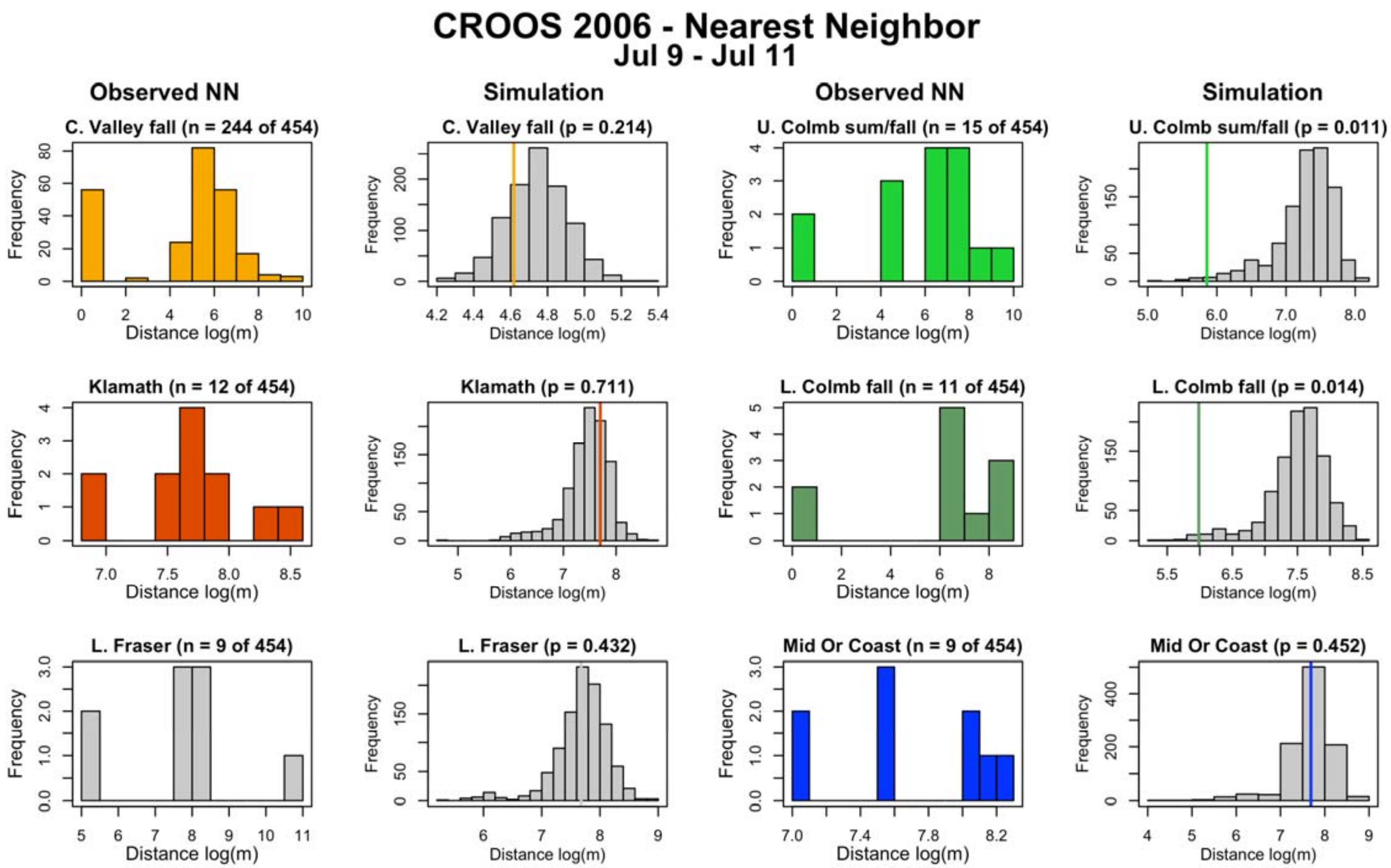


Figure 31. Mean nearest neighbor and frequency histograms for July 9 to July 11 2006. Upper Columbia sum/fall Chinook and Lower Columbia fall Chinook exhibited mean nearest neighbor distances that were closer than those obtained from a Monte Carlo simulation in a significant number of the permutations.

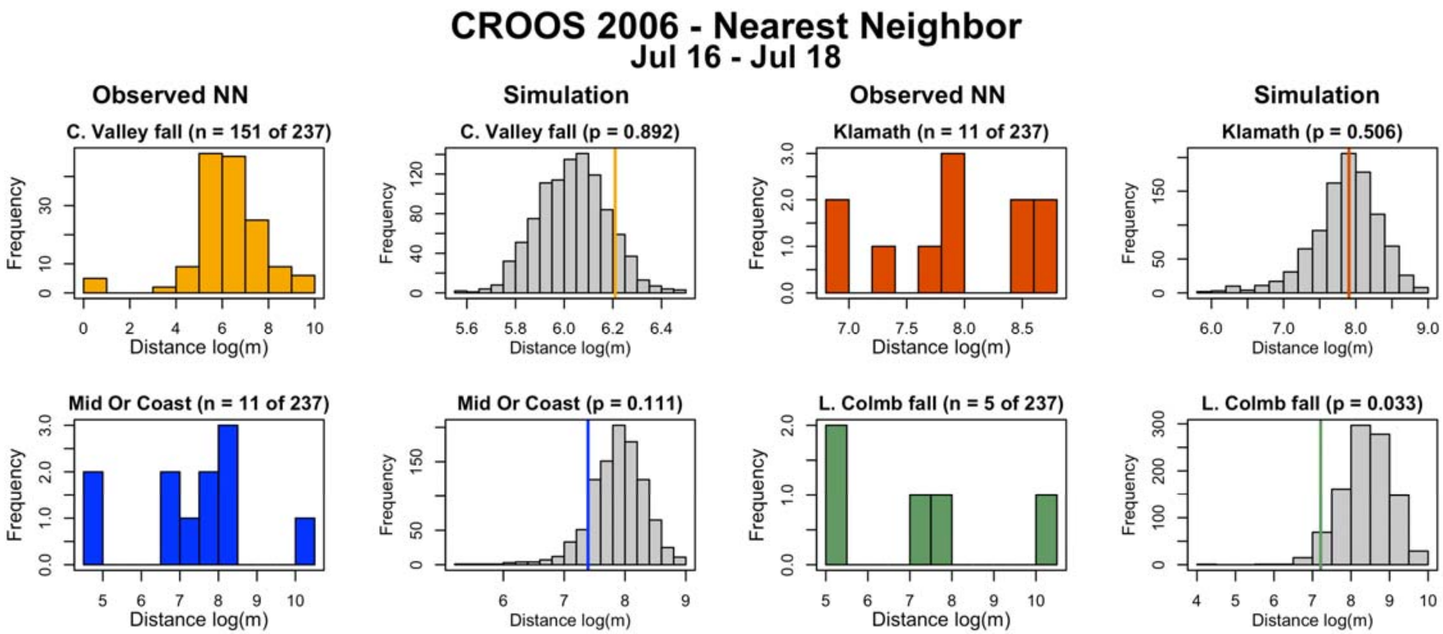


Figure 32. Mean nearest neighbor and frequency histograms for July 16 to July 18 2006. For the Lower Columbia fall stock, only 3.3% percent of the randomized simulations obtained a mean nearest neighbor distance less than the observed mean value.

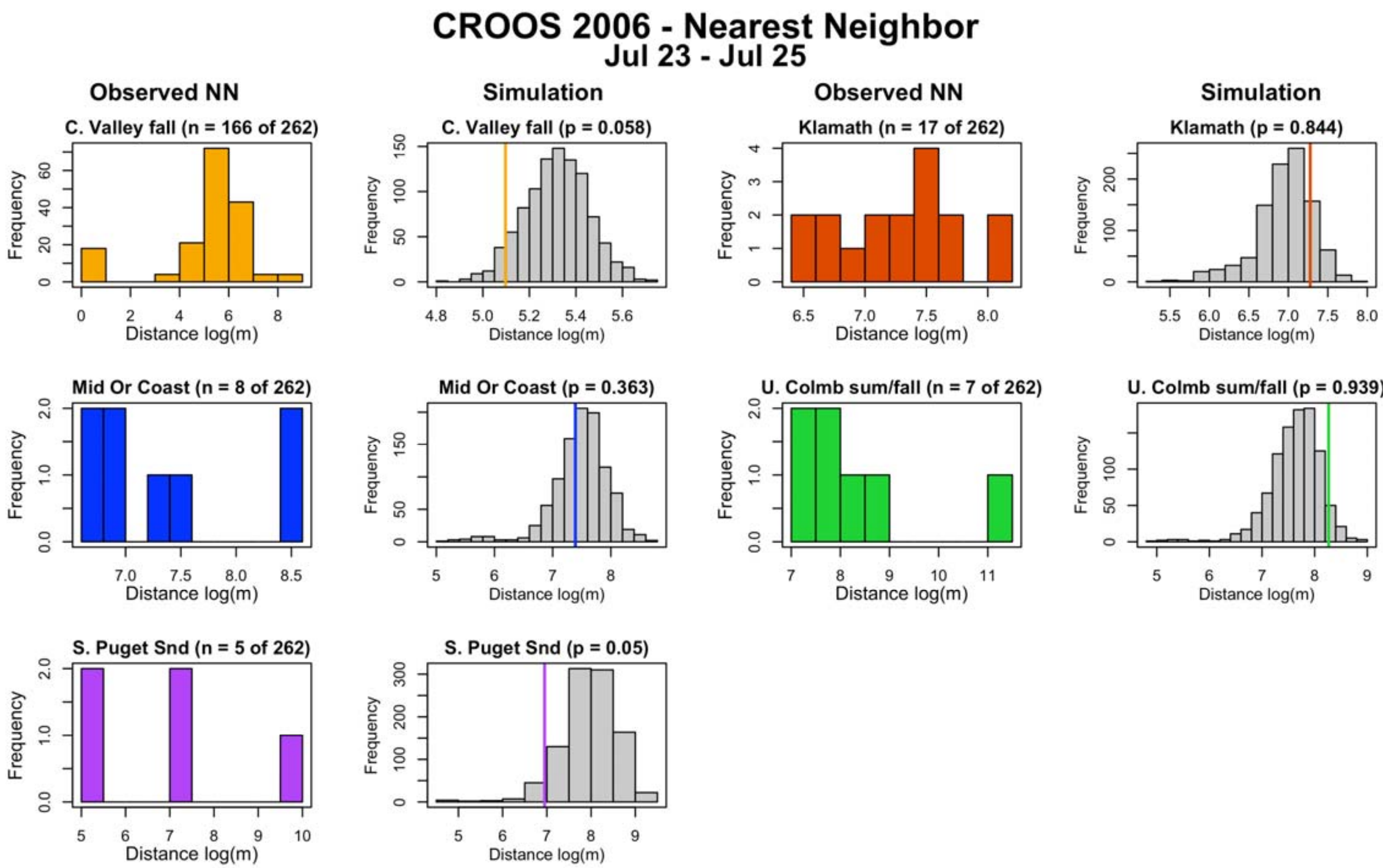


Figure 33. Mean nearest neighbor and frequency histograms for July 23 to July 25, 2006. Evidence for stock-based aggregations were observed for Central Valley fall chinook and the South Puget Sound stock.

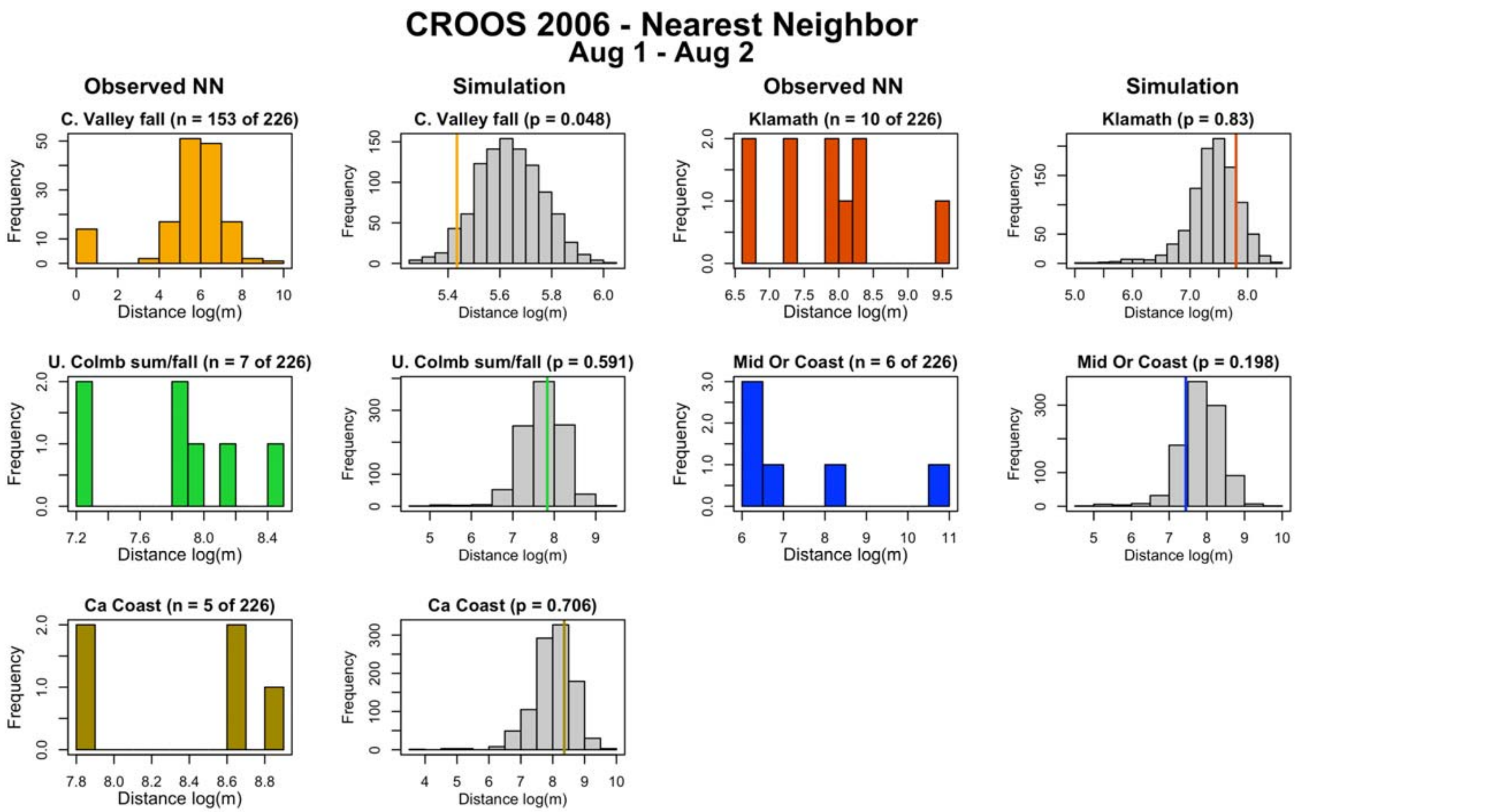


Figure 34. Mean nearest neighbor and frequency histograms for Aug 1 to Aug 2, 2006. Evidence for a stock-based aggregation was observed for Central Valley fall Chinook during the period.

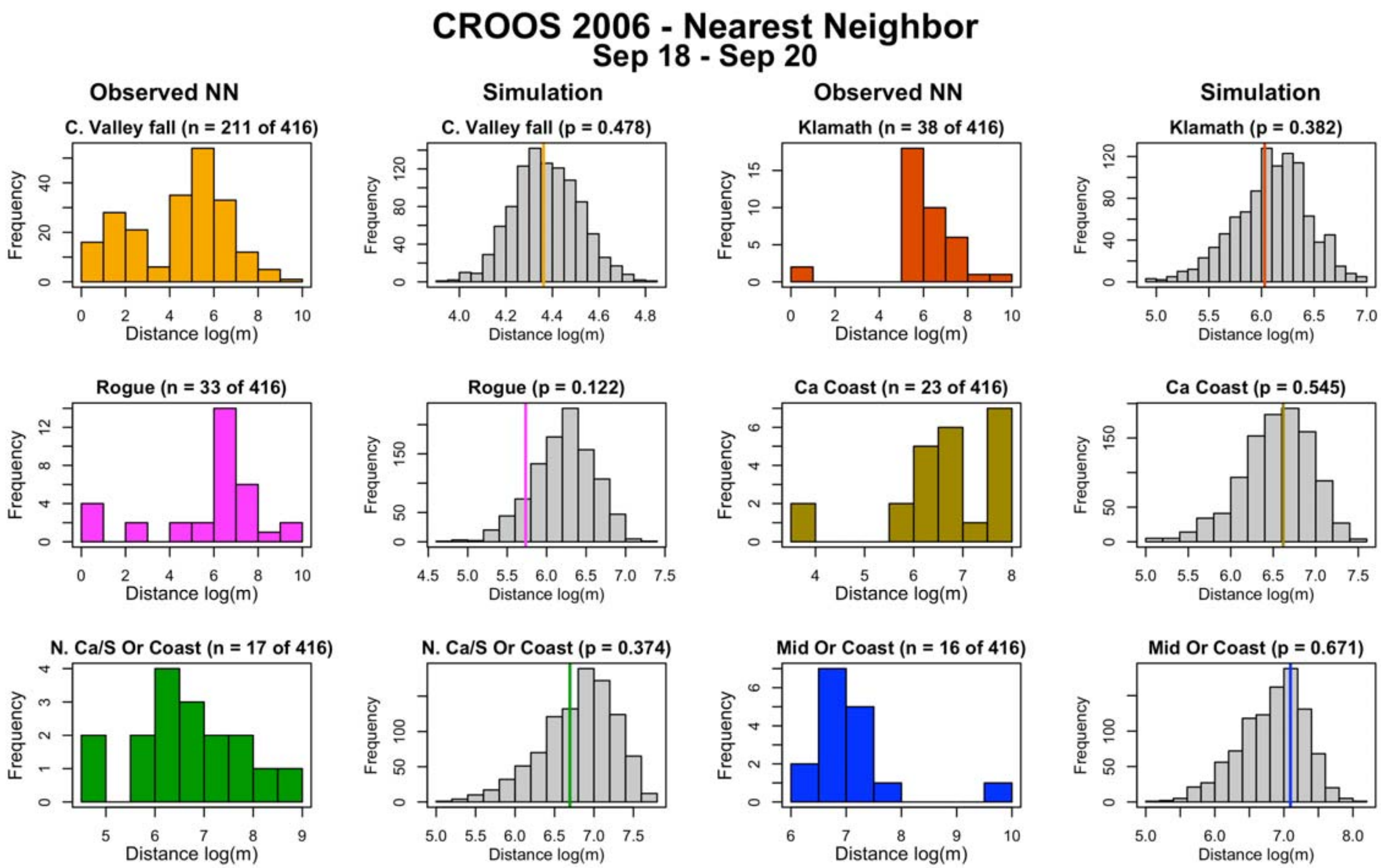


Figure 35. Mean nearest neighbor and frequency histograms for September 18 to September 20, 2006. Rogue River Chinook displayed some evidence for stock-based aggregation during the period.

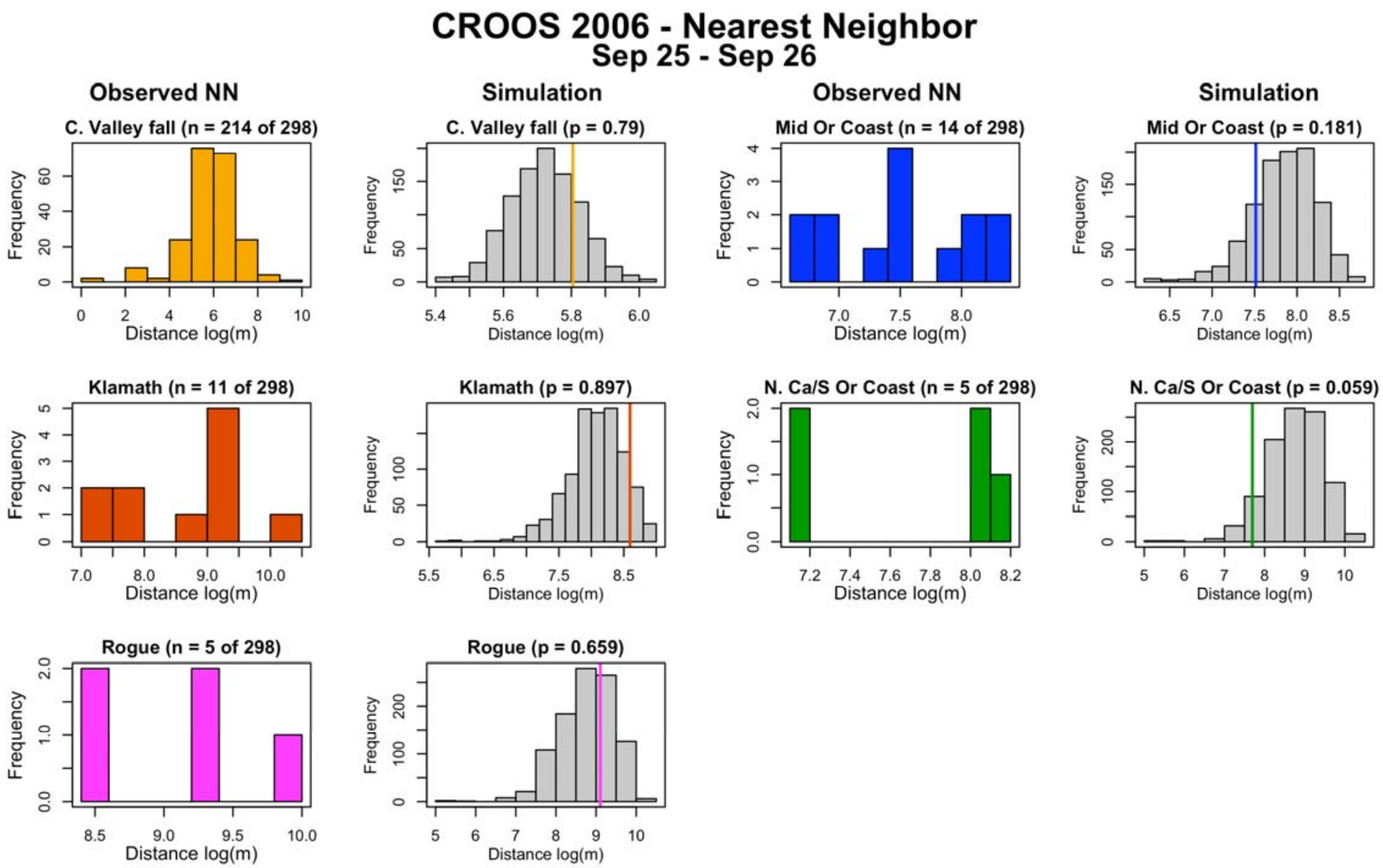


Figure 36. Mean nearest neighbor and frequency histograms for September 25 to September 26, 2006. There was some evidence for a stock-based aggregation of the N. Cal / S. Oregon stock. None of the other stocks showed any evidence for aggregation.

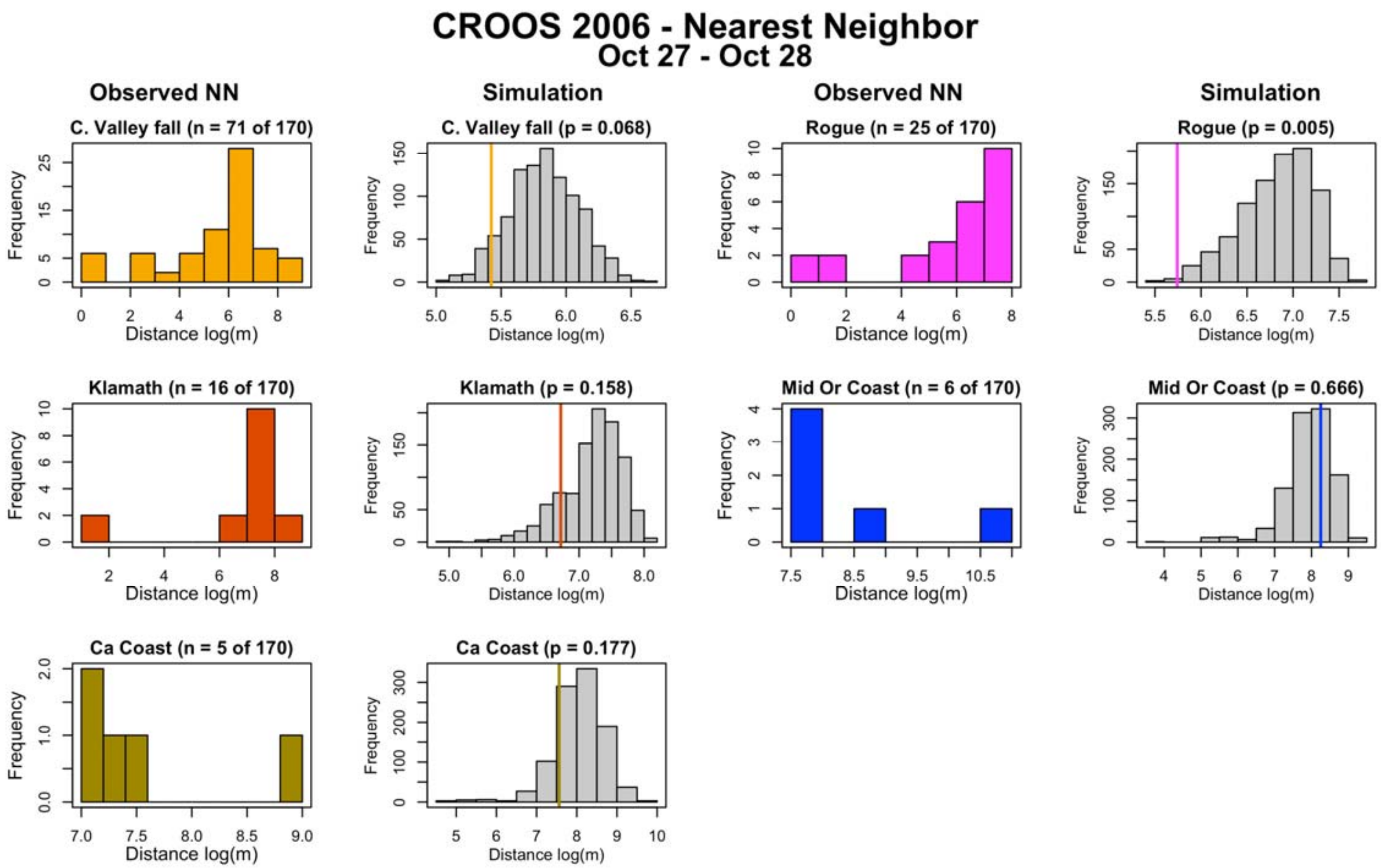


Figure 37. Mean nearest neighbor and frequency histograms for October 27 to October 28 2006. The catch of Rogue River Chinook indicated a stock-based aggregation. Central Valley fall Chinook also exhibited a reasonably high degree of aggregation. Klamath River and California Coast Chinook appear somewhat aggregated. Mid Oregon Coast Chinook showed no evidence for a stock-based aggregation.

Nearest neighbor (NN) frequency histograms suggested that Chinook were intermittently found in stock-specific aggregations. However, averaging the sum of nearest neighbor distances then comparing to a Monte Carlo simulation did not reveal the scale at which these aggregations occur. Additionally, averaging the nearest neighbor distance could have a tendency to average-out smaller aggregations that were present within a subset of the population. Cumulative distributions (CD) of the nearest neighbor distance were used to investigate the same time periods used for the mean NN frequency plots. NN cumulative distribution plots required a larger sample size than the mean NN plots for a meaningful assessment of aggregations, therefore the June 11 – June 13 time period was not analyzed using CD plots. Furthermore, only the most abundant stocks were analyzed during each time period. Cumulative distribution results (Figures 38-44) were generally in agreement with those obtained with mean NN distances. However, the CD test revealed evidence for stock-based aggregation not detected with mean NN distances. Mean NN distances did not show a strong signal indicating that Central Valley fall Chinook were spatially more proximate than expected from July 9-11(Figure 31). Conversely, the CD plot for that same period detected some evidence of stock-based aggregation below 500 meters (Figure 38). In addition, Klamath River Chinook did not appear to be spatially aggregated during the Sep 18-20 period based on mean NN results (Figure 35). However, Klamath River Chinook appeared significantly aggregated during that same period based on CD results (Figure 42). These 2 cases of dissimilar results provided an indication that the calculated p-value from the Monte Carlo simulation of the NN frequency histograms can obscure potential aggregations. Calculated p-values should be treated as an indicator of the degree of aggregation, not as a statistical cutoff. Repeated runs of a simulation, while they yielded similar results, were not precisely reproducible. Each run can produce a slightly different p-value depending on the set of randomizations generated.

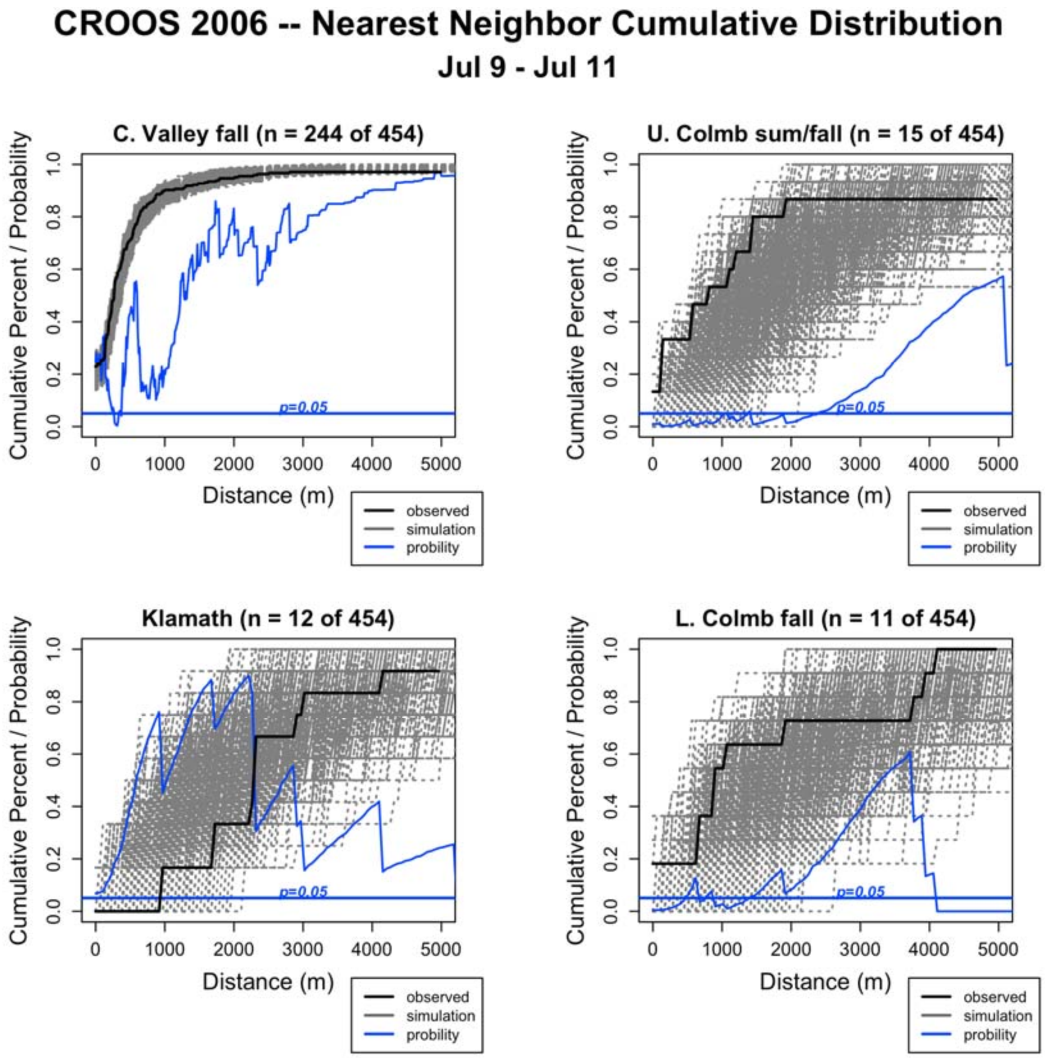


Figure 38. Cumulative distribution of stocks for the 3-day period of July 9-11. Upper Columbia and Lower Columbia Chinook were substantially more aggregated than the random simulations. Klamath River Chinook did not appear to be aggregated. The Central Valley stock showed some aggregation at distances less than 500m.

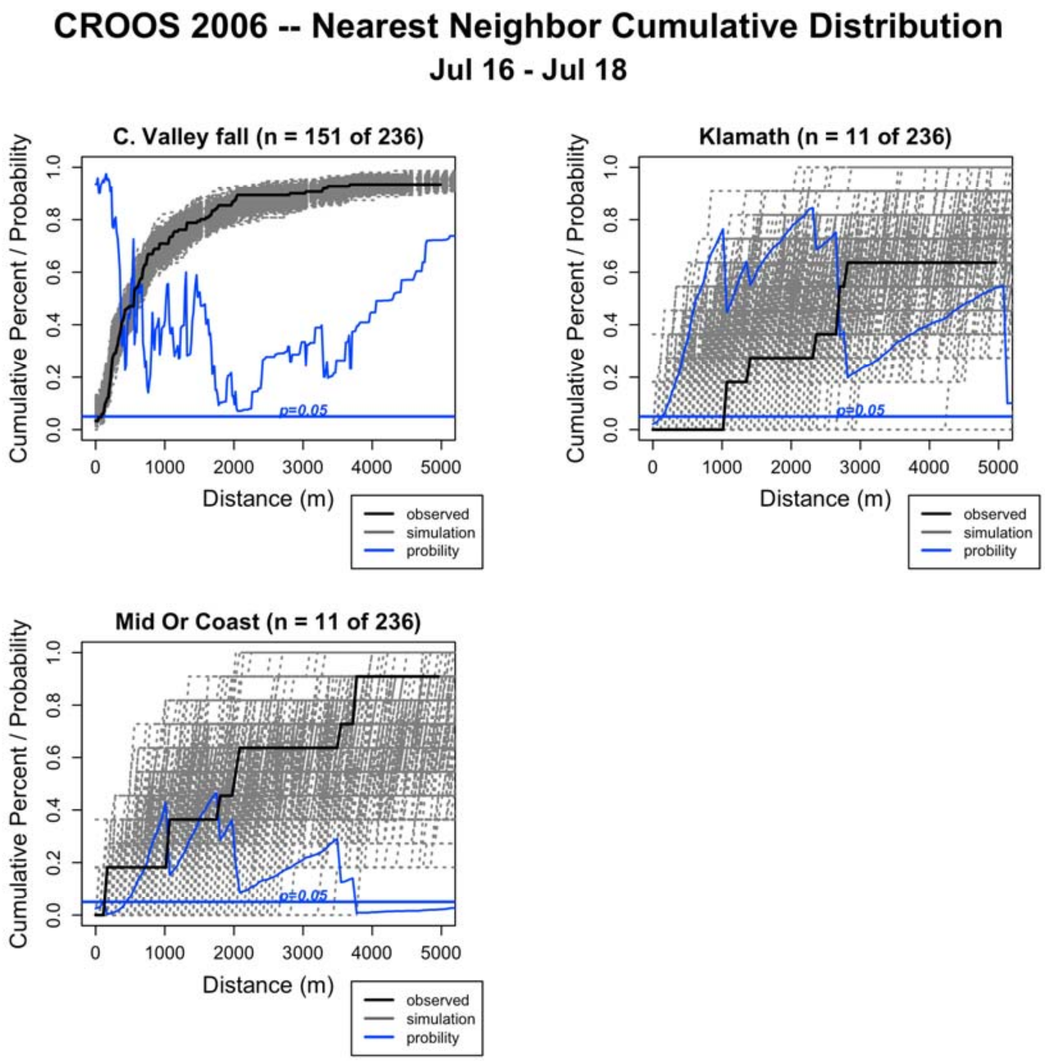


Figure 39. Cumulative distribution of stocks for the 3-day period of July 16-18. There was little evidence for stock-based aggregations during this period.

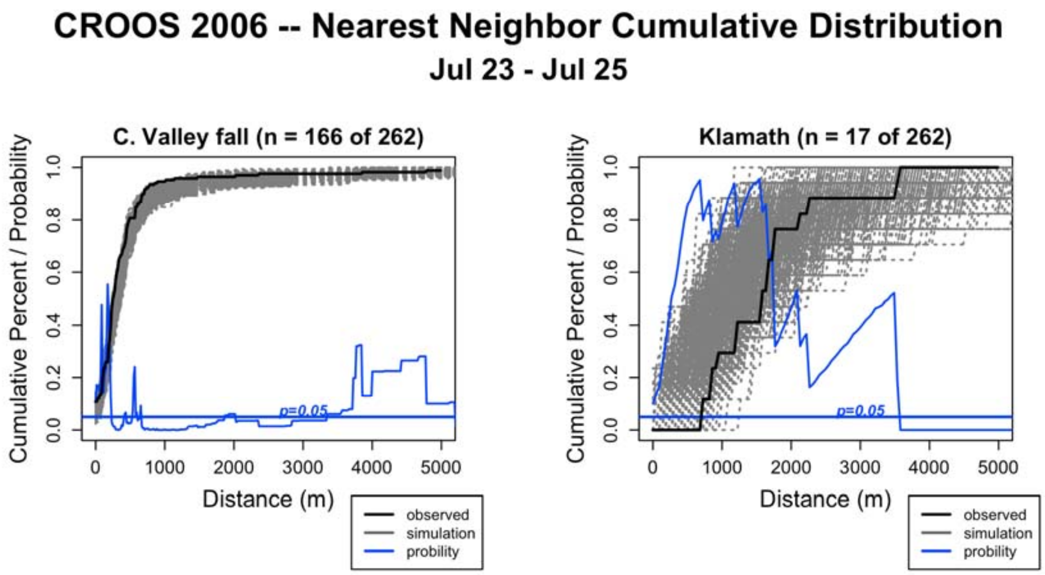


Figure 40. Cumulative distribution of stocks for the 3-day period of July 23-25. Central Valley Chinook showed a strong indication of aggregation compared to random simulations at the observed catch points.

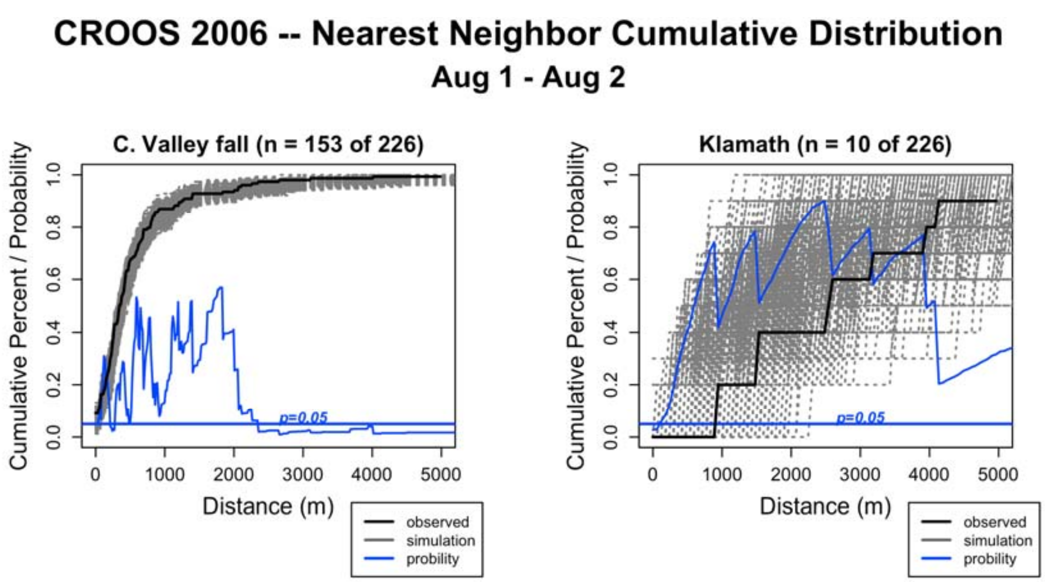


Figure 41. Cumulative distribution of stocks for the 2-day period from Aug 1-2. Central Valley Chinook showed a tendency to be more aggregated at 250 meters than the simulations.

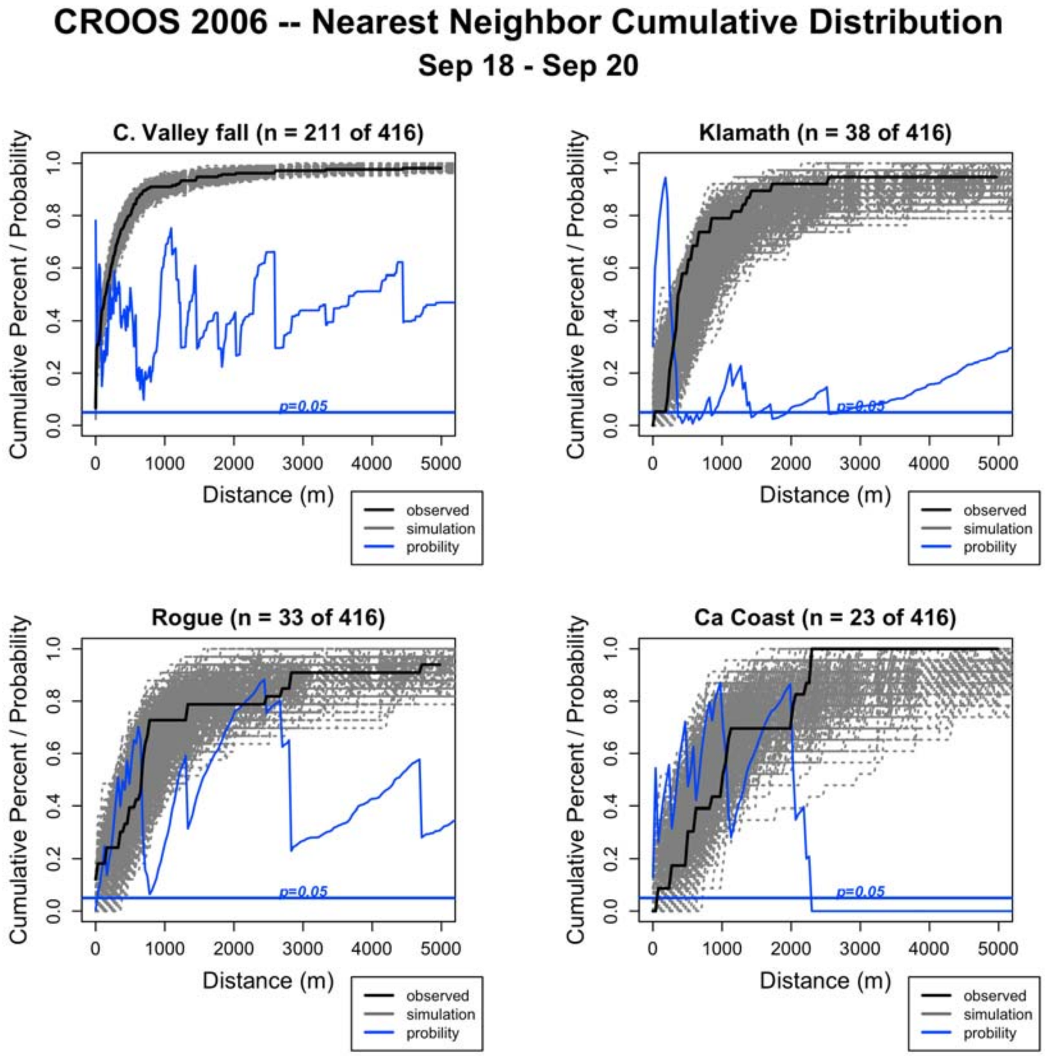


Figure 42. Cumulative distribution of stocks for the 3-day period from Sep 18-20. Klamath River Chinook exhibited an aggregation signal.

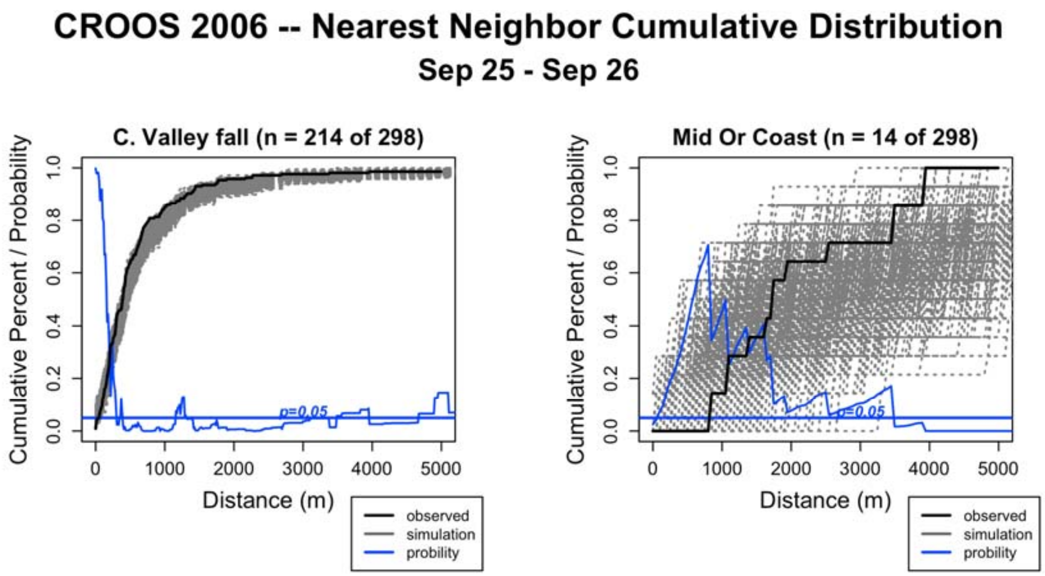


Figure 43. Cumulative distribution of stocks for the 2-day period from Sep 25-26. Central Valley Chinook showed an indication of aggregation.

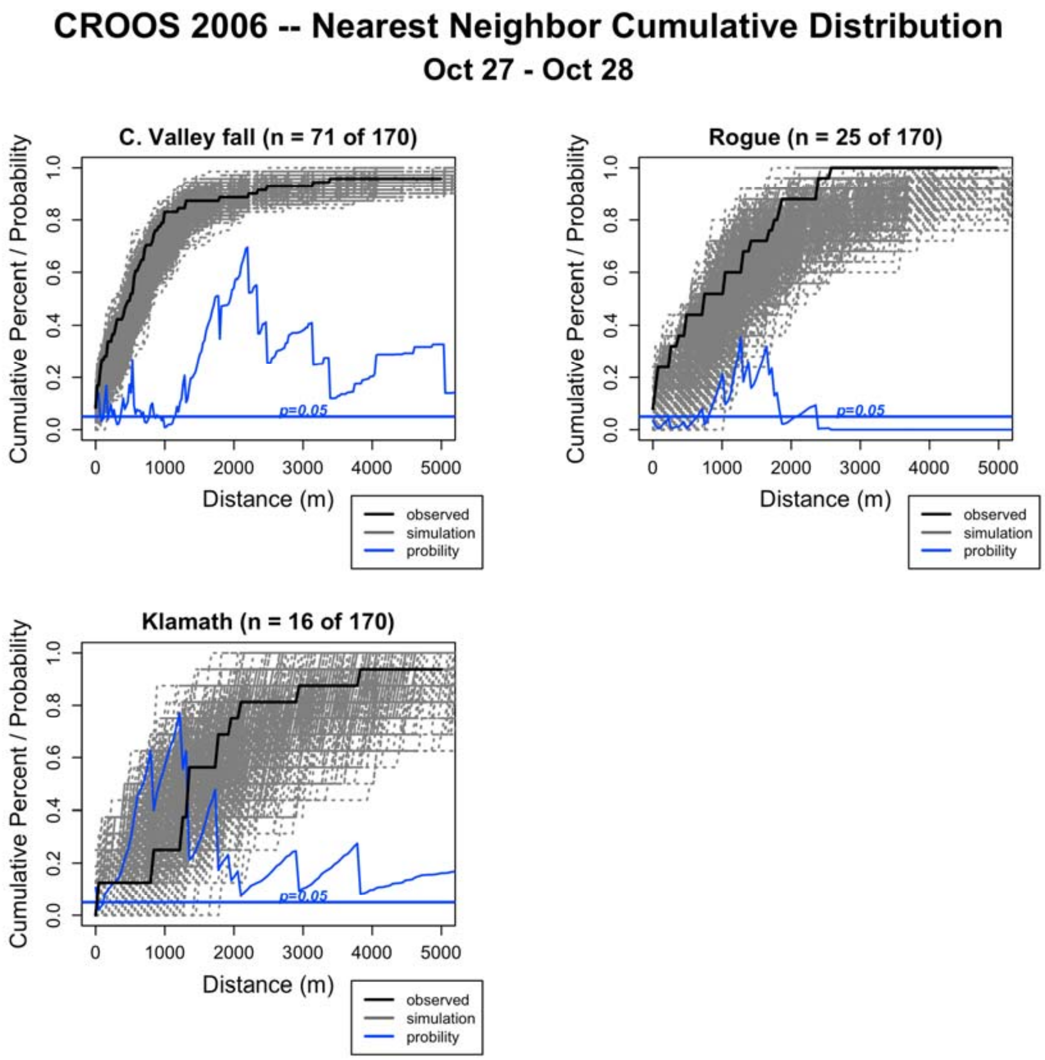


Figure 44. Cumulative distribution of stocks for the 2-day period from Oct 18-20. Both Rogue River and Central Valley Chinook exhibited an aggregation signal below 1000 meters.

Discussion

Evidence that the marine distribution and the migration patterns of Pacific salmon are inherited traits has been accumulating for more than two decades. Unique populations of Pacific salmon have been shown to occur in specific ocean regions, be found within a specific range of their home stream, and follow a largely fixed migration pathway (Brannon and Hershberger 1984; Groot and Margolis 1991; Healey 1983; Nicholas and Hankin 1988; Pearcy and Fisher 1990; Trudel et al. 2009; Weitkamp and Neely 2002; Weitkamp 2010). While unique stocks vary in their ocean distribution, they generally occur over a geographic area that broadly overlaps the range of numerous other stocks. This was true for Chinook salmon caught in the Oregon ocean fishery for the 2006 and 2007 sample years. However, important Chinook stocks to the Oregon fishery were observed to express distinct spatial and temporal patterns in their distribution. Many stocks shared a distribution that grouped them with other similarly distributed populations. Stock distribution is an important consideration for the effective management of Chinook salmon in the mixed-stock ocean fishery. This study investigated additional factors that possibly influence the ocean distribution of unique stocks. The cohesion of groups of population cohorts and age-class groups of specific populations was also examined. Stock-specific analysis of distribution, age-structure and cohort aggregation in this study were dependent upon accurate genetic identification of ocean-caught Chinook using the genetic baseline establish in Seeb et al. (2007).

2007 Coastal distribution

The results of this study indicated that ocean-caught Oregon Chinook were found in mixed-stock aggregations predominantly made up of fish that originated in the spawning streams and hatcheries of California and Oregon. Aggregations consisted of unique stocks with both similar and significantly different marine distributions. The 2007 Oregon catch, though limited to that single year, demonstrated 3 distinct patterns of ocean distribution – a southern group of stocks, a northern group of stocks and a coastwide group distributed evenly north to south. Stocks from Southern Oregon and Northern California made up the southern group. This group contains members of the south migrating Oregon stocks identified by Nicholas and Hankin (1988) with the addition of stocks from the Klamath River and California Coast. Beacham et al. (2006) reported that Klamath River Chinook were genetically much more similar to the coastal stocks of Southern Oregon than to the Central Valley Chinook in California. In terms of ocean distribution and seasonal abundance, our findings suggested that Klamath River Chinook were quite similar to Rogue River stock from southern Oregon.

Stocks from the coastwide group formed the most diverse group with the highest between-stock variability. It included Chinook stocks originating from the upper Columbia River, Deschutes River, mid Oregon Coast and the Central Valley of California. Both the Deschutes River stock and the mid Oregon Coast stock were left orphaned by the preferred cut of the tree dendrogram. The necessity to apply an additional statistical tool – a pariwise t-test that compared the mean catch latitude of unique stocks – to place these orphaned stocks in the coastwide group may reflect a greater degree of within-stock variability. Higher variability among the individuals of unique population would likely result in a stock that did not fit as tightly with any single group. High within-group variability of Mid Oregon Coast Chinook would not be surprising. This stock originates in the coastal Oregon streams from the Elk River to the Siuslaw River (Figure 8). Variability in Deschutes River stock may also be explainable. Deschutes River Chinook are a wild stock that nevertheless included two fish with hatchery marks. If these fish were indeed hatchery reared, their most probable origin was the upper Columbia or Snake River (Figure 7). Contamination from other upper basin stocks potentially increases the variability in the observed ocean distribution of Deschutes River Chinook.

The Northern group consisted of stocks from the lower and mid Columbia River, North Oregon coast and South Puget Sound. North Oregon Coast Chinook were caught at a mean latitude well to the north of all other stocks yet were placed in the northern group. Although they overlap with other northern stocks, they could justifiably merit the creation of a fourth group of which they would be the sole members. The North Oregon Coast stock was more regularly caught inshore compared to other stocks. Individuals from the North Oregon Coast stock were also consistently among the oldest observed fish. Possibly, North Oregon Coast Chinook had a tendency to move rapidly inshore toward their home streams after returning to Oregon waters from more northern locales. Alternatively, they may have utilized a nearshore southward migration route then remained inshore after arrival.

Columbia River stocks from the upper basin clustered naturally with the coastwide group. Stocks from the lower and mid Columbia resolved to the northern group. While it might be pretentious to draw broad conclusions from a single year, this finding suggest that upper basin Columbia River stocks range more widely and farther south than lower basin stocks. A similar pattern was noted in adult CWT recoveries from Weitkamp (2010) on a much larger geographic scale for the northern extent of Columbia River stocks. Stocks from the upper Columbia and Snake River were recovered in higher percentages in Alaskan waters than were the stocks from the lower basin. Both upper and lower basin stocks in the Weitkamp study had a low number of CWT recoveries south of the Columbia River.

Spring-run Chinook are believed to range more widely at sea than fall-run (Healey 1983; Healey 1991; Weitkamp 2010). The most abundant spring-run Chinook in our study originated from the Central Valley. This study did not support the concept of a more extensive ocean migration for spring-run compared to fall-run Central Valley Chinook. Both stocks fall into the coastwide group. The mean latitude for the catch of Central Valley spring Chinook falls just 0.1° north of the mean latitude for Central Valley fall-run. It is not possible to compare the entire range of each stock beyond the boundaries of the Oregon Coast, but in the context of the study area, spring-run Chinook from the Central Valley have a nearly identical range as fall-run. Trudel et al. (2009) reported that spring-run juvenile Chinook from the coastal streams of Oregon, Washington and the Salish Sea also did not conform to spring-run and fall-run classifications of migratory behavior. However, they found that spring and fall-run stocks from the Columbia River did conform. Ocean migration distance appears to be a stock-specific trait indicative of genetic lineage regardless of run-type. In a microsatellite analysis of Pacific Rim Chinook, Beacham et al. (2006) reported that spring-run Chinook populations in the upper Columbia basin were strongly differentiated from summer and fall runs in the upper basin. Outside the Columbia basin, they reported that spring-run and fall-run Chinook were not as strongly differentiated. They also noted that fall-run and summer-run Chinook from the upper basin were related, but distinct from lower Columbia fall-run Chinook.

While the observed differences in the distribution of Oregon Chinook adds further support to a genetic influence over ocean distribution, the obvious implication of the results was that the Oregon fishery could effectively pursue the northern group and the southern group separately. This has in fact been true in the past. Fishery restrictions in 2006 closed fishing along the southern Oregon Coast to protect Klamath River Chinook. Precise spatial and temporal resolution of stock-specific abundance and patterns of movement has the potential to facilitate a more granular approach to Chinook management in Oregon. Distributional trends of stock groups have implications for a directed harvest of select salmon populations and the potential to offer an alternative to the coastwide closure of fisheries.

Stock composition and age structure

In coastal locations where the Chinook catch was aggregated in mixed-stock shoals, the relative contribution of individual stocks to these aggregations changed over time. In addition, the age structure for some stocks also changed during the season. California stocks, in particular, were observed to undergo a shift in mid-summer toward a younger age-class structure as a result of the in-migration of 3-year-olds. Rogue River and Klamath River Chinook displayed a nearly identical coastal range in the Oregon catch and appeared to increase and decrease together in the overall stock composition. It's notable, however, that the age-class structure of Rogue River Chinook remained relatively constant throughout the season compared to Klamath River Chinook, which displayed an influx of 3-year-olds in mid to late summer. The former location of the 3-year-old California Chinook before they entered the Oregon fishery is a mystery. Trudel et al. (2009) reported that many populations of coastal Chinook appeared to remain in the vicinity of their home river until they reach 2 or even 3 years of age. It is possible that many 3-year-old Chinook from the Central Valley and Klamath River also initiate a northward migration into Oregon waters as late as their 3rd year at sea. Two-year-olds were not sampled in the Oregon troll fishery, however, so that determination cannot be made. Regardless of the source of in-migrating 3-year-olds, it was apparent that some stocks maintain at least a partial cohesion with age-class cohorts while at sea.

Chinook stocks from the Columbia River made up approximately 7% of the total catch in each year of this two-year study. Their catch was largely limited to the spring and early summer. This was also true of Chinook from the South Puget Sound. Trudel et al. (2009) noted that some juvenile Columbia River salmon actively swam southward after exiting the mouth of the Columbia River. Given the generally low catch rates of Columbia River Chinook, their older age-class structure, and their exit from the fishery by mid summer, it seemed likely that Columbia River Chinook taken in the Oregon ocean fishery were predominantly adults caught returning to coastal Oregon prior to beginning their freshwater spawning run. We found no corroborating evidence that southward swimming juvenile Columbia River Chinook reared and matured along the Oregon Coast. The age-class structure of Columbia River Chinook from the 2006 and 2007 sample years was similar to the age-class structure of salmon passing over the Bonneville Dam on their upstream migration (Table 12 and Table 13). Age 3 fall-run Chinook contributed a higher percentage to the Oregon catch than they represented at Bonneville Dam, but this could be explained by the relatively high percentage of 3-year-olds in the Mid Columbia Tule catch (Table 1). Despite the younger age-structure of the Mid Columbia Tule stock, they appeared to exit the Oregon fishery simultaneously with other Columbia River stocks. Furthermore, very few yearling Chinook from the Columbia River have been sampled south of the river in over 12 years of the Columbia River plume survey (Joe Fisher, personal communication). Interestingly, Norris et al (2000) investigated CWT recoveries of Columbia River upriver bright fall Chinook off the coast of Alaska and found a similar age structure as that described in this study for upper Columbia Chinook. The catch was predominantly 4 and 5 year-olds. Both studies were constrained by an inability to sample young salmon. The low catch of Columbia River Chinook in this study compared to their total population size raises the possibility that the Oregon catch was comprised of a small segment of returning spawners that overshot the river on their return migration from more northern waters. It's also possible that a small subset of Columbia River Chinook spend a few additional weeks feeding along the Oregon Coast before ascending the river. Whether this is accidental, a behavioral adaptation or an innate life history trait unique to a segment of the population is a matter for future investigation.

Table 12. Age class structure of fish going over the fish ladder at Bonneville Dam in 2006 and 2007. The numbers represent the percentage of each age class.

Run Time	2006				2007			
	3 yrs	4 yrs	5 yrs	6 yrs	3 yrs	4 yrs	5 yrs	6 yrs
Spring	2.2	79.8	16.8	1	24.5	52.4	22.6	0.6
Summer	5.8	33.7	53.3	4.6	37.4	29.9	33.4	4.7
Fall	21.1	32.5	35.7	3	17.8	46.2	22.5	2.8

Table 13. Age class structure of Columbia River stocks caught in the sample area in 2006 and 2007. The numbers represent the percentage of each age class. Data is adapted from Table 1. The summer-run Chinook are exclusively the Upper Columbia Sum/Fall stock. Deschutes Fall, Mid Columbia Tule and Snake River Fall make up the Fall run.

Run Time	2006				2007			
	3 yrs	4 yrs	5 yrs	6 yrs	3 yrs	4 yrs	5 yrs	6 yrs
Spring	-	-	-	-	-	-	-	-
Summer	0.0	35.3	64.7	0	14.0	40.0	44.0	2.0
Fall	60.0	36.0	4.0	0	53.6	41.1	5.3	0

Stock aggregation recognition of kin and population conspecifics

Nearest neighbor analysis of the observed catch distribution suggested that the mean distance between population conspecifics was frequently lower than would be expected in a random distribution at the given catch locations. It must be acknowledged that this was not true for all stocks and was not consistently observed over time for any given stock. Specific populations appear to aggregate, but it was not possible to obtain a snapshot of fish locations at a fixed point in time. The best resolution was based on the cumulative catch over a 2 to 3 day period. Aggregations may reflect an artifact of stock movement over a given time period or the rare opportunity to observe an authentic aggregation that has been stable for the duration of the time slice. We do not suggest that Chinook salmon migrate to sea in mass and remain schooled with population and age-specific cohorts. At any given time, a stock was widely distributed. It appeared in the study that aggregations dissolve and coalesce through time. The factors that initiated this behavior were unknown, though potentially, aggregations could form as a migratory response. It seems most plausible that separate groups of river and age cohorts take up together and strike off in many smaller, loosely schooled and impermanent aggregations. McKinnell et al. (1997) previously suggested a similar state of affairs in their investigation of steelhead CWT recoveries.

If the observed aggregations reflect a true tendency for some degree of stock-based schooling behavior, salmon must be able to recognize cohorts at sea. Migrating adult coho and sockeye have demonstrated an ability to discriminate population-specific odors in freshwater environments. Groot et al. (1986) found that adult sockeye from Great Central Lake on Vancouver Island preferred water conditioned with adults of their population over unconditioned water. The ability to detect population-specific odors appeared to be variable among populations, however, as sockeye from nearby Sproat Lake did not show a preference. Adults for these experiments were collected near the terminus of the freshwater migration where the chemical odors associated with their natal waters were presumed to play a more significant role in homing behavior. Quinn and Tolson (1986) concluded that coho salmon also were able to distinguish population-specific odors. Juveniles from the Big Qualicum and Quinsam rivers in British Columbia were attracted to water with chemical traces of their own population over unconditioned neutral water. Furthermore, when presented with a choice of water conditioned by Quinsam River juveniles or water conditioned by Big Qualicum juveniles, both groups were more attracted to their own population odors. Mature jacks from Quinsam River were also attracted to juveniles of their own population. As with sockeye, the authors noted differences between the two populations – Quinsam River coho were more strongly attracted to their own population compared to Big Qualicum coho in both the juvenile and mature jack experiments. Courtenay et al. (1997) transported coho embryos from Big Qualicum, Quinsam and Puntledge hatchery to Rosewell Creek Hatchery where they were reared in separate tanks. They found that coho fry all prefer odors from their own population over the other two.

We are not aware of any experiments performed with ocean salmon to determine if they possess an ability to recognize population conspecifics at sea. Successful live capture of adult, ocean salmon followed by transportation to a laboratory setting to observe natural behavior would obviously be a challenging adventure. It's been suggested that cues from the earth's magnetic field and the position of the sun may play a role in directing salmon migration on the open sea (Quinn 1980; Quinn and Brannon 1982). As salmon near the location of their home river, olfaction then plays a greater role in guiding salmon to their natal spawning ground (Dittman and Quinn 1996). In any population, homing ability likely varies between individuals. Larkin and Walton (1969) suggested that navigational accuracy theoretically increases with increasing school size. We are not aware of any experimental evidence that supports Larkin and Walton. However, it's observed that salmon from a given river tributary are more closely related to salmon from a different tributary of the same river compared to other rivers. In addition, salmon from a given river are more closely related to those from a nearby river rather than a distant river (Beacham et al. 2006). Straying might be the result of a navigational error by individuals with a less adept homing talent. The ability to recognize and remain in proximity to population cohorts at sea, especially during migration to feeding grounds or natal streams, might be an advantageous trait in salmon.

Central Valley Chinook

Weitkamp (2010) found that more than 75 percent of Central Valley fall Chinook were harvested in the coastal waters of California. Even though a smaller percentage of the total Central Valley fall-run appears to be harvested in Oregon, they were, in fact, the dominant stock contributor in 2006. They have been described as the “workhorse” of the Oregon fishery. (PFMC 2009b)

The contribution of fall Chinook from the Central Valley declined dramatically over the two-year study. In 2006, the Central Valley fall-run made up 60 percent of the Chinook harvest. One year later the Central Valley fall-run accounted for only 7.8 percent of the total Chinook catch. Adjustments to the collection protocol do not allow a direct comparison of CPUE between 2006 and 2007. Nevertheless, the 82 percent decline of Central Valley fall Chinook catch from 2006 to 2007, in retrospect, foreshadowed the concomitant drop in escapement reported on the Sacramento River in 2007. Returning adults decreased from 276,600 in 2006 to 90,476 in 2007, a 67 percent reduction – Central Valley fall jacks fell from 10,995 in 2006 to 2,122 in 2007, a 79 percent decline (PFMC 2009a; PFMC 2010). In addition to the catch declines, the change in the age structure of Central Valley fall Chinook was another early indicator of a potential problem. In 2006, 3-year-olds dominated the catch while a year later the majority of the catch were by 4-year-olds (Table 11). Analysis of in-season stock compositions and age structure could prove to be a valuable tool to assess the current status of individual stocks and provide an additional data point to help forecast the subsequent season.

Conclusion and future research

Chinook salmon harvested by ocean fishermen in Oregon near-shore waters exhibit stock-based patterns in their coastal range. While other studies have reported similar findings regarding the ocean distribution of unique stocks of salmon, this study demonstrates that stock-based differences in distribution can be observed on moderate scales of 200 to 400 kilometers along the Oregon coast. In addition, some individual stocks appear to remain close to their home streams while other stocks undertake a more extensive migration. The degree of flexibility in space and time of the observed ranges has not been investigated. Physical conditions of the ocean environment in any given year, however, presumably play a role in the distribution. Coded wire tag recoveries with decades of data suggest that stock-specific distribution is remarkably stable year over year regardless of prevailing ocean conditions (Norris et al. 2000; Weitkamp 2010). It is currently unknown whether the distribution of unique stocks is also fixed at the more restricted scale of this study. The extent to which the distribution of individual stocks is fixed has important ecological significance in a variable ocean environment. Local variations or regional trends affecting ocean conditions has the potential to disproportionally impact several key stocks in the Oregon salmon fishery. Predicting the future abundance of important stocks is a critical component of fishery planning.

This study demonstrates that Chinook may be loosely associated with population conspecifics during the ocean phase of their life cycle. Further study will be required to determine whether the observed stock-specific aggregations were a statistical coincidence, the result of a common coastal range, or made up of Chinook that recognized and actively aggregated with population conspecifics while at sea.

As demonstrated in this study, genetic stock identification provides a basis to investigate salmon aggregations and migration patterns at multiple scales of inquiry from a few hundred meters to thousands of kilometers. No other technique currently available can provide an equal level of spatial and temporal detail at equivalently large sample sizes. In addition, the difficulty of applying CWTs to wild stocks during their downstream migration limits the population scope of CWT studies. Currently, migratory patterns of individual stocks are largely assessed solely with hatchery reared fish. While the range of wild and hatchery reared Pacific salmon appear similar, reared Atlantic salmon from the Simojoki River in Finland have been shown to posses a lower migration activity with shorter marine migration distances compared to wild salmon from the Simojoki (Jutila et al. 2003).

Commercial fisheries that target ocean Chinook take a mixture of individual stocks in the catch. The stock composition of Chinook landings is dependent upon the ocean location where the fishery is prosecuted (Beacham et al. 2005). In addition, at any given location the stock composition changes throughout the season (Seeb et al. 2004; Tucker et al. 2009). Conservation and management of Chinook salmon takes place at a scale that is designed to maintain the continued viability of individual stocks. Individual stocks may experience year-to-year variability in response to local conditions encountered within their freshwater and marine rearing habitats (Mueter et al. 2002; Lindley et al. 2009). Effective management of the ocean Chinook fishery therefore requires an estimate of the abundance of individual populations and a basic knowledge of where individual stocks are likely to be found in the ocean at a specific time when they are vulnerable to the fishery. A fishery that can be regulated to harvest a specific mixture of individual stocks or one that can preferentially target or avoid a given set of stocks is a desirable strategy for fisheries management. In each case, the restrictions and closures imposed on the Oregon Chinook fishery in 2006, 2008 and 2009 were enacted in response to the decline of a single, key component of the stock mixture found in Oregon waters.

Conservation and management of the ocean Chinook fishery in Oregon entails preserving both abundance and diversity. Yearly and in-season assessment of the stock composition, age structure, and coastal distribution of individual stocks from the Oregon fishery can potentially offer greater control of the stock mixture harvested as well as early indications of future stock abundance trends. Continuing this study to obtain a multi-year, long-term profile of the stock-specific distribution of Oregon Chinook salmon could prove indispensible to the successful management of individual Chinook populations. It could also provide information to help direct a greater degree of preparation for the community of parties interested in the future of Oregon salmon.

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