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Title: Tags Versus Genetics: Identifying Which Tool Provides the Best Information about Chinook Salmon (*Oncorhynchus tshawytscha*) Distributions in the California Current.

Abstract approved:

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Gil Sylvia

The movement of Chinook salmon through space and time, across political boundaries, and through fisheries, creates one of the most complex marine resource management problems in the world. Information garnered from the recovery of coded-wire tags (CWTs) has been used since the 1970s to direct management decisions. Growing concern surrounding the quality and limitations of CWT data spurred interest in technologies that may improve stock specific information for Chinook salmon. Genetic stock identification (GSI) is one of the rapidly growing technologies with significant potential for generating information that could be used

in addition to CWT data to improve salmon management. This is the first study to explicitly compare the capabilities of CWT and GSI data to identify stock-specific distribution patterns of Chinook salmon. Our results demonstrate that GSI data are a powerful tool that can be used to investigate stock-specific Chinook distributions at refined space-time scales that cannot be investigated with traditionally reported CWT data. Additionally, we found that, at coarse space-time scales, CWT and GSI data provide similar stock distribution information, lending support to the critical assumption that CWT data reflect the distribution patterns of the untagged fish they are intended to represent. As a by-product of this comparison, we describe the distribution and migration patterns of the Chinook stocks most commonly encountered in the commercial fishery off the coasts of Oregon and California. GSI and other 21st century genetics-based tools have potential to play a critical role in improving salmon management regimes of the future.

Tags Versus Genetics: Identifying Which Tool Provides the Best Information about Chinook Salmon (Oncorhynchus tshawytscha) Distributions in the California Current.

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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.

Ryan James Flaherty, Author

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued) Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure Page

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

Tags versus genetics: identifying which tool provides the best information about Chinook salmon (*Oncorhynchus tshawytscha)* distributions in the California current.

Introduction

As the quintessential icon of the Pacific Northwest, salmon contribute to the food supply, economy, and health of the United States and are a critical source of spiritual and physical sustenance for Northwest Indian tribes. Pacific salmon (*Oncorhynchus spp.)* typically exhibit a spatially dynamic life history, expending significant time in both freshwater and marine environments (Groot and Margolis, 1991). While at sea, salmon may travel thousands of kilometers from their natal stream, often crossing state and international boundaries while being subject to multiple commercial, sport and tribal fisheries. The movement of Pacific salmon through space and time, across political boundaries, and through fisheries, creates one of the most complex marine resource management problems in the world.

The growth and survival of salmon is affected by where they migrate and how long they spend in certain areas of the ocean(Pearcy, 1992; Pearcy and McKinnell, 2007; Tucker et al., 2011). Understanding their distribution through space and time helps scientists and managers to distinguish the factors affecting their survival and reproductive success and may improve our ability to effectively manage them as resource. Coded-wire tags (CWTs) and genetic stock identification (GSI) are tools that can provide information on where and when specific stocks of salmon are encountered in the ocean.

Background

Prior to 1970, research focused on identifying ocean distributions of Chinook salmon (*O. tshawytscha)* was conducted via fin-clipping juveniles or externally tagging adults captured at sea (Johnson 2004). Mark-recapture studies employing fin clipping and ocean tagging methods revealed that complex mixtures of salmon stocks were harvested in ocean fisheries, but those methods had minimal ability to identify distribution patterns of individual stocks. The small number of possible fin clip combinations (only 15 – 20 groups of fish could be studied at one time), and the lack of coordination across state and political boundaries, made it difficult to determine coast-wide distribution patterns (Pacific Salmon Commission 2005). As fisheries management evolved managers desired more refined information about marine distribution patterns of specific stocks of salmon. It became clear that a new technology would be needed to address management needs of the future and CWTs were a promising answer.

Coded-wire tags are minute (1.1 mm) pieces of magnetized steel wire that are inserted into the nasal cartilage of juvenile salmonids. Introduced in the late 1960s as a tool to evaluate experiments carried out by salmon hatcheries, the CWT quickly became the most widely utilized means of tracking the fate of specific groups of Chinook and Coho salmon from release through maturity (Jefferts et al., 1963). Etched upon each tag is a code that is associated with fish type (e.g., species, stock, size, age) and release information (e.g., date, location, rearing type, number tagged). Fish bearing tags with the same code belong to an individual "release group." While in many cases only a fraction of the fish belonging to a release group may be implanted with a CWT, all fish belonging to a particular release group are of the same type (species, stock, age) and are raised and released under the same conditions. Management agencies typically aim to sample twenty percent of the ocean harvest for the presence of coded-wire tagged salmon. CWTs are detected either visually, in areas where removal of the adipose fin indicates the presence of a CWT, or electronically. Once detected, the head of the tagged salmon is sent to a laboratory where the tag is removed, the code visually read, and data processed. Those data are sent to the Regional Mark Processing Center to be archived in its centralized database known as the Regional Mark Information System (Nandor et al., 2010).

The primary function of CWT data is to assist the decision-making process used to manage salmon stocks along the west coast of North America (Nandor et al., 2010). In the late 1970s, management agencies from Alaska, British Columbia, Washington, Oregon, and California developed coast-wide catch sampling and reporting protocols to facilitate sharing of data on where and when fish from individual release groups were harvested (Pacific Salmon Commission, 2005). The coordinated, coast-wide release and recovery of CWTs was followed by the development of cohort analysis methods in the mid-1980s. Cohort analysis methods utilize CWT recovery data to estimate stock-specific, age-specific, and fishery-specific exploitation and survival rates, age specific maturation rates, survival from release to age 2, and total mortality (Chinook Technical Committee, 1988). Results of cohort analysis quantify and characterize the timing and location of fishery impacts for the entire migratory range and life cycle of individual stocks (Pacific Salmon Commission 2005). The information provided by CWT-based cohort analysis is heavily relied upon by management agencies to design salmon fisheries that exploit abundant stocks while avoiding those that are less plentiful (Nandor, Longwill, and Webb 2010). In 1985 the United States and Canada entered a Memorandum of Understanding when signing the Pacific Salmon Treaty which stated in part: “The Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations (Pacific Salmon Treaty pg. 123).” In addition to cohort analysis, CWT data have been used to address a variety of questions about the distribution and migration patterns of adult (Nicholas and Hankin, 1988; Norris et al., 2000; Weitkamp, 2010; Weitkamp and Neely, 2002) and juvenile salmonids (Fisher et al., 2014; Morris et al., 2007; Trudel et al., 2009; Tucker et al., 2011), run timing, in-season survival (Holt et al., 2009), stray rates (Candy and Beacham, 2000; Quinn and Fresh, 1984) and hatchery experiments. Today, all salmon fishery management agencies in the Pacific Northwest depend upon coded-wire tags.

The CWT has provided unrivaled information about the ocean distribution patterns and fishery impacts of Chinook salmon for over four decades. However, CWT data have inherent weaknesses which have caused growing concerns about their quality and the inferences we draw from them. The most obvious drawback of CWT data, and the root of much of the concern surrounding these data, is that they provide specific information only for fish that are tagged and recovered. Because it is not feasible to tag each fish (due to cost and logistics of tagging and recovering sufficient numbers of salmon), and because the vast majority of tagged fish are reared in hatcheries, analysts are forced to rely upon expansion factors and assumptions when estimating fishery impacts for the naturally produced and untagged counterparts of each stock. For instance, one assumption used in all salmon management models built around CWT data, is that tagged salmon behave in the same manner as the untagged individuals they are intended to represent. That belief forms the very first assumption listed in the technical documentation for the PFMC's "Fishery Regulation Assessment Model" and is also an underlying assumption of the Chinook Technical Committee's "Exploitation Rate Analysis" (Chinook Technical Committee, 1988; Model Evaluation Workgroup (MEW), 2008). It is difficult to tag and recover sufficient numbers of naturally produced salmon so there have been few attempts to validate the assumption using CWT methods. However, the studies that have been conducted suggest that hatchery indicator stocks and naturally produced stocks are subject to similar fishing patterns, at least at large spatial scales (Satterthwaite et al., 2014; Weitkamp, 2010; Weitkamp and Neely, 2002).

The inability to tag each fish with coded-wires generally requires high exploitation rates to recover adequate numbers of CWTs for statistically reliable analyses. During the 1980s Chinook salmon stocks were considered abundant enough to support high exploitation rates. However, beginning in the early 1990s many naturally produced (presumably wild) stocks began to decline rapidly, spurring managers to reduce fishery impacts in order to meet conservation goals. Survival rates continued to plummet and uncertainty surrounding the ability of some naturally produced stocks to persist led to several stocks being listed under the Endangered Species Act as either threatened or endangered, causing managers to further restrict the extent to which fisheries were allowed to operate. Limited access to hatchery produced salmon stocks, due to concerns for naturally produced stocks, led to fewer CWTs being recovered which increased uncertainty surrounding CWT data and analyses based on them(Pacific Salmon Commission, 2005).

The fishery regulations that were put in place to meet escapement goals for naturally produced salmon not only limited the number of CWTs being recovered, but severely restricted access to hatchery raised salmon. Politicians and fisheries managers came under pressure to provide access to hatchery produced salmon while constraining impacts on the imperiled naturally produced stocks. Many management agencies attempted to address that problem by mass-marking salmon produced at hatcheries and implementing mark-selective fisheries. Mass-marking is a term that describes removing the adipose fin from hatchery produced fish so that they may be detected visually. Mark-selective fisheries operate under the premise that fish bearing an adipose clip may be retained while un-clipped fish must be released with the expectation that catch-and-release mortality will be significantly less than one hundred percent. Unfortunately, the implementation of mass-marking and mark-selective fisheries has proven to be a double edged sword. On the one hand, mark-selective fisheries undoubtedly reduce the total mortality of naturally spawning populations of salmon. However, in a mark selective fishery, exploitation rates for

CWT hatchery stocks (marked salmon) are no longer representative of exploitation rates for naturally produced stocks (unmarked salmon) thereby impairing the ability of CWT data to monitor fishery impacts on the naturally produced stocks that fisheries managers strive to conserve. As mark-selective fisheries become more abundant, estimating mortality for naturally spawning stocks becomes more and more dependent on assumptions and methods that cannot be readily validated (e.g. catch-and-release mortality rate), casting further doubt on the reliability of the CWT system to monitor stocks whose exploitation rates are constrained by the Pacific Salmon Treaty and Endangered Species Act (Pacific Salmon Commission 2005).

The ability of the CWT system to provide data adequate for quantifying and characterizing fishery impacts on naturally spawning salmon populations was formally investigated in 2005. Twice during that year, the Pacific Salmon Commission gathered an “Expert Panel” of fishery scientists and tasked them with identifying the weaknesses of the CWT system as well as alternate technologies that might be used in addition to, or in lieu of, the CWT. The findings of the Expert Panel indicated that, at the time, there were no alternative technologies that could provide the Pacific Salmon Commission with the data necessary for cohort analysis and the implementation of fishery regimes as dictated by the PST (Finding 1; Pacific Salmon Commission 2005). However, the Expert Panel noted that several alternative technologies could potentially be used to supplement the information provided by the release and recovery of CWTs. The Expert Panel identified genetic stock identification (GSI) as a technology that showed great potential for providing information that could be used in addition to the CWT system to improve salmon management.

GSI is a tool that utilizes naturally occurring variations in DNA to differentiate between salmon stocks and has been applied to salmon research and management for decades (Shaklee et al., 1999). Advances in the standardization of a microsatellite baseline for Chinook salmon made it possible to accurately estimate (with confidence >90%) the origin of individual Chinook salmon harvested from fisheries along the west coast of North America (Seeb et al., 2007). These genetics-informed individual assignment estimates have been used to explore a wide range of questions pertaining to salmon biology such as marine distribution and migration patterns of adult salmon (Bellinger et al., 2015; Ireland, 2010; Satterthwaite et al., 2014), juvenile salmon (Tucker et al., 2011; Van Doornik et al., 2007), and population specific migration timing (Parken et al., 2008).

Many of the limitations inherent in CWT data are strengths of GSI and vice versa. For example, information pertaining to the natal origin and age of the fish provided by GSI is typically not as precise as CWT data. CWTs inform us of the exact age, stock, hatchery, and release location of tagged fish whereas GSI data typically provide the general geographic region or, at best, the river basin from which a fish originated. GSI also requires the collection of scale samples for age analysis. Conversely, the ability to use genetics-based data to study salmon distributions eliminates the conundrum of not being able to tag every salmon in the ocean. By taking advantage of the genetic "tag" present in every Chinook salmon we are able to expend less fishing and sampling effort to collect the same amount of information pertaining to the location of salmon in the marine environment. Furthermore, it becomes more feasible to gather information regarding where rare, wild and untagged stocks occur. Additionally, because a tissue sample can be harvested from a fish without killing the individual, it is possible to utilize GSI to estimate salmon distributions in space-time areas that may be closed to harvest. Finally, it is relatively easy to design a study that takes advantage of GSI in such a way that it allows the investigation of salmon distributions at fine space-time scales. For instance, a genetics based individual assignment estimate paired with GPS coordinates can provide precise information on the location and time a specific stock was encountered (e.g. Bellinger et al. 2015; Ireland, 2010).

West Coast Salmon Genetic Stock Identification Collaboration

Declining abundance of the Klamath River Fall Chinook stock in 2005, and its negative implications for commercial fisheries and coastal communities, spurred Oregon’s Congressional leaders to meet with members of the Oregon State University faculty to develop a science based solution for avoiding weak salmon stocks without closing the entire fishery. The eventual result of that meeting was the formation of Project CROOS (Collaborative Research on Oregon’s Ocean Salmon), a collaboration between fishermen, scientists and management bodies aimed at evaluating the utility of GSI to provide real-time information on salmon stocks encountered off the Oregon coast. It was hypothesized that availability of real-time data could enable managers and/or industry to make in-season adjustments to the fishery, allowing industry to concentrate fishing effort in areas not inhabited by scarce stocks. Furthermore, it was speculated that information gathered by the project could increase knowledge of the marine distribution and migration patterns of salmon stocks commonly encountered in waters off the Oregon coast. Beginning in 2008, methods developed by Project CROOS were implemented in Oregon and California under the West Coast Salmon Genetic Stock Identification Collaboration (WCS-GSI). In 2010 and 2011 the WCS-GSI attempted to sample all commercial fisheries and areas from Cape Falcon, Oregon to Santa Barbara, California. The GSI data they collected are explored in this study.

Objectives of this study

The key objective of this study was to explore, compare, and contrast the capabilities of CWT and GSI data to identify fine-scale, stock-specific, distribution patterns of Chinook salmon off the coasts of Oregon and California. In addressing that objective, we described the marine distribution of the Chinook salmon stocks most commonly encountered in Oregon and California's commercial troll fisheries, evaluated the similarity between CWT- and GSI-based estimates of those distributions, and provided an example of how GSI data collected by the WCS-GSI can be used to identify distribution patterns at refined space-time scales that cannot be investigated with traditionally reported CWT data. The study concludes with suggestions for how data similar to those collected by the WCSGSI could be used managers to monitor, evaluate, and manage fishery impacts on specific salmon stocks at refined space-time scales.

This study is the first regional-scale comparison of the capability of CWT and GSI data to identify stock-specific salmon distributions and we expect that the information herein will contribute to better informed fishery management in several ways. While management agencies are aware of the general distributions of Chinook stocks commonly encountered in Oregon and California's fisheries, those distributions have yet to be thoroughly described in the scientific literature at the level of detail found herein. Perhaps more importantly, previous descriptions of Chinook distribution patterns have been estimated from CWT recoveries. Due to the concern surrounding the CWT system and the inferences drawn from analysis of CWT data, and because the Pacific Salmon Commission's Expert Panel identified GSI as a technology that could potentially replace the CWT system, it is beneficial to compare how CWT and GSI data differ in their ability to provide information on where and when stocks of Chinook are encountered in the study area. Additionally, because we examine the similarity between CWT- and GSI- based distribution estimates, this study will provide a rough evaluation of the key assumption that CWT'd fish behave similarly to the untagged fish they are intended to represent. Finally, we demonstrate the capacity of GSI data to identify distributions of specific stocks of salmon at space-time scales that the current CWT system is unable to investigate, suggesting that GSI can contribute to an improved management of our ocean Chinook salmon fisheries.

Methods

Our key objective was to compare the capabilities of CWT and GSI data for identifying fine-scale, stock-specific, distributions of Chinook salmon encountered in the commercial troll fisheries operating off Oregon and California. The spatial scope of this study encompassed the area between Cape Falcon, OR (45.76 N) to Point Sur, CA (36.3 N). The temporal scope spanned from May to September.

CWT data

The CWT data used in this study were obtained through the Regional Mark Processing Center's online Regional Mark Information System (RMIS) database (http://www.rmpc.org/). In this study we define "CWT data" as information that is garnered from the release and recovery of coded-wire tagged Chinook salmon encountered in the commercial troll fishery. The CWT database can provide the user with a large number of variables related to the life history of the release group represented by each tag code. Our analyses used the subset of CWT variables displayed in Table 1.

Table 1. Summary and description of the CWT variables used in this study.

CWT Variable	Description
tag code	Identifier code on a tag to denote a release group.
recovery date	Date closest to that in which the catch occurred in the fishery.
stock name	Stock location name.
release location RMIS basin	Geographic region or release.
recovery location name	Location where CWT was recovered.
fishery	Fishery in which recovery occurred.
CWT first mark count	Number tagged and given 1st mark (adipose clip) corrected for tag loss and mortality.
CWT second mark count	Number tagged and given 2nd mark corrected for tag loss and mortality.
non-CWT fisrt mark count	Number with no CWT given 1st mark.
non-CWT second mark count	Number with no CWT given 2nd mark.
estimated number	Estimated number of tagged fish in the catch with the same CWT.
study type	Type of study reflected by release group.
species	Species of fish.
run	Run of the release group (i.e. Spring, Summer, Fall, etc.)

We selected only CWTs that were recovered from the commercial troll fishery and excluded any CWTs from purely experimental release groups (study type “E” in CWT database). Historical effort data for the commercial troll fisheries were acquired from the Pacific Fishery Management Council’s “Historical data of Ocean Salmon fisheries bluebook” (http://www.pcouncil.org/salmon/background/document-library/historical-data-of-ocean-salmon-fisheries/). The effort data provided by the Council were aggregated by year, month and catch area.

Genetic data

The GSI data analyzed in this study were provided by the WCSGSI collaboration. GSI-based individual assignment estimates and WCSGSI effort data were accessed via the WCSGSI's online data portal (pacificfishtrax.org). Fishermen participating in the collaboration were assigned hand-held global positioning system (GPS) units. Those GPS units served two critical purposes. First, they were used to record the approximate time and location of each fish that was caught and sampled. When a fish was captured, the fisherman was required to collect several scale samples along with a clip of fin tissue for genetic analysis. The second purpose of the GPS unit was to record each fisherman's "fishing track." Fishing tracks were monitored by programming the GPS to record the location of fishermen at 5 minute intervals. Each 5 minute interval is called a "track point." The information provided by these track points can be used to estimate fishing effort. In this study, one boat day of WCSGSI sampling effort equated to at least 10 recorded track point intervals (i.e. at least 50 minutes of fishing was required to qualify as a boat day; most "days" were considerably longer than 50 minutes). This study utilized two major components of the WCSGSI dataset: GSI informed individual assignments and track point data. These components provided the date, time, location and most likely population of origin for each salmon encountered during 2010 and 2011 as well as the means to estimate the amount of effort expended to collect those samples.

Initial data preparation

There were four fundamental differences in characteristics and dimensions of information provided by the CWT and WCSGSI databases: 1) the number of salmon that can be represented by a single data point; 2) the spatial scale at which natal origin is identified; 3) the space-time scale at which capture location is identified; and 4) the amount of effort expended to collect the data. Before we compared how CWT and WCSGSI data represented distributions of salmon we processed the data to account for those differences. The methods we used are described below.

The first fundamental difference between CWT and WCSGSI data is the number of salmon represented by a single data point. While a single data point in the WCSGSI database corresponds to an individual fish, a single CWT recovery typically represents multiple fish from that release group. There are two reasons why a single CWT recovery is often assumed to represent more than one fish. First, only a fraction of the landed catch is sampled for the presence of CWTs. In Oregon and California, management agencies strive to sample at least twenty percent of the landed catch for the presence of CWTs. Because only a fraction of the catch is sampled, it is often assumed that tags are present in the catch but not detected. This variable, "estimated number" (Table 1), is calculated by the reporting agency (either Oregon Department of Fish and Wildlife or California Department of Fish and Game) and represents the number of tagged fish in the catch with the same CWT. Equation 1 is the general framework used to generate the CWT database variable "estimated number."

Equation 1 – CWT sampling rate expansion (Johnson and Parker, 1990):

$$R_{T,i,j} =\propto R_{o,i,j}$$

Where $R_{T,i,j}$ is the estimated number of recoveries of code (*T*) during time (*i*) in area (*j*), $R_{o,i,j}$ is the observed number of tags of the appropriate code and alpha is the sampling expansion factor (total catch/sampled catch).

The second reason a single CWT recovery is often assumed to represent more than one fish is because, typically, only a fraction of the fish belonging to a release group are implanted with a CWT. The CWT database contains information on the total number of fish belonging to each release group as well as the number of fish in each group that are tagged. With that information, CWT recoveries can be expanded to account for the fraction of fish in the release group that did not receive a tag. The tagging expansion we used was calculated from the following variables which are found in the CWT release database: “cwt 1st mark count”, “cwt 2nd mark count”, “non cwt first mark count”, and “non cwt second mark count.” CWT 1st mark count represents the number of fish that receive a CWT and mark, where “mark” is means of visually identifying the presence of a CWT (typically an adipose fin clip). We applied equation 2, below, to expand CWT recoveries to account for tagging rate.

Equation 2 – CWT tagging rate expansion (from Johnson and Parker 1990):

$$C_{i,j} = bR_{T,i,j}$$

Where $C_{i,j}$ is the total estimated contribution of the release group bearing code (T) to the catch in time (i) and area (j) and b is the tagging expansion factor (total fish released/total fish marked):

$$b = \frac{CWT\ 1st\ mark + CWT\ 2nd\ mark + Non\ CWT\ 1st\ mark + Non\ CWT\ 2nd\ mark}{CWT\ 1st\ mark + CWT\ 2nd\ mark}$$

The second fundamental difference between CWT and GSI data is the scale at which they identify the natal origin of a salmon. CWT data provide us with the specific stock a salmon belongs to as well as the hatchery, and stream where it was reared and released. In contrast, the GSI data used in this study provided an *estimate* of either the general geographic region a salmon originated from (e.g. Mid-Oregon Coastal) or, at best, the river basin or origin (e.g. Klamath River). To account for this difference, each CWT recovery was assigned to an equivalent GSI reporting group, termed a "CWT GSI equivalent" (CGE). Assignment to CGEs were based on stock location name, run type and release location (Table 2). GSI individual assignments were used in the analysis only if the probability that they were correct was greater or equal to ninety percent.

Table 2. The assignment of CWT recoveries to their equivalent GSI reporting group. Assignment was based on three variables: stock location name, release location RMIS basin and run type. Stock abbreviations: **CC** - California Coastal, **CVF** - Central Valley Fall, **CVS** - Central Valley Spring, **K** - Klamath, **LCF** - Lower Columbia Fall, **LCS** - Lower Columbia Spring, **MCT** - Mid-Columbia Tule, **MOC** - Mid-Oregon Coastal, **NCSOC** - Northern California/Southern Oregon Coastal, **NOC** - North-Oregon Coastal, **R** - Rogue, **S** - Snake, **UCSF** - Upper Columbia Summer Fall, **W** – Willamette. Release Location RMIS Basin abbreviation: **CECA** - Central California Coast; **CECR** - Central Columbia River; **KLTR** - Klamath R, Trinity R; **LOCR** - Lower Columbia R; **NOCA** - Northern California Coast; **NOOR** - Northern Oregon Coast, **SAFA** - Sacramento R, Feather R, American R; **SJOA** - San Joaquin R; **SNAK** - Snake R; **UPCR** - Upper Columbia R.

GSI Equivalent	CWT Stock Location Name	Release Location RMIS region	Run
CC	EEL RIVER	NOCA	Fall
CC	HOLLOW TREE CREEK	CECA	Fall
CC	MAD RIVER	NOCA	Fall
CVF	AMERICAN RIVER	CECA	Fall
CVF	AMERICAN RIVER	SAFA	Fall
CVF	AMERICAN RIVER	SJOA	Fall
CVF	BATTLE CREEK BELOW CNFH	SAFA	Fall
CVF	COLEMAN NFH	CECA	Fall
CVF	COLEMAN NFH	CECA	Late Fall
CVF	COLEMAN NFH	SAFA	Fall
CVF	COLEMAN NFH	SAFA	Late Fall
CVF	COLEMAN NFH	SJOA	Late Fall
CVF	FEATHER R HATCHERY	CECA	Fall
CVF	FEATHER RIVER	CECA	Fall
CVF	FEATHER RIVER	SAFA	Fall
CVF	FEATHER RIVER	SJOA	Fall
CVF	MERCED RIVER	SJOA	Fall
CVF	MOKELUMNE RIVER	CECA	Fall
CVF	MOKELUMNE RIVER	SJOA	Fall
CVF	SAC R AB COLLINSVILLE	SAFA	Late Fall
CVF	SAN JOAQUIN RIV AB BROAD	SJOA	Fall
CVF	TEHAMA-COLUSA FF	SAFA	Fall
CVS	FEATHER R HATCHERY	CECA	Spring
CVS	FEATHER R HATCHERY	SAFA	Spring
CVS	FEATHER RIVER	CECA	Spring

CVS	FEATHER RIVER	SAFA	Spring
CVW	SAC R AB FEATHER	SAFA	Winter
K	HORSE LINTO CREEK	KLTR	Fall
K	IRON GATE HATCHERY	KLTR	Fall
K	K RIVER	KLTR	Fall
K	TRINITY RIVER	KLTR	Spring
K	TRINITY RIVER	KLTR	Fall
LCF	ABERNATHY CR 25.0297	LOCR	Fall
LCF	BIG CR HATCHERY	LOCR	Fall
LCF	COWLITZ R 26.0002	LOCR	Fall
LCF	ELOCHOMAN R 25.0236	LOCR	Fall
LCF	GRAYS R 25.0093	LOCR	Fall
LCF	KALAMA R 27.0002	LOCR	Fall
LCF	LEWIS R 27.0168	LOCR	Fall
LCF	TANNER CR (BNVILLE)	LOCR	Fall
LCF	WASHOUGAL R 28.0159	LOCR	Fall
LCS	CLACKAMAS R EARLY	LOCR	Spring
LCS	COWLITZ R 26.0002	LOCR	Spring
LCS	LEWIS R 27.0168	LOCR	Spring
MCT	COLUMBIA (N BONNEVL)	CECR	Fall
MCT	COLUMBIA (N BONNEVL)	LOCR	Fall
MCT	SPRING CR 29.0159	CECR	Fall
MCT	SPRING CR 29.0159	LOCR	Fall
MOC	COOS R - PUBLIC	SOOR	Fall
MOC	COQUILLE R	SOOR	Spring
MOC	COQUILLE R	SOOR	Fall
MOC	COW CR (S UMPQUA R)	SOOR	Fall
MOC	ELK R (ELK R HT)	SOOR	Fall
MOC	GARDINER CR (UMPQUA)	SOOR	Fall
MOC	UMPQUA R(ROCK CR HT)	SOOR	Spring
NCSOC	CHETCO R	SOOR	Fall
NCSOC	LOBSTER CR PRIVATE	SOOR	Fall
NCSOC	ROWDY CREEK, SMITH R	NOCA	Fall
NOC	NESTUCCA R (CEDAR CR	NOOR	Spring
NOC	SALMON R	NOOR	Fall
NOC	TRASK R (TRASK HT)	NOOR	Spring
NOC	TRASK R (TRASK HT)	NOOR	Fall
Rogue	COLE RIVERS HATCHERY	SOOR	Spring
Rogue	COLE RIVERS HATCHERY	SOOR	Fall
Rogue	ROGUE R LWR	SOOR	Fall
S	F S R	SNAK	Fall

S	LYONS FERRY HATCHERY	SNAK	Fall
S	LYONS FERRY HATCHERY	SNAK	Late Fall Upriver Bright
S	S R-LOWR 33.0002	CECR	Fall
S	S R-LOWR 33.0002	SNAK	Fall
S	S R-LOWR 33.0002	SNAK	Late Fall Upriver Bright
UCSF	METHOW & OKANOGAN	UPCR	Summer
UCSF	PRIEST RAPIDS (36)	CECR	Fall
UCSF	PRIEST RAPIDS (36)	CRGN	Fall
UCSF	PRIEST RAPIDS (36)	UPCR	Fall
UCSF	S +PRIEST RAPIDS	UPCR	Fall
UCSF	WELLS DAM (47)	CECR	Summer
UCSF	WELLS DAM (47)	UPCR	Summer
UCSF	WELLS HATCHERY	UPCR	Summer
UCSF	WENATCHEE R 45.0030	UPCR	Summer
W	MCKENZIE HATCHERY	LOCR	Spring
W	SANTIAM R S FK	LOCR	Spring
W	W R MID FK	LOCR	Fall

The third fundamental difference between CWT and GSI data is the scale at which they identify where and when fish are captured. WCSGSI data identify where in space and time a fish is encountered with much greater precision than CWT data. WCSGSI data provide the approximate geographic coordinates and time of an encounter of an individual fish, whereas typical reporting formats for CWT data provide the catch area and date where and when a tagged fish is landed (this is an important note, CWT data tell us where and when a fish is *landed* at port but not necessarily where and when in the ocean it was caught). To be able to directly compare CWT and WCSGSI based estimates of salmon distribution, CGEs and WCSGSI encounters were assigned to the catch area (Tillamook, Newport, Southern Oregon, Klamath Oregon, Klamath California, Fort Bragg, San Francisco and

Monterey) and month (May – September) where they were recovered (Figure 1, Table 3). CWT fish were assumed to have been caught in the same catch area in which they were landed. CWTs that were recovered in historical management areas that overlapped multiple study areas were not included in this analysis (accounted for less than 1 percent of all recoveries initially queried for this study).

Table 3. Assignment of CWT recoveries to catch areas based on RMIS database variable "recovery_location_name."

Area Assignment	Tillamook	Newport	Southern Oregon	Klamath Oregon	Klamath California	Fort Bragg	San Francisco	Monterey
CWT recovery location name	ASTORIA TROLL 3	ASTORIA TROLL 4	BANDON TROLL	BROOKINGS TROLL 6	BIG LAG.- SPAN. FLAT	C.VIZCAINO-FORT ROSS	FORT ROSS-PIGEON PT	PIGEON PT.-POINT SUR
	CHARLESTON TROLL 3	COOS BAY TROLL 4	BANDON TROLL 5	COOS BAY TROLL 6	BIG LAG.-CENTERV.BEA	C.VIZCAINO-NAVARR.HD	PT.ARENA-PIGEON PT.	PIGEON PT-CA/MEX.BOR
	DEPOE BAY TROLL 3	DEPOE BAY TROLL	BROOKINGS TROLL 5	GOLD BEACH TROLL	CA/OR BDR.- HMBT.JET	NAVARRO HD-FORT ROSS	PT.ARENA-PT.REYES	POINT SUR-CA/MEX.BOR
	GARIBALDI TROLL	DEPOE BAY TROLL 4	COOS BAY TROLL	GOLD BEACH TROLL 6	CA/OR BOR-BIG LAGOON	SPAN.FLAT-C.VIZCAINO	PT.ARENA-PT.SAN PEDR	
	GARIBALDI TROLL 3	GARIBALDI TROLL 4	COOS BAY TROLL 5	NEWPORT TROLL 6 AREA 2406	CA/OR BOR-CENTER.BEA	SPAN.FLAT-NAVARRO HD	PT.REYES-PIGEON PT.	
	NEWPORT TROLL 3	NEWPORT TROLL 4	DEPOE BAY TROLL 5	NEWPORT TROLL AREA 6	CA/OR BOR-FA.KLAM.RC	SPAN.FLAT-PT.ARENA	PT.SN.PEDRO-PIGN.PT.	
	PACIFIC CITY TROLL	NEWPORT TROLL-HECETA	GARIBALDI TROLL 5	PORT ORFORD TROLL	CENTERV.BE-SPAN.FLAT			
	PACIFIC CITY TROLL 3	SIUSLAW BAY TROLL 4	NEWPORT TROLL 5	PORT ORFORD TROLL 6	FA.KLA.RC-BIG LAGOON			
		WINCHESTER B TROLL 4	PORT ORFORD TROLL 5	SIUSLAW BAY TROLL 6	FA.KLA.RC-CENTERV.BE			
			SIUSLAW BAY TROLL 5		FA.KLAM.RC-SPAN.FLAT			
			WINCHESTER B TROLL					
			WINCHESTER B TROLL 5					
			WINCHESTER OCEAN TRL					

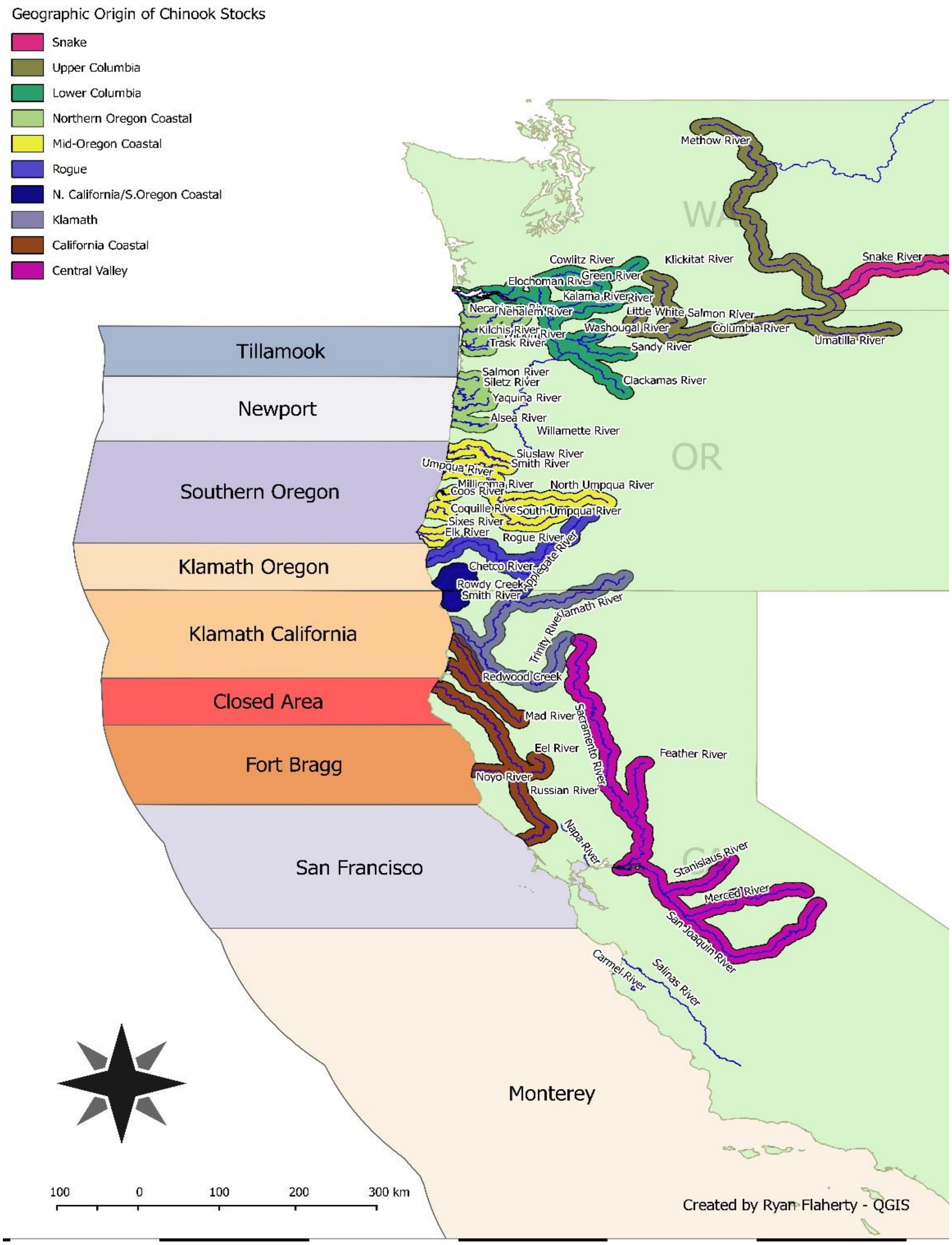

Figure 1. Map depicting the coarse scale catch areas used in this study and the rough geographic origin of the majority of stocks examined in this study.

We incorporated fishing effort into our salmon distribution estimates and therefore the fourth and final fundamental difference between the CWT and WCSGSI data used in this study was the amount of fishing effort associated with their collection. All participants of the commercial fishery serve as samplers for the CWT program. Consequently, we used the total fishing effort expended by the commercial fleet in a time and area when estimating our CWT-based distributions of Chinook salmon. Records of historical fishing effort across year, month and area were accessed online via the PFMC's historical documentation (http://www.pcouncil.org/salmon/background/document-library/historical-data-of-ocean-salmon-fisheries/). The WCSGSI fishing effort is different because not all Oregon and California salmon trollers participated in the WCSGSI collaboration during 2010 and 2011. Additionally, record of the fishing effort expended by WCGSI participants is reported as trackpoints (the 5-minute intervals recorded by GPS units discussed previously). To create indexes for comparison with the CWT data, we estimated stock specific relative abundance across all months and areas using equations 3 and 4.

Equation 3 – Estimate stock specific encounter rate *S*.

$$S_{c,i,j,d} = \frac{C_{i,j,d}}{E_{i,j,d}}$$

Where $S_{c,i,j,d}$ is the estimated encounter rate of stock c during month i and area j as estimated by data type d (i.e., CWT or GSI) , $C_{i,j,d}$ is the estimated contribution of that stock during month *i* and area *j* as estimated by data type *d* and $E_{i,j,d}$ is the estimated amount of fishing effort that was expended during month *i* and area *j* as estimated by data type *d*.

Equation 4 – Stock specific relative catch rate $S^{!}$.

$$S^{!}_{c,i,j,d} = \frac{S_{c,i,j,d}}{MAX(S_{c,d})}$$

Where $MAX(S_{c,d})$ is the maximum encounter rate of stock *c* across all month x area strata as estimated by data type *d*. Equation 4 serves to standardizes CWT- and GSI-based relative abundance estimates for direct comparison to one another. Values obtained from Equation 4 were assumed to represent how the data, whether it be CWT or GSI, represents distributions of Chinook salmon through space and time.

Data aggregates

We investigated CWT- and GSI- based distribution patterns at the *catch-area* x *month* spatiotemporal scale. CWT-based distribution patterns were estimated from CWT data aggregated over three different time periods: early (1977 – 1983), mid-late (1987 – 2011) and late (2010 – 2011). The early period represents a time when the commercial salmon fishery was subject to less stringent regulations which allowed for the recovery of CWTs across the broadest spatio-temporal extent. However, because relatively few individual stocks were tagged and recovered in fisheries off Oregon and California during the early period, the mid-late period was chosen to allow for comparisons of CWT- and WCSGSI-based distributions across a greater number of individual Chinook stocks. The late period was chosen to facilitate direct comparisons between the information provided by two years of CWT and the information provided by two years of WCSGSI data. WCSGSI data were aggregated over 2010 – 2011. All plots and statistical analyses in this study were based on these four time- and data-dependent aggregates: early CWT, mid-late CWT, late CWT and WCSGSI.

Tileplots

Tileplots were created to illustrate the distribution of overall CWT recoveries, WCSGSI encounters, fishing effort and relative abundance at the catch-area x month spatiotemporal scale. These plots resembled a matrix of colored tiles with catch-area on the y-axis and month on the x-axis. Each tile represented one catch-area x month stratum (i.e. Tillamook x July). High values of the variable being plotted were represented by hot colors (red) and low values by cool colors (blue). CWT tag recoveries were expanded for sampling and tagging rates (Equation 2). CWT recoveries, WCSGSI encounters and fishing effort were transformed by dividing the value in each area-month stratum by the maximum value, for the appropriate variable, found across all strata (similar to Equation 4). This transformation adjusted the scale so that, regardless of the variable being plotted, the range of values would be between 0 and 1. The highest value across all strata equaled 1 (indicated by deep red in all tileplots), values that were closer to the highest value were closer to one, and values further from the highest value were closer to zero (indicated by dark blue). These tileplots were created to illustrate the spatio-temporal distribution of data throughout the study area.

Additionally, stock-specific relative abundance estimates (Eq. 4) based on CWT and WCSGSI data were plotted at the *month x catch-area* in space-time. Tileplots were created from each data aggregate allowing for up to four tileplots for each stock (i.e., one tileplot each for early CWT, mid-late CWT, late CWT and WCSGSI data aggregates). To be included in this analysis a CWT-GSI equivalent needed to average a minimum of ten physical CWT recoveries per year (before expansion for sampling and tagging rate). This criterion was selected because it allowed for the greatest number of stock-specific relative encounter rate estimate comparisons between CWT and GSI data while still providing enough information to plot CWT-based estimates across the space-time scope of this study.

Statistical comparison of CWT and GSI distribution estimates

We evaluated the similarity between CWT- and GSI-based stock specific distribution estimates by using four tools: Mantel's test, MRPP (multi-response permutation procedures), non-metric multidimensional scaling (nMDS) ordination, and Spearman's rho correlation coefficient.

Distance measure

The first step for most of these techniques (Mantel's test, nMDS ordination and MRPP) is to calculate a matrix of distances between a set of items in multidimensional space. In this study we calculated the distances between sets of CWT- and GSI-based estimates of stock specific relative abundance across space-time strata. The distance between two items is representative of how similar those items are to one another (smaller values indicate similarity, larger values indicate dissimilarity). Sorensen (also known as Bray-Curtis) distance was the measure chosen in each analysis. The Sorensen distance between two items is calculated as the shared abundance of variables divided by the total abundance of variables in those items. In this study our “items” were stock-data objects (Klamath stock as estimated by GSI for instance) and the variables being measured was the relative abundance in each space-time stratum (each stratum had relative abundance estimates for all stock-data items). Sorensen distance between items *i* and *h* calculated as:

Equation 5 - Sorensen distance,

$$D_{i,h} = \frac{\sum_{j=1}^{p} |a_{i,j} - a_{h,j}|}{\sum_{j=1}^{p} a_{i,j} + \sum_{j=1}^{p} a_{h,j}}$$

where there are p attributes (i.e. month x area strata) of the items (McCune and Grace, 2002).

Mantel’s Test

Mantel’s test is a method used to assess the correlation between two distance matrices of the same dimensions (Legendre and Legendre, 2012). The null hypothesis of the Mantel test is that the distances between objects in the first matrix are not related to the corresponding distances in the second matrix. The general procedure is to first calculate the correlation between the two distance matrices and then use a randomization procedure to evaluate whether the observed correlation is significantly different from those generated at random. The standardized Mantel statistic (r), calculated as the Pearson correlation coefficient between the two matrices, measures the strength of relationships between the two matrices and ranges from -1 to 1. All Mantel's tests were run in PC-ORD. Here, Mantel's test was utilized to assess the correlation between Sorensen distance matrices calculated from CWT- and WCSGSI-based matrices of relative encounter rate estimates across catch-area x month strata (Figure 2).

Nonmetric multi-dimensional scaling ordination

Ordinations plot objects as points along one or more axes based on their relationship with each other. Non-metric multidimensional scaling plots dissimilar objects far apart in ordination (k) space and plots similar objects close together (Legendre and Legendre, 2012). Non-metric multidimensional scaling is based on an iterative search for the best positions of *n* objects (objects were either area-month-data type strata or Chinook stock-data type strata in this study) on *k* axes that minimizes the stress of the k-dimensional configuration. Stress evaluates how well the ordination represents the information in the distance matrix. All ordinations were created in PC-ORD (McCune and Mefford, 1999) using Sorensen distance and the "slow and thorough" autopilot setting (random starting coordinates, 250 runs with real and 250 runs with randomized data, maximum of 500 iterations per run, $10e^{\wedge -7}$ stability criterion).

We used nMDS ordinations to visualize the similarity between CWT and WCSGSI based stock-specific distributions across catch-area x month strata. These ordinations were based on stock-data x stock-data Sorensen distance matrices which were calculated from stock-data x month-area matrices of the estimated relative encounter rate of various salmon stocks. Separate ordinations were created to compare estimates based on CWT data from each time period with estimates based on WCSGSI data pooled over 2010 – 2011.

Multi-Response Permutation Procedures (MRPP)

MRPP are tests that compare pre-defined groups of objects based on the average between-object distance within each group (Berry and Mielke, 1983). All MRPP analyses were automated by PC-ORD version 6 (McCune and Mefford, 2011). The first step of MRPP is to calculate the average within-group distance x_i for each group *i*. The separation between points in each group is then characterized by delta, the weighted mean within group distance (McCune et al., 2002) :

Equation 6 – Weighted mean within group distance,

$$\text{delta} = d = \sum_{i=1}^{g} C_i x_i$$

for *g* groups where C is a weight dependent on the number of items in each group. The weighting recommended by PC-ORD was calculated as (from McCune et al., 2002):

Equation 7 – Used for weighting groups in MRPP,

$$C_i = \frac{n_i}{N}$$

Where n_i is the number of objects in group i and *N* is the total number of objects. Smaller values of delta indicate a tendency for clustering and larger values indicate little clustering. Once delta has been calculated, the next step is to evaluate whether a delta that small is unusual with respect to other possible partitions of the same size that could be made with the same objects. PC-ORD approximates the distribution of all possible deltas from a continuous Pearson type III distribution. The test statistic, T is then calculated as (from McCune et al., 2002):

Equation 8 – Test statistic for MRPP,

$$T = \frac{d - m_d}{s_d}$$

Where T equals the observed delta (*d*) minus the expected delta (mean delta, m_d) divided by the standard deviation of expected delta (s_d). The more negative *T*, the stronger the separation between the groups being compared. The p-value associated with *T* is determined by numerical integration of the Pearson type III distribution. A more specific description of how the pvalue is determined can be found in Mielke et al. (1980). Lastly, PC-ORD provides the chance-corrected within-group agreement (A) which is calculated as (from McCune et al., 2002):

Equation 9 – Chance-corrected within group agreement,

$$A = 1 - \frac{d}{m_d}$$

The agreement statistic provides a measure of effect strength independent of the sample size and describes within group homogeneity. *A* ranges from 0 – 1 and values greater than 0.3 are considered to be large (McCune et al., 2002). Large values of *A* indicate high within-group homogeneity.

In this study, MRPP was used to test the hypothesis of no difference in average within-group ranked Sorensen distances between paired groups of objects. Our “objects” were the stock-data objects that were plotted via nMDS ordination. The stock-data objects were grouped based on distribution patterns that were revealed in our tileplots. We overlaid polygons on the nMDS ordinations to provide visual representation of the groups being tested by MRPP. Rank-transformed MRPP was chosen to enhance the correspondence of MRPP results with the nMDS ordinations which were used to illustrate the relationship between objects (McCune et al., 2002).

Spearman correlation coefficient (r)

We utilized Spearman’s *rho* to evaluate if stock-specific distribution estimates based on CWT data were correlated to stock distribution estimates based on WCSGSI data. We created month-area-data x stock matrices of relative abundance (Figure 2). Spearman’s rho was then calculated on a stock by stock basis between pairs of CWT and WCSGSI relative abundance estimates (for example the distribution of Rogue River Chinook as estimated by CWT data and the distribution of Rogue River Chinook as estimated by GSI), where each data point is the stock-specific month and location.

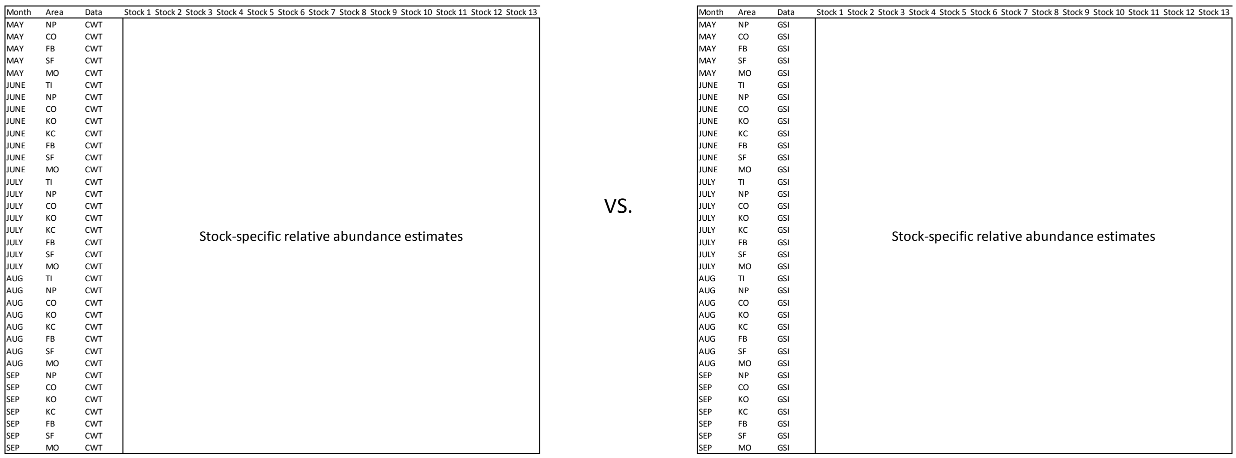

Figure 2. Example of how stock-specific relative abundance matrices were constructed. Areas: TI – Tillamook, NP – Newport, CO – Central Oregon, KO-Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey. Data denotes which data type was utilized to estimate relative abundance. Matrices such as these served as the backbone for many of the analyses presented in this study.

The fundamental idea behind the Spearman r coefficient is that two variables carry the same information if the object with the highest rank of variable 1 also has the highest rank of variable 2 and so on for all other objects (Legendre and Legendre, 2012). The formula for calculating Spearman correlation between variable j and variable k is:

$$r_{jk} = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n^3 - n}$$

where *d* is the difference in ranks of variable *j* and *k* for object *i* of *n* total objects. The coefficient ranges from -1 to 1. Variables that are perfectly matched, in term of ranks, would equal 1 in a direct relationship, -1 for an inverse relationship and zero when monotonic relationship between the two variables is absent. Significance of the Spearman coefficient is tested against the null hypothesis that r=0. We used the statistical program R to compute all correlation coefficients. R determines the p-value associated with the correlation between two variables by using algorithm AS 89 adapted from Best and Roberts (1975).

Utilizing GSI to identify distribution patterns at resolutions beyond the capacity of CWTs

It is difficult if not impossible to use CWT data to investigate fine scale distribution patterns due to the difficulty of recovering adequate numbers of tagsand the coarse spatial scale reported for recoveries. CWT data are reported by catch areas (i.e. Tillamook, Newport, Southern Oregon, etc.), which are quite large. CWT recovery data also provide the year and statistical week when a tag was recovered which would hypothetically allow CWT data to inform us of salmon distributions at weekly intervals. However adequate numbers of CWTs are rarely recovered over such short intervals making it difficult to use CWT data to investigate weekly or even bi-monthly distribution patterns. Furthermore, historical fishing effort data is not readily obtainable at the weekly or bi-monthly time interval. Therefore, the finest space-time scale at which CWT data can readily provide information regarding salmon distributions is the *catch-area x month* space-time scale.

One of the key contrasts between these data is that WCSGSI data provide the specific time, latitude and longitude for each individual assignment on record. Given adequate numbers of encounters, one could investigate stock distribution patterns at any space time scale. However, similar to CWT data, as the space-time scale becomes more refined it becomes more difficult to encounter adequate numbers of fish. We used WCSGSI data to calculate stock specific encounter rates at three additional space-time scales: *bi-month x area*, *month x bi-area* and *bi-month x bi-area*. Similar to our investigation of WCSGSI and CWT data at the month x area scale, tileplots were utilized to provide graphical representation of how effort, encounters and estimated encounter rate were concentrated through space and time. Those tileplots were subsequently used to make inferences about whether WCSGSI data may be able to reveal fine scale marine distribution patterns of Chinook salmon (Figure 3).

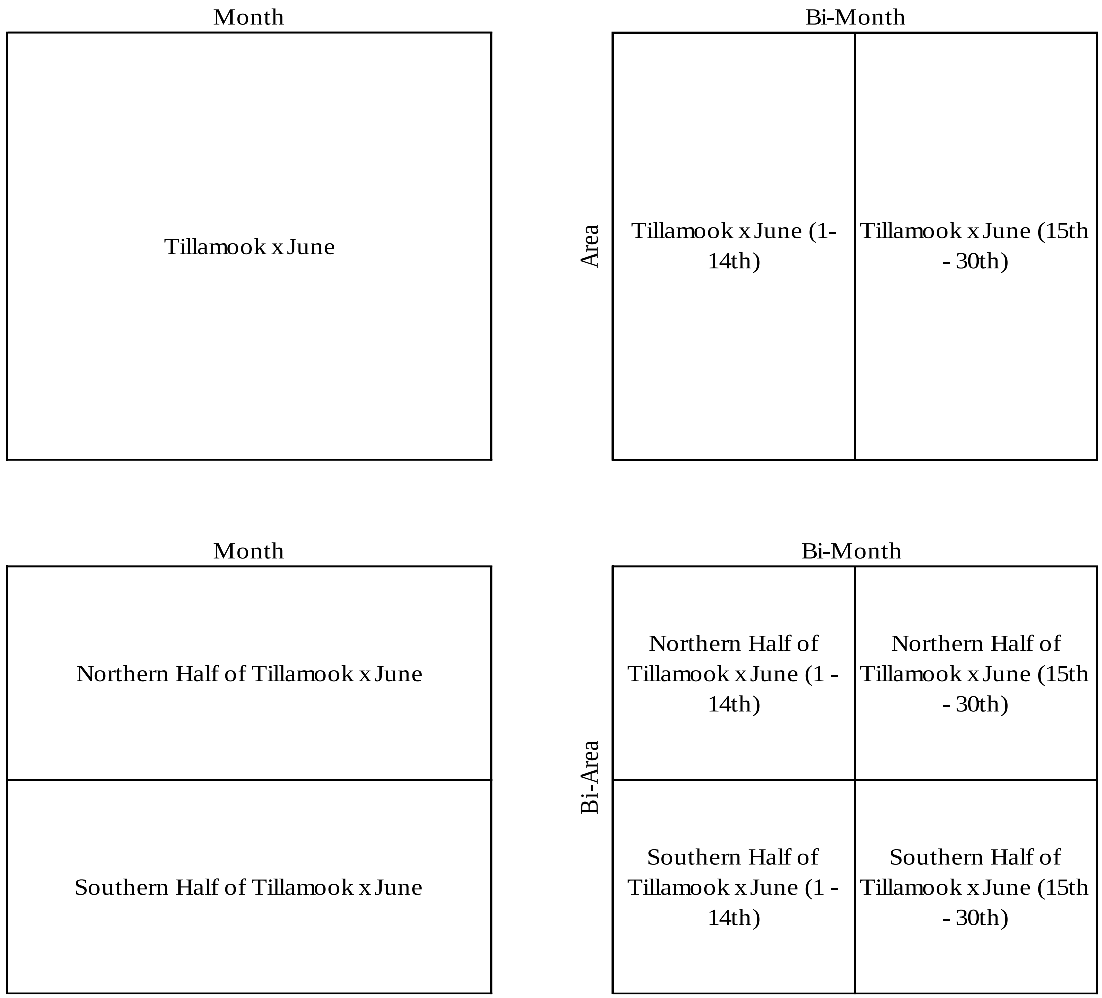

Figure 3. Examples of the space-time scales explored with data collected by the West Coast Salmon Genetic Stock Identification collaboration.

Lastly, Mantel's method was employed to evaluate inter-annual variation between data from years 2010 and 2011 aggregated over each spatiotemporal scale. The Mantel's tests were based on pairs of Sorensen distance matrices, one from each year (2010 and 2011), calculated from stock x area-month matrices of estimated encounter rate. This method tested the null hypothesis of no relationship between distance matrices based on 2010 and 2011 relative abundance estimates. The Mantel test was used to evaluate whether the data were consistent between years, which could be important if these data were used to support management concepts based on consistent temporal patterns of stocks across space.

Results

Our objective was to investigate the capacity of CWT and GSI data to characterize distribution patterns of specific stocks of Chinook salmon off the coasts of Oregon and California. We utilized tileplots to provide visual representation of CWT and GSI-based distribution patterns. The relationship between patterns provided by each data type was evaluated with Spearman's correlation, Mantel's method, ordination and multi-response permutation procedures. Additionally, we used GSI data to estimate Chinook salmon distributions at refined space-time scales and evaluated consistency of these distributions between 2010 and 2011.

Recovery statistics

We compared WCSGSI data aggregated from 2010 - 2011 to CWT data aggregated from three different time periods, early (1977 – 1983), mid-late (1987 - 2011) and late (2010 - 2011), to compare CWT- and GSI-based estimates of Chinook salmon distributions off the coasts of Oregon and California. This study utilized a total of 77,196 CWT recoveries. Of those, 9,980 were recovered during the early period, 61,445 during the mid-late and 5,711 recovered during the late period. We used standard methods to expand CWT recoveries to account for tagging rates. Expanded, the CWT recoveries represented an estimated 1.4 million Chinook salmon.

Chinook salmon distributions estimated from CWT data were compared with distribution estimates derived from 15,394 GSI individual assignment estimates gathered by the WCSGSI collaboration during 2010 (6,955) and 2011 (8,439).

CWT recoveries and fishing effort aggregated over the mid-late and late periods shared a similar distribution across catch areas with WCSGSI encounters and sampling effort. Recoveries, encounters and effort were concentrated in Newport, Southern Oregon, Fort Bragg and San Francisco and were largely absent in Tillamook and Klamath Oregon (Figure 4). The WCS-GSI collaboration collected a moderate number of samples in the Klamath California area, where constraining fishing regulations resulted in very few CWT recoveries during the mid-late and late period. CWT data aggregated over the early period were unique when compared to all other aggregates, with the greatest number of recoveries, as well as the most fishing effort, occurring in the Klamath California area. Nearly 60% of all CWTs recovered during the early period were recovered from the Klamath Oregon and Klamath California catch areas. There was a general lack of recoveries (Figure 4a) and effort (Figure 4b) in the Tillamook area across each of the data aggregates.

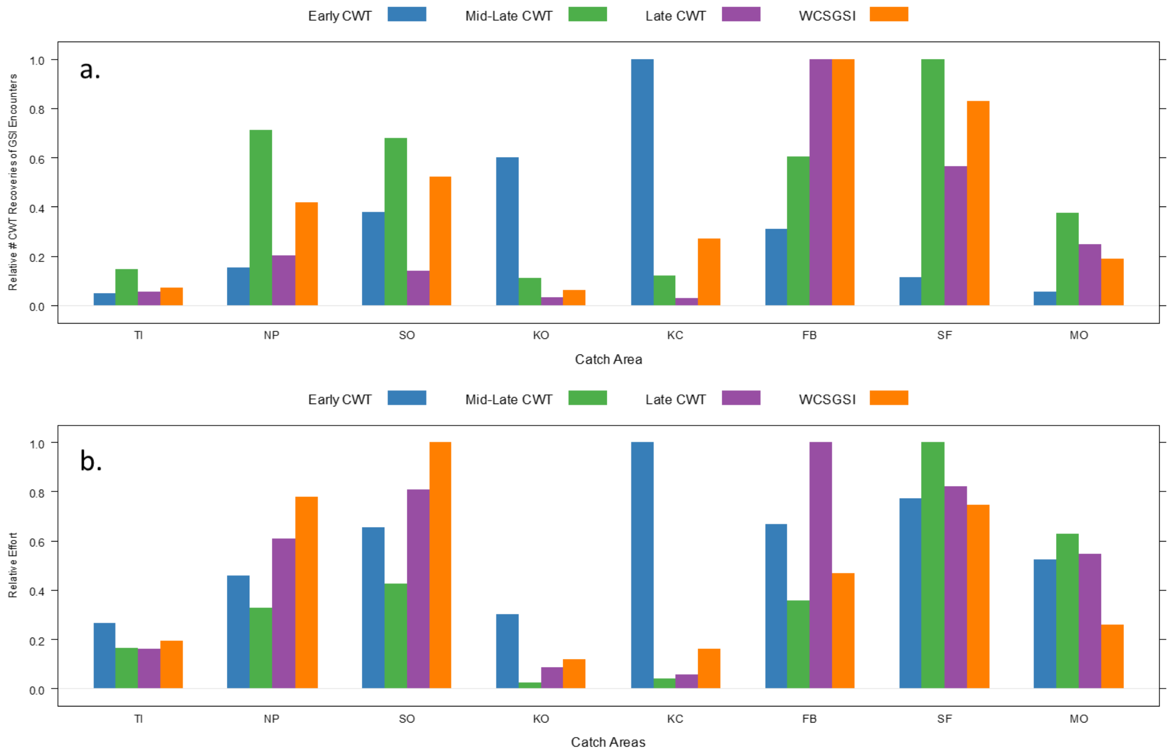

Figure 4. Panel (a. is a barplot depicting the relative number of CWT recoveries or GSI encounters in each catch area (TI – Tillamook, NP – Newport, CO – Central Oregon, KO- Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey) during each time period-data aggregate (Early: CWTs, 1977 – 1983; Mid-Late: CWTs, 1987 – 2011; Late (CWTs, 2010 – 2011; and WCSGSI (GSI, 2010 – 2011). No expansions were applied to CWT data to account for tagging or sampling rates. Panel (b. is a barplot depicting the relative fishing effort expended in each catch area by the commercial fleet (Early, Mid-late, Late bars) and by samplers employed by the WCSGSI.

The distribution of recoveries, encounters and effort across months varied slightly between data aggregates (Figure 5). Data aggregated over the early period indicated that CWT recoveries (Figure 5a) and fishing effort (Figure 5b) were high in May, decreased in June, then peaked during July and August. Data aggregated over the mid-late period indicated that CWT recoveries and fishing effort were spread more or less evenly across months. The late period CWT aggregate indicated that the greatest number of recoveries, as well as the most fishing effort, occurred during July and August. Finally, the WCSGSI collaboration appeared to have collected tissue samples from the greatest number of salmon between June and August. Fishing effort expended by the WCSGSI had a bi-modal distribution across months with peaks occurring in June and August. One commonality shared across all data aggregates was a general dearth of data gathered, or effort expended, during September.

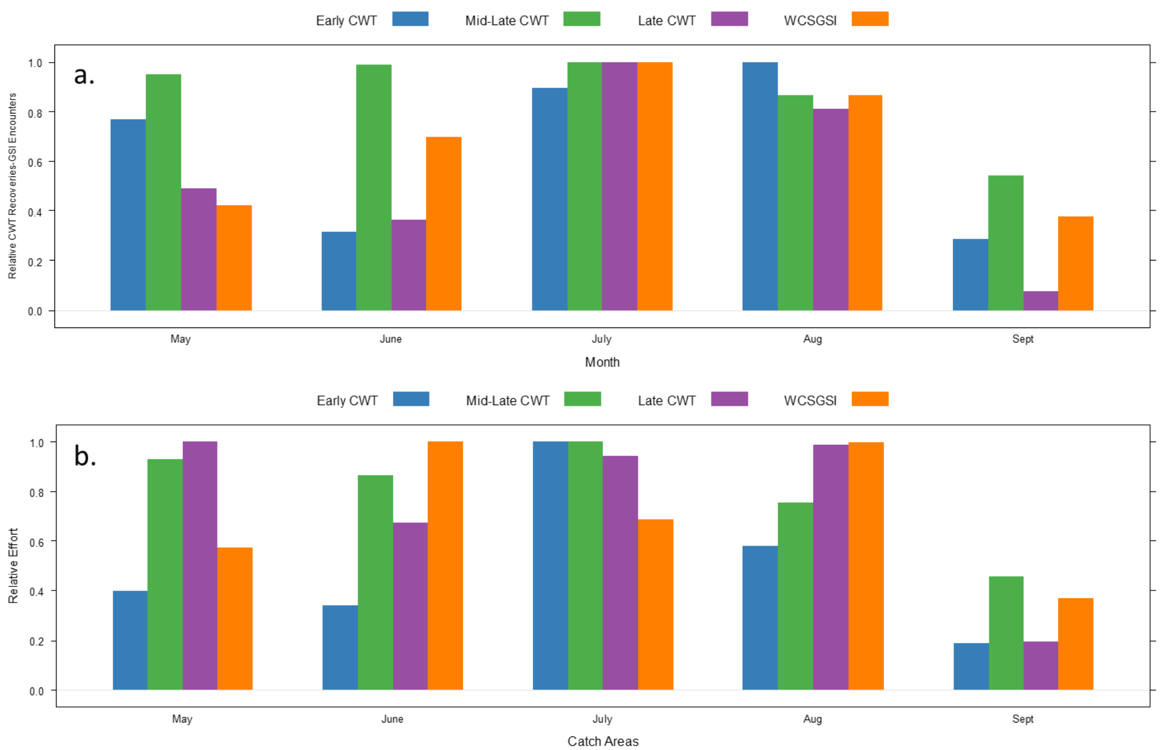

Figure 5. Panel (a. depicts the relative number of CWT recoveries or GSI encounters for each month (May - September) across data aggregates (Early: CWTs, 1977 – 1983; Mid-Late: CWTs, 1987 – 2011; Late: CWTs, 2010 – 2011; WCSGSI: GSI, 2010 – 2011). Panel (b. illustrates the relative amount of fishing effort during each month across data aggregates.

Specific stocks were included in this study if there was an average of at least 10 CWT recoveries (before expansion) or 10 GSI encounters per year over the time period the data were aggregated. Nine stocks met that criterion in the early aggregate. Of those nine, CWTs from Klamath (55.5% of total recoveries), Rogue (26.1%) and Central Valley Fall (8.8%) Chinook salmon were recovered in the greatest numbers (Fig. 6). Twelve stocks met the criterion for the mid-late CWT aggregate and, once again, the majority of recoveries came from the same three stocks. However it was Central Valley Fall (50.4% of total recoveries), rather than Klamath River (21.5%), that made up the greatest proportion of CWTs recovered. Moderate to low numbers of Mid-Oregon coastal, Snake River, Northern California/Southern Oregon coastal and Upper Columbia Summer/Fall were also recovered from 1987 - 2011. The late CWT aggregate featured 11 stocks that met our criterion and was dominated by recoveries of Central Valley Fall stock (71% of total recoveries).

Fifteen stocks from the WCSGSI aggregate met our criterion. Similar to the mid-late and late period CWT aggregates, the greatest number of encounters assigned as Central Valley Fall Chinook (46%; Figure 6). The WCSGSI collaboration encountered low to moderate numbers of Rogue, Klamath, Mid-Oregon Coastal, Mid-Columbia Tule, Northern California/Southern Oregon coastal, and Upper Columbia Summer/Fall Chinook. A notable difference between the CWT and GSI datasets was that the WCSGSI collaboration encountered a relatively large number of California Coastal Chinook (first stock listed in Figure 6). California Coastal Chinook, a stock of wild salmon, have rarely been tagged and therefore CWT data are unable to provide specific information on where and when these fish are encountered. California Coastal Chinook salmon are listed as threatened under the Endangered Species Act.

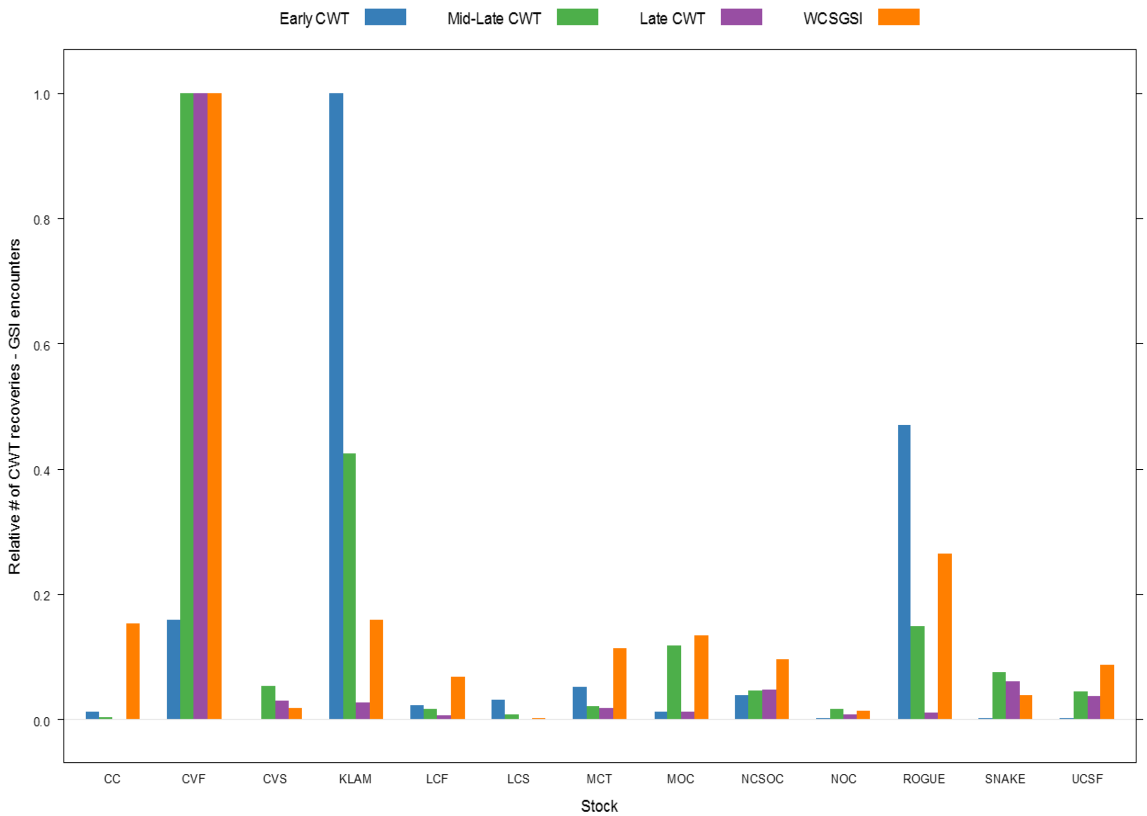

Figure 6. Barplot illustrating the relative number of CWT recoveries or WCSGSI encounters in each data aggregate across 13 stocks of Chinook salmon. There are four data aggregates: Early (CWTs, 1977 – 1983), Mid-Late (CWTs, 1987 – 2011), Late (CWTs, 2010 – 2011) and WCSGSI (GSI, 2010 – 2011). Chinook stock abbreviations: CC – California Coastal, CVF – Central Valley Fall, CVS – Central Valley Spring, K – Klamath, LCF- Lower Columbia Fall, LCS – Lower Columbia Spring, MCT – Mid Columbia Tule, MOC – Mid-Oregon Coastal, NCSOC – Northern California/Southern Oregon Coastal, NOC – North Oregon Coastal, R – Rogue, S – Snake, UCSF – Upper Columbia Summer/Fall.

Distribution of CWT recoveries, WCSGSI encounters, fishing effort and relative encounter rate

The distributions of expanded CWT recoveries, WCSGSI encounters, fishing effort and estimated encounter rate were plotted at the *area x month* (e.g. Newport x June) space-time scale (Figures 7 – 9). The early CWT, mid-late CWT, late CWT and WCSGSI data aggregates were able to provide abundance estimates across 40, 40, 33 and 38 of the 40 possible area x month strata, respectively. The patterns illustrated in Figures 7 – 9 suggested that the distribution of WCSGSI encounters, sampling effort and encounter rate are more similar to the distribution of mid-late and late period CWT data than to CWT data collected during the early period.

The distribution of WCSGSI encounters (Figure 7d) appeared to share three distinguishing characteristics with CWT recoveries aggregated over the mid-late (Figure 7b) and late periods (Figure 7c): relatively high concentrations of CWT recoveries and GSI encounters in the Newport, Southern Oregon, Fort Bragg, and San Francisco areas, low concentrations of recoveries and encounters in the Tillamook, Klamath Oregon and Klamath California areas, and an apparent shift in concentration from San Francisco to the north as the season progresses. A comparison of plots based on late period CWT (Figure 7c) and WCSGSI data (Figure 7d) reveals an advantage of utilizing GSI technology to monitor Chinook distributions: because genetic samples can be taken non-lethally the WCSGSI collaboration was able to collect samples during non-retention fisheries in 2010 (Table 7). The information from those samples allowed insight into how Chinook were distributed in areas closed to retention fishing (i.e. Klamath California and Fort Bragg during June, all areas during September). The distribution of CWT recoveries from the early period (Figure 7a) appeared to be concentrated in areas to the north of and including the San Francisco catch area with the greatest number of recoveries occurring in July and August. A comparison of tileplots based created from the early and mid-late periods reveals fisheries closures in the Klamath Oregon and Klamath California catch areas that began in the late 1980s (Figure 7a vs. 7b).

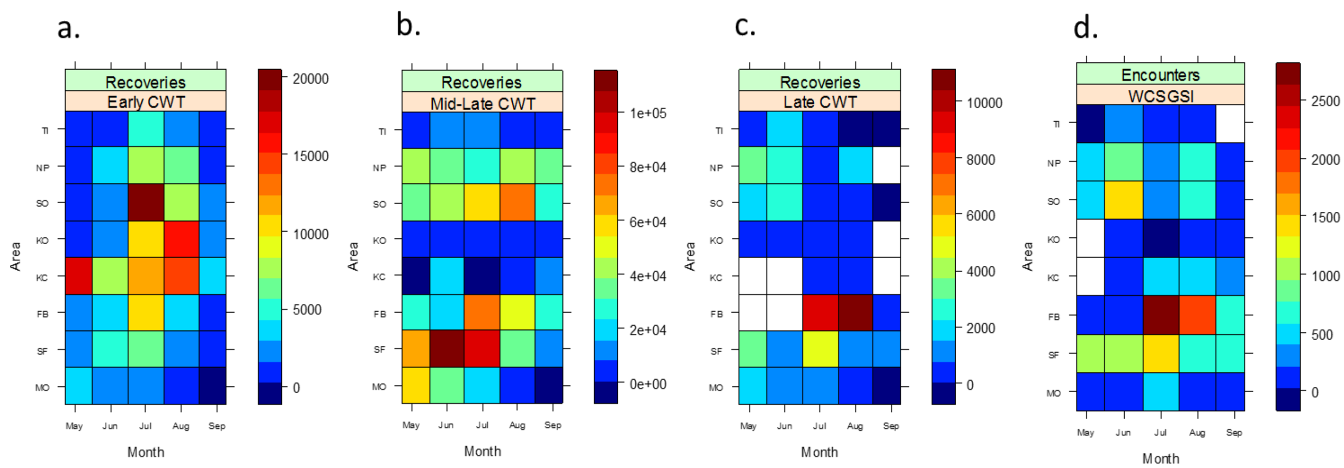

Figure 7. Tileplots illustrating the distribution of total CWT recoveries (panels a – c) and WCSGSI encounters (panel d). The deep red tile represents the space time stratum where the greatest number of CWTs were recovered or GSI samples were collected. White tiles indicate space-time strata where no fishing effort took place. These plots were created from four different data aggregates: Early (CWTs, 1977 – 1983), Mid-Late (1987 – 2011), Late (2010 – 2011), and WCSGSI (2010 – 2011). Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

Tileplots of fishing effort (Figure 8) revealed distribution patterns that were comparable to those observed in plots depicting the distribution of recoveries (Fig. 7).

WCSGSI sampling effort (Figure 8d), as well as total commercial effort during the late period (Figure 8c), appeared to be greatest in the Newport, Southern Oregon, Fort Bragg and San Francisco catch areas. The distribution of effort during the mid-late period (Figure 8b) appeared similar, but with noticeably more effort occurring in Monterey, the southernmost catch area. The distribution of effort as estimated by data aggregated over the early period (Figure 8a) was unique when compared to the mid-late, late and WCSGSI aggregates. During the early period, fishing effort was focused south of the Oregon-California border during May and June, and then spread evenly along the coast from July through August. Effort was low in Tillamook and Brookings, as well as during the month of September, regardless of the data aggregate being examined.

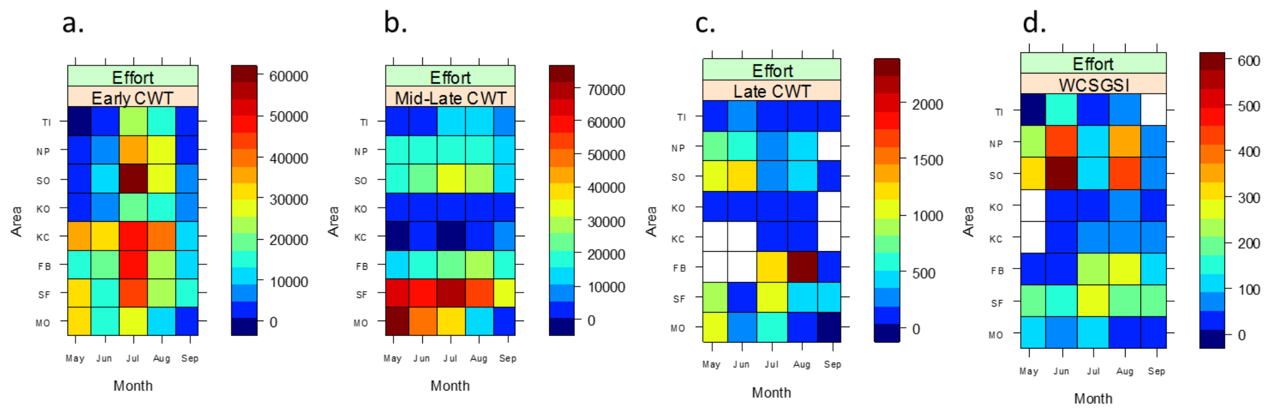

Figure 8. Tileplots illustrating the distribution of the fishing effort data used in this study. Panels a – c are based on historical fishing effort data obtained from the Pacific Fisheries Management Council. Panel (d.) illustrates the distribution of sampling effort expended by fishermen collaborating with WCSGSI. The deep red tile represents the space time stratum where the greatest amount of fishing effort took place. White tiles represent strata where no fishing effort occurred. These plots were created from four different data aggregates: Early (CWTs, 1977 – 1983), Mid-Late (1987 – 2011), Late (2010 – 2011), and WCSGSI (2010 – 2011). Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

CWT- and GSI-based estimates of overall (i.e. not stock-specific) relative Chinook abundance were plotted at the catch-area x month space-time scale (Figure 9) to create a visual representation of this species' catch distribution through space and time. Distribution patterns varied depending on the data aggregate from which they were estimated. Plotting relative encounter rate estimated from the early period CWT aggregate (Figure 9a) revealed that Chinook salmon were evenly distributed from Newport through Klamath California for the duration of the season with localized concentrations of Chinook occurring in Tillamook during May and in the Klamath Oregon and Klamath California areas as the season progressed. In the mid-late period, Chinook were encountered coast-wide during May and June (Figure 9b). The distribution of encounter rate during the mid-late period narrowed slightly as the season progressed; by September salmon appeared to be encountered at the highest rate between Newport and Fort Bragg. Our late-period CWT tileplot (Figure 9c) suggested Chinook were encountered coast-wide but at relatively low rates in Southern Oregon and Klamath Oregon and at relatively high rates south of the Oregon-California border. The late period CWT aggregate also revealed evidence of a south – north shift in where encounter rate was greatest, hinting at the possibility of a south - north migration of Chinook salmon occurring off the California coast during the commercial troll fishery in 2010 and 2011. Reflecting patterns observed in the plot based on late-period CWT data, our plot based on WCSGSI data (Figure 9d) indicated that Chinook salmon were encountered at higher rates south of the Oregon/California border and strongly suggested the existence of a shift in overall salmon density from San Francisco to the Klamath California area as the season progressed. Lastly, although not as clear as the south – north shift of encounter rate, the tileplot estimated from WCSGSI data (Figure 9d) suggested that salmon may converge from both the south and north as the season progresses.

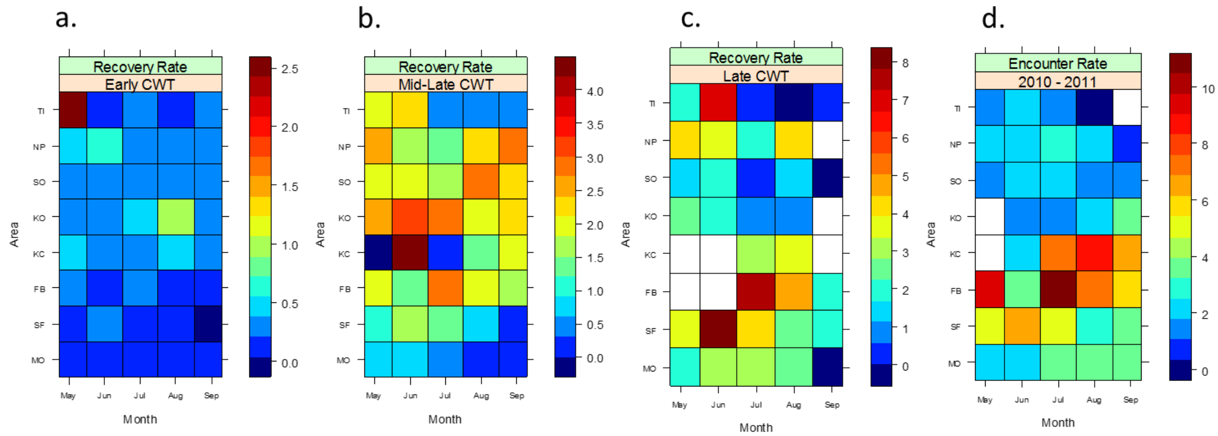

Figure 9. Tileplots illustrating the distribution of estimated CWT recovery and WCSGSI encounter rates. The tile with a value of 1 (indicated by deep red) represents the space-time stratum where the highest estimated recovery or encounter rate occurred. White tiles represent space-time strata where no fishing effort took place. The deep red tile represents the space time stratum with the greatest estimated recovery rate. White tiles represent strata where no fishing effort occurred. These plots were created from four different data aggregates: Early (CWTs, 1977 – 1983), Mid-Late (1987 – 2011), Late (2010 – 2011), and WCSGSI (2010 – 2011). Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

Comparison of CWT and WCSGSI based stock specific distribution patterns

CWT- and GSI-based stock-specific relative encounter rate estimates were plotted across 40 month x area strata (Figures 10 – 19). These plots were created to provide a visual reference for how catch patterns differ between data types. The plots revealed two key findings: 1) CWT and WCSGSI data appear to provide a similar representation of stock specific catch distribution at the month x area space-time scale and, 2) Chinook salmon encountered in commercial troll fisheries off the coasts of Oregon and California exhibit one of three broad catch patterns: primarily encountered north of the Oregon/California border (“Oregon” pattern), primarily encountered between Southern Oregon and Fort Bragg ("Southern Oregon/Northern California"; "S OR/N CA" pattern) or, historically encountered coast-wide but encountered south of the Oregon/California border during 2010 and 2011 ("Central Valley" pattern).

The "Oregon" pattern consisted of stocks that were encountered primarily north of the Oregon-California border. Seven Chinook stocks exhibited this pattern: Lower Columbia Fall, Lower Columbia Spring, Mid-Columbia Tule, Northern Oregon Coastal, Upper Columbia Summer/Fall, Mid-Oregon Coastal and Snake River. Plots based on CWT (all aggregates) and WCSGSI data both suggested that these stocks were concentrated in waters off the Oregon coast during the commercial troll fishery (Figures 10 - 13). Tileplots created from the Early CWT (Figure 10a) aggregate were difficult to interpret (due to high estimated relative encounter rates in the Tillamook x May stratum, a result of relatively low fishing effort in the Tillamook x May stratum but many fish caught) but nevertheless indicated these stocks were encountered primarily north of the border. Relative abundance estimated from the mid-late (Figure 11), late (Figure 12) and WCSGSI (Figure 13) aggregates suggested that two subgroups existed within stocks that exhibit the Oregon distribution, with one subgroup being encountered further south than the other: Mid-Oregon Coastal, Upper Columbia Summer/Fall and Snake River stocks were consistently encountered, albeit at a low rate, south of the Oregon-California border (Fig. 11e – g, Fig. 12d – e, Fig. 13e – g). Interestingly, the plot of Mid-Oregon Coastal Chinook salmon as estimated by the WCSGSI aggregate depicted a convergence on the Southern Oregon and Klamath Oregon catch areas from the north and south as the season progressed (Figure 13 panel f).

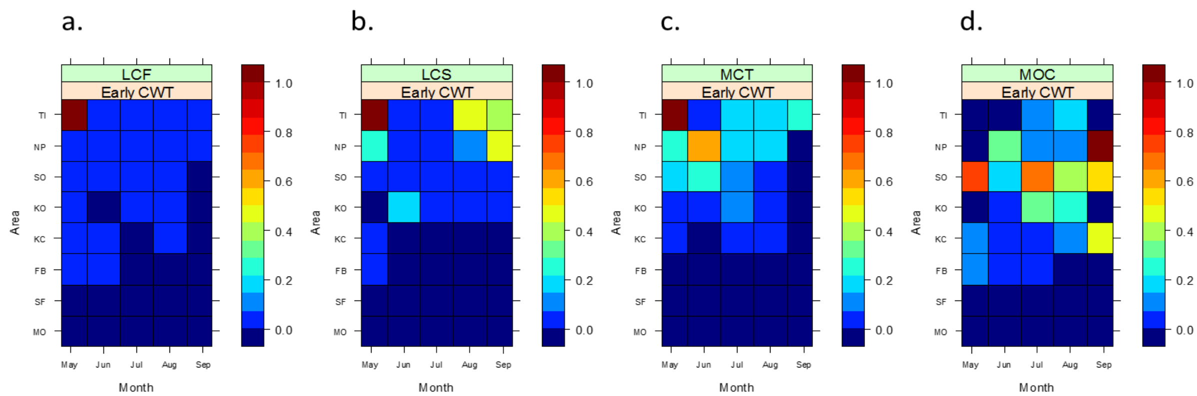

Figure 10. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the “Oregon” distribution as estimated by the Early CWT aggregate (CWT data collected from 1977 – 1983). Four stocks that exhibit this distribution can be plotted from the Early CWT aggregate: Lower Columbia Fall (LCF), Lower Columbia Spring (LCS), Mid-Columbia Tule (MCT), and Mid-Oregon Coastal (MOC). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery or encounter rate occurred (indicated by deep red). White tiles indicate space-time strata where no fishing effort occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

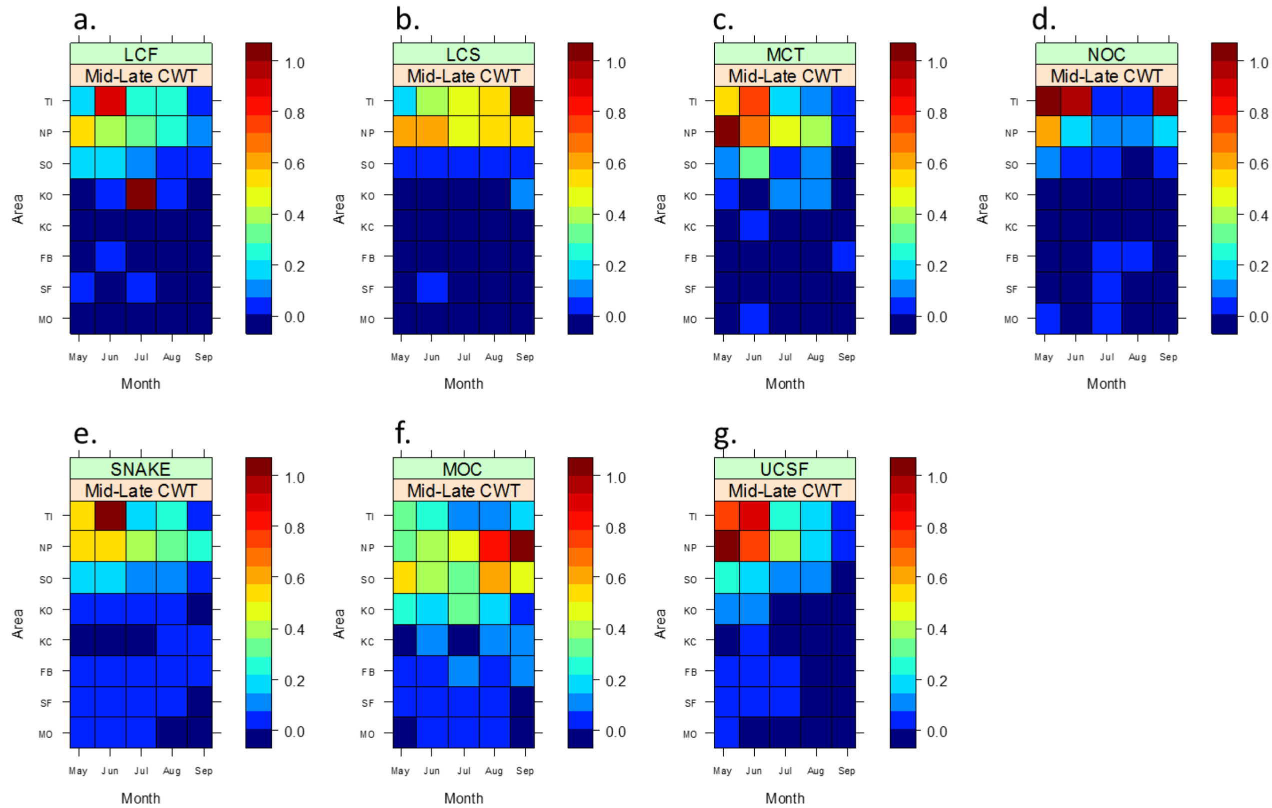

Figure 11. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the "Oregon" distribution as estimated by the Mid-Late CWT aggregate (CWT data collected from 1987 – 2011). Seven stocks that exhibit the Oregon distribution can be plotted from the Mid-Late CWT aggregate: Lower Columbia Fall (LCF), Lower Columbia Spring (LCS), Mid-Columbia Tule (MCT), Northern Oregon Coastal (NOC), Snake River (S), Mid-Oregon Coastal (MOC), and Upper Columbia Summer/Fall (UCSF).). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery or encounter rate occurred (indicated by deep red). White tiles indicate space-time strata where no fishing effort occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

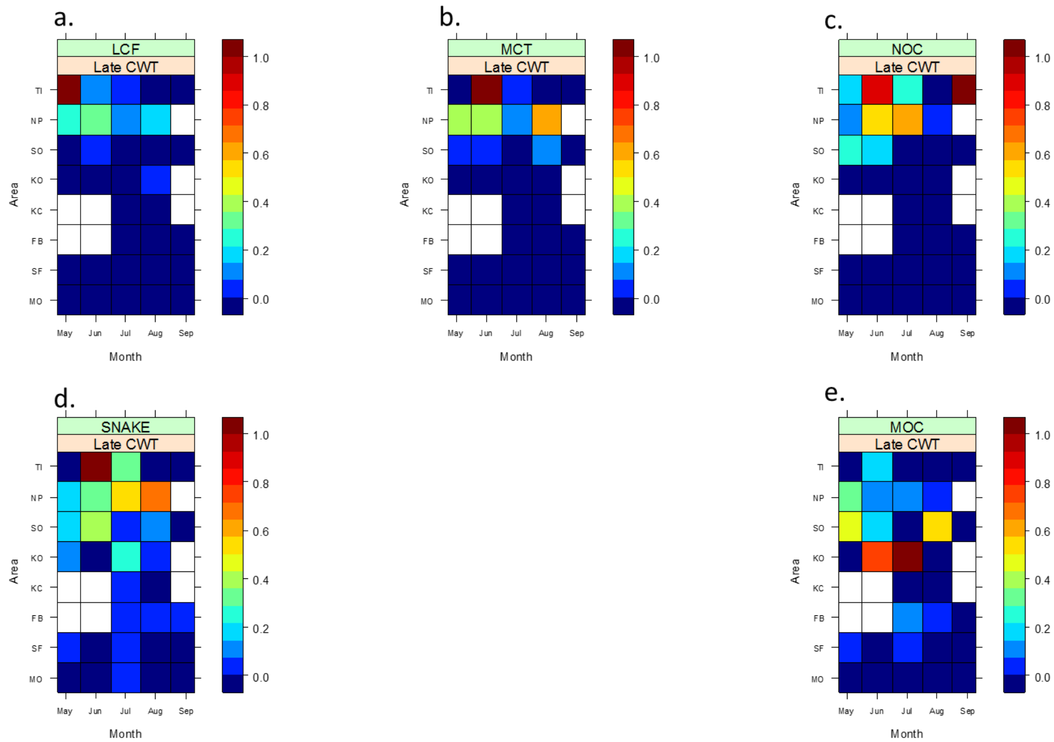

Figure 12. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the "Oregon" distribution as estimated by the Late CWT aggregate (CWT data collected from 2010 – 2011). Five stocks that exhibit the Oregon distribution can be plotted from the Late CWT aggregate: Lower Columbia Fall (LCF), Mid-Columbia Tule (MCT), Northern Oregon Coastal (NOC), Snake River (S), and Mid-Oregon Coastal (MOC). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery or encounter rate occurred (indicated by deep red). White tiles indicate space-time strata where no fishing effort occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

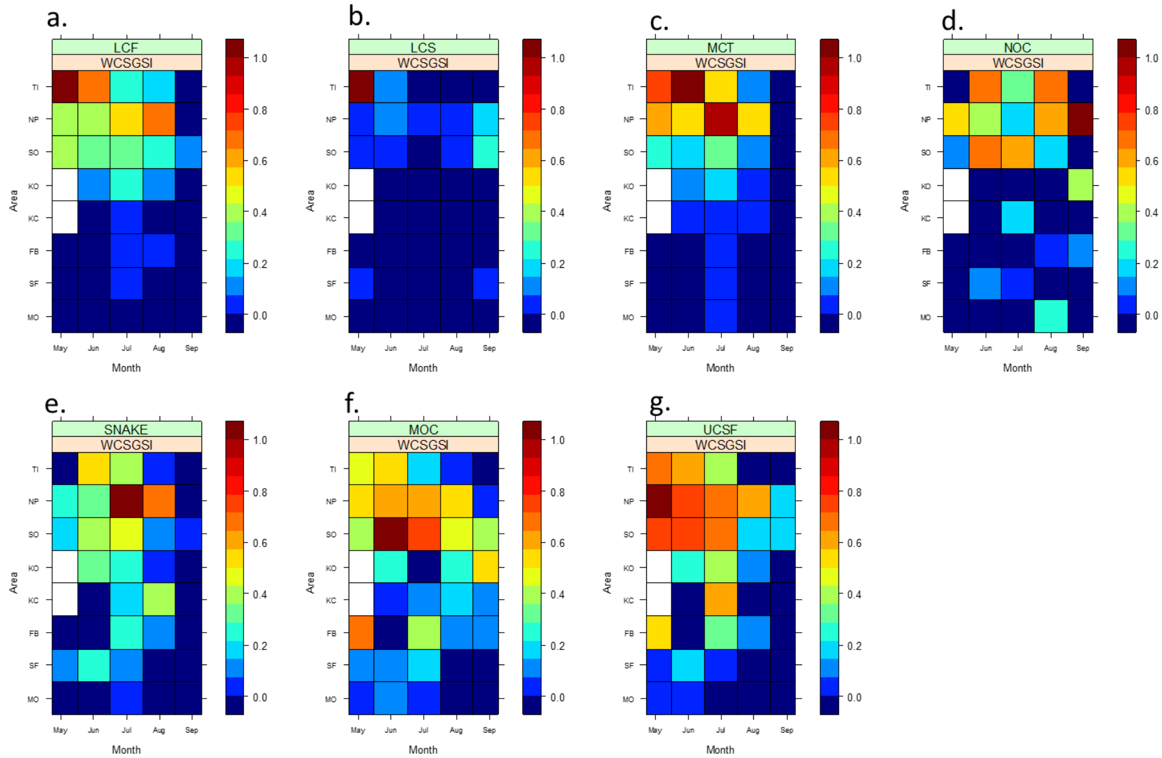

Figure 13. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the "Oregon" distribution as estimated by the WCSGSI data aggregate (GSI data collected from 2010 – 2011). Seven stocks that exhibit the Oregon distribution can be plotted from the WCSGSI aggregate: Lower Columbia Fall (LCF), Lower Columbia Spring (LCS), Mid-Columbia Tule (MCT), Northern Oregon Coastal (NOC), Snake River (S), Mid-Oregon Coastal (MOC), and Upper Columbia Summer/Fall (UCSF).). The tile with a value of 1 represents the space-time stratum where the greatest estimated encounter rate occurred (indicated by deep red). White tiles indicate space-time strata where no fishing effort occurred. Area labels: TI – Tillamook, NP – Newport, SO – Southern Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

The second pattern distribution pattern, Southern Oregon/Northern California, was exhibited by Rogue, Klamath, Northern California Southern Oregon Coastal and California Coastal stocks of Chinook salmon (Figures 14 - 17). Each series of plots calculated from CWT data (Figures 14 – 16) suggested that, while encountered coast-wide, these stocks were most commonly encountered from Southern Oregon to the Fort Bragg catch area. Conveying a slightly different distribution, tileplots based on WCSGSI relative abundance estimates (Fig. 16) suggested these four stocks were encountered primarily between Klamath Oregon and Fort Bragg, a narrower and more southerly distribution than what was suggested by our plots created from CWT data. Interestingly, WCSGSI tileplots also appeared to hint at a south to north shift in encounter rate as the season progressed from May through September.

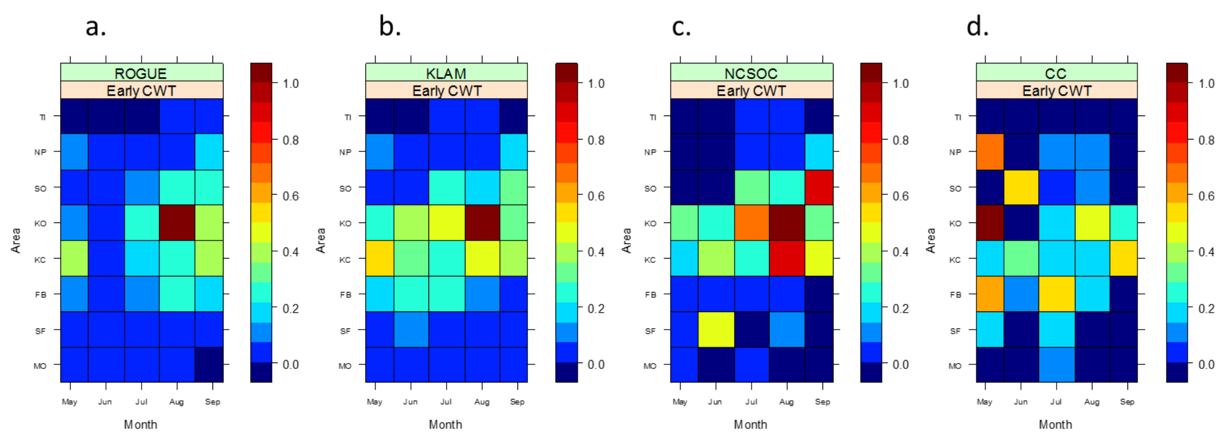

Figure 14. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the Southern Oregon/Northern California distribution pattern as estimated by the Early CWT aggregate (CWT data collected from 1977- 1983). Relative encounter rate for four stocks of Chinook salmon exhibiting the Southern Oregon/Northern California distribution pattern can be plotted from the Early CWT aggregate: Rogue River (R), Klamath River (K), Northern California/Southern Oregon Coastal (NCSOC), and California Coastal (CC). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery or encounter rate occurred (indicated by deep red). Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

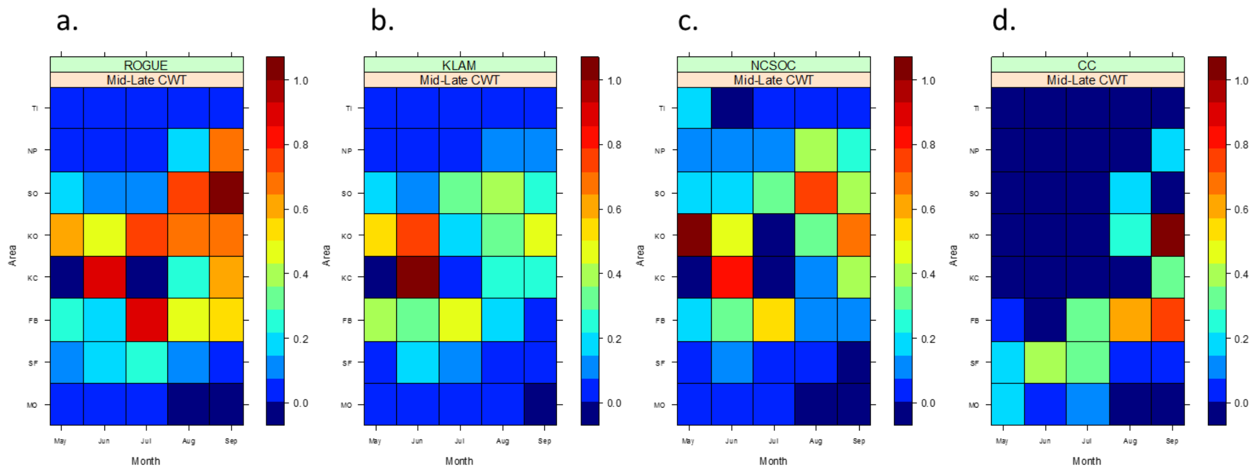

Figure 15. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the Southern Oregon/Northern California distribution pattern as estimated by the Mid-Late CWT aggregate (CWT data collected from 1987 - 2011). Relative encounter rate for four stocks of Chinook salmon exhibiting the Southern Oregon/Northern California distribution pattern can be plotted from the Mid-Late CWT aggregate: Rogue River (R), Klamath River (K), Northern California/Southern Oregon Coastal (NCSOC), and California Coastal (CC). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery or encounter rate occurred (indicated by deep red). Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

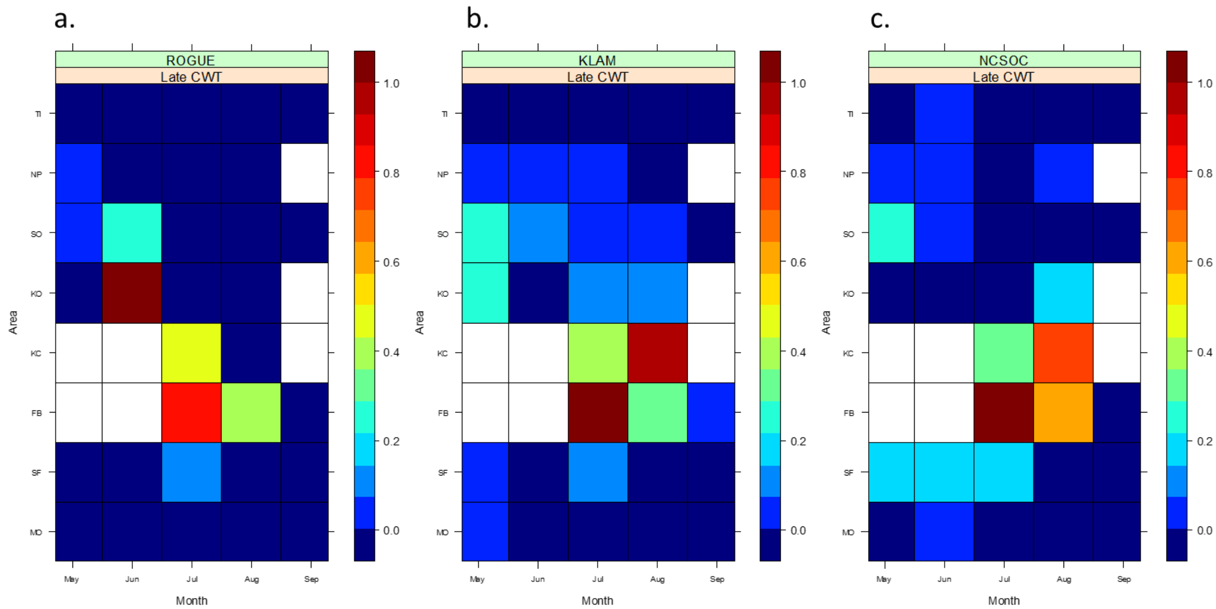

Figure 16. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the Southern Oregon/Northern California distribution pattern as estimated by the Late CWT aggregate (CWT data collected from 2010 - 2011). Relative encounter rate for three stocks of Chinook salmon exhibiting the Southern Oregon/Northern California distribution pattern can be plotted from the Mid-Late CWT aggregate: Rogue River (R), Klamath River (K), and Northern California/Southern Oregon Coastal (NCSOC). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery rate occurred (indicated by deep red). White tiles indicate strata where no fishing effort was expended. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

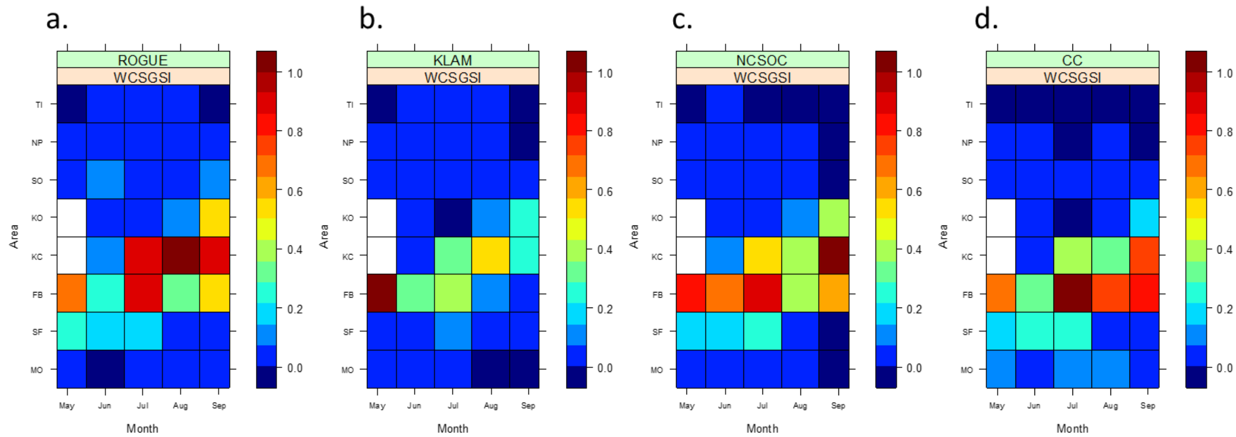

Figure 17. Tileplots illustrating the distribution of relative encounter rate for stocks exhibiting the Southern Oregon/Northern California distribution pattern as estimated by the WCSGSI aggregate (GSI data collected from 2010 - 2011). Relative encounter rate for four stocks of Chinook salmon exhibiting the Southern Oregon/Northern California distribution pattern can be plotted from the WCSGSI CWT aggregate: Rogue River (R), Klamath River (K), Northern California/Southern Oregon Coastal (NCSOC) and California Coastal (CC). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery rate occurred (indicated by deep red). White tiles indicate strata where no fishing effort was expended. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

Chinook salmon from California's Central Valley exhibited a unique catch distribution when compared to stocks belonging to the Oregon or S.OR/N.CA groups. Central Valley fall, and to a lesser degree Central Valley spring Chinook appeared to have two, possibly time-dependent, catch distribution patterns (Figures 18 & 19). Tileplots based on CWT recoveries from the mid-late period suggested Central Valley Fall were caught at relatively even rates off the shores of Oregon and California (Fig 18b). Conversely, early and late period CWT (Figs. 18a and 18c), as well as WCSGSI data (Fig. 18d), suggested that Central Valley Fall stock were encountered more frequently south of the Oregon-California border. The catch distribution of Central Valley Fall Chinook appeared to converge from the north and from the south to either San Francisco (as estimated by the WCSGSI aggregate) or Fort Bragg (as estimated by the CWT aggregates) as the season progressed.

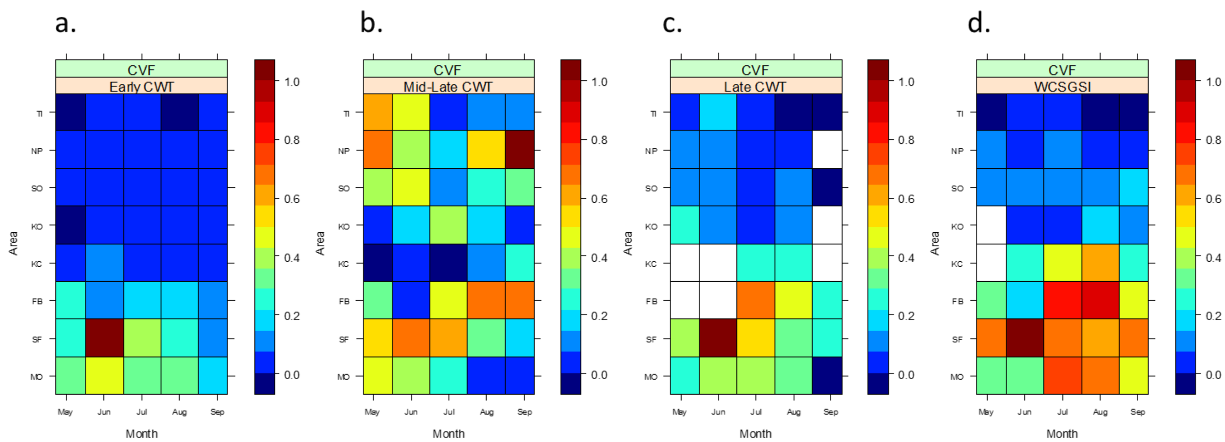

Figure 18. Tileplots illustrating the distribution of relative encounter rate for Central Valley Fall Chinook (CVF) as estimated by four different data aggregates (a. – Early: CWTs 1977 – 1983; b. – Mid-Late: CWTs 1987 – 2011; c. – Late: CWTs 2010 – 2011; d. – WCSGSI: GSI 2010 – 2011). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery rate occurred (indicated by deep red). White tiles indicate strata where no fishing effort was expended. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

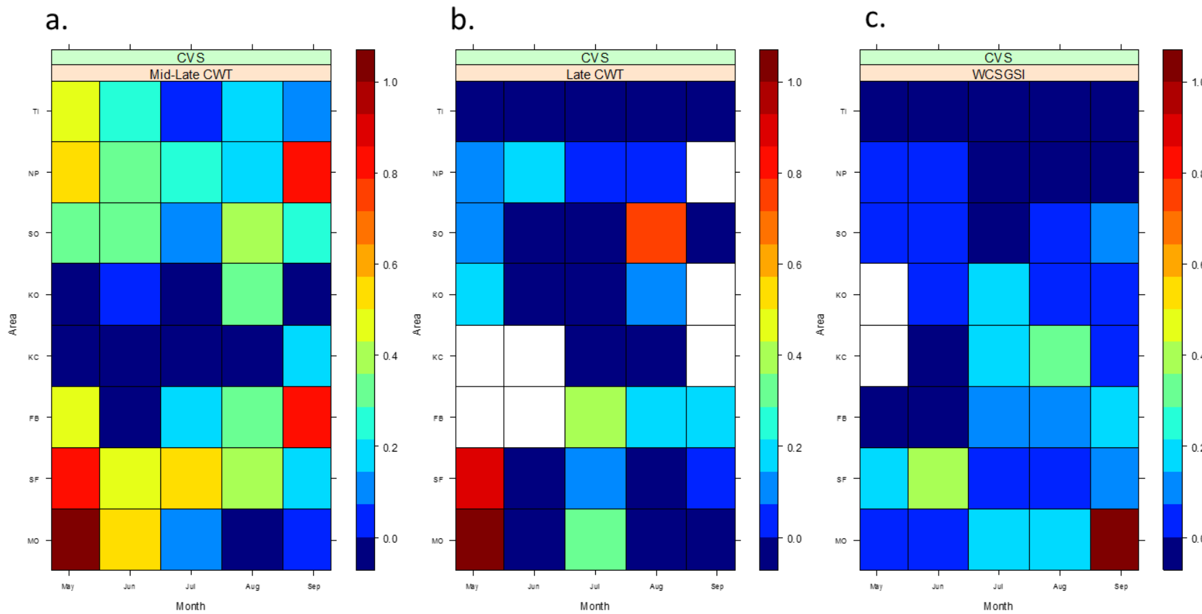

Figure 19. Tileplots illustrating the distribution of relative encounter rate for Central Valley Spring Chinook (CVS) as estimated by three different data aggregates (a. – Mid-Late: CWTs 1987 – 2011; c. – Late: CWTs 2010 – 2011; d. – WCSGSI: GSI 2010 – 2011). The tile with a value of 1 represents the space-time stratum where the greatest estimated recovery rate occurred (indicated by deep red). White tiles indicate strata where no fishing effort was expended. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey.

Statistical analyses

Spearman's Correlation

Spearman's rho correlation coefficient was used to evaluate the relationship between CWT- and GSI-based estimates of stock-specific relative abundance across catch-area x month space-time strata (Table 4). With few exceptions, and regardless of the time period over which the CWT were aggregated, the results indicated a moderate to strong positive correlation between CWT- and WCSGSI-based estimates.

This suggests our CWT- and GSI-based estimates of stock-specific relative abundance are more similar to one another than would be expected by chance.

Table 4. Spearman's rho correlations between CWT and WCSGSI based stock-specific encounter rate estimates. "CWT aggregate" indicates which CWT aggregate was used for comparison against the WCSGSI estimates. WCSGSI data were aggregated across 2010 - 2011. Bold text highlights insignificant correlations. Higher values of (r) denote stronger positive correlation between CWT and WCSGSI based encounter rate estimates.

Chinook stock	CWT aggregate being compared to GSI	r statistic	pvalue
California Coastal	Early (1977 - 1983)	0.46	0.001
Central Valley Fall	Early (1977 - 1983)	0.76	<0.001
	Mid-Late (1987 - 2011)	**0.16**	**0.15**
	Late (2010 - 2011)	0.8	<0.001
Central Valley Spring	**Mid-Late (1987 - 2011)**	**-0.14**	**0.81**
	Late (2010 - 2011)	**0.07**	**0.33**
Klamath	Early (1977 - 1983)	0.6	<0.001
	Mid-Late (1987 - 2011)	0.72	<0.001
	Late (2010 - 2011)	0.67	<0.001
Lower Columbia Fall	Early (1977 - 1983)	0.64	<0.001
	Mid-Late (1987 - 2011)	0.8	<0.001
	Late (2010 - 2011)	0.72	<0.001
Mid-Columbia Tule	Early (1977 - 1983)	0.81	<0.001
	Mid-Late (1987 - 2011)	0.71	<0.001
	Late (2010 - 2011)	0.71	<0.001
Mid-Oregon Coastal	Early (1977 - 1983)	0.39	0.007
	Mid-Late (1987 - 2011)	0.62	<0.001
	Late (2010 - 2011)	0.37	0.01
Northern California/Southern Oregon Coastal	Early (1977 - 1983)	0.35	0.01
	Mid-Late (1987 - 2011)	0.38	0.008
	Late (2010 - 2011)	0.56	<0.001
Northern Oregon Coastal	Mid-Late (1987 - 2011)	0.51	<0.001
	Late (2010 - 2011)	0.56	<0.001
Rogue River	Early (1977 - 1983)	0.63	<0.001
	Mid-Late (1987 - 2011)	0.68	<0.001
	Late (2010 - 2011)	0.47	0.003
Snake River	Mid-Late (1987 - 2011)	0.58	<0.001
	Late (2010 - 2011)	0.61	<0.001
Upper Columbia Summer/Fall	Mid-Late (1987 - 2011)	0.65	<0.001
	Late (2010 - 2011)	0.58	<0.001

There were three instances when CWT- and GSI- based relative abundance were not correlated to one another. Two such instances existed between CWT- and GSI-based estimates of the distribution of Central Valley Spring Chinook. CWT-based estimates of Central Valley Spring Chinook from both the middle and late periods had weak, and statistically insignificant correlation to the corresponding

WCSGSI-based estimate (middle: r = - 0.14, p = 0.81; late: r = 0.07, p = 0.33). The other insignificant correlation existed between relative abundance estimates of Central Valley Fall chinook calculated from mid-late period CWT and WCSGSI data (r = 0.16, p = 0.15).

Mantel test

Mantel's method was used to evaluate the correlation between pairs of distance matrices calculated from CWT and GSI based *stock x area-month* matrices of relative abundance (Table 5; see Figure 2 for example of matrix design). Three pairs of matrices were considered in this analysis: Early period CWT vs. WCSGSI, Mid-late period CWT vs. WCSGSI and Late period CWT vs. WCSGSI. Mantel's test requires each matrix in a pairing to consist of the same objects in the same order. Because CWT and WCSGSI data provided information across different strata, which was observed in the tileplots discussed previously, the matrices varied in dimension depending on the time period over which CWT recoveries were aggregated. The mid-late period CWT aggregate allowed for comparison across the greatest number of stocks and strata (12 and 37, respectively) while the late period allowed for the least (11 and 31). Results of the Mantel's test indicated that a moderate, positive, correlation existed between early period and WCSGSI based distance matrices (r = 0.71, p < 0.001) as well as between distance matrices calculated from midlate CWT and WCSGSI data (r = 0.71, p < 0.001) suggesting that those data aggregates are more similar to one another than would be expected by chance. Mantel's test between distance matrices calculated from the late period CWT and WCSGSI data aggregates indicated that there was no correlation (r = 0.1, p = 0.44). No tests were run between CWT aggregates as the main focus of this study was a comparison between CWT and GSI not CWT aggregates from different time periods.

Table 5. Mantel test to evaluate the correlation between Sornesen distance matrices calculated from CWT- and WCSGSI-based estimates of stock specific relative abundance for Chinook salmon. "CWT aggregate" indicates which CWT aggregate was used to estimate the CWT-based stock-specific relative abundance. All WCSGSI data were aggregated over 2010 and 2011. The standardized Mantel statistic (r) is calculated as the Pearson coefficient between the two matrices where higher values denote greater similarity.

CWT aggregate	Stock x Strata	r statistic	p-value
Early (1977 - 1983)	8 x 37	0.71	< 0.001
Mid-Late (1987 - 2011)	12 x 37	0.71	< 0.001
Late (2010 - 2011)	11 x 31	0.1	0.44

Non-metric multidimensional scaling (nMDS) ordination and MRPP

Variation between stock specific relative encounter rate estimates based on CWT and GSI data was explored with two multivariate statistical tools: nMDS ordination and MRPP (Figures 20 – 22). The results indicated that WCSGSI and CWT based stock-specific distribution patterns are similar at the catch-area x month space time scale. The nMDS ordinations of CWT and WCSGSI relative abundance estimates represented the data very well in 2 dimensions (final stress for each ordination <= 12). The ordinations tended to plot stocks in clusters that corresponded to the general distribution patterns detected in the stock-specific tileplots (Oregon, Southern Oregon/Northern California, and Central Valley patterns). Polygons were overlain upon the ordinations to define those clusters. The ordinations revealed that Central Valley stocks were not plotted within either the Oregon or Southern

Oregon/Northern California clusters, suggesting that their distribution was different than the distribution of stocks belonging to either the Oregon or S.OR/N.CA groups. In general, stocks that exhibited the Oregon catch pattern were plotted further from one another than stocks that exhibited the S.OR/N.CA catch pattern suggesting greater variability between catch distributions of stocks from the Oregon group. CWT- and WCSGSI-based estimates of Central Valley Fall relative abundance were plotted closer to one another in the ordinations of CWT data pooled over the early (1977 – 1983) and late period than in the ordination of CWT data pooled over the mid-late period (1987 – 2011), reflecting patterns observed in our tileplots as well as our calculation of Spearman’s correlation.

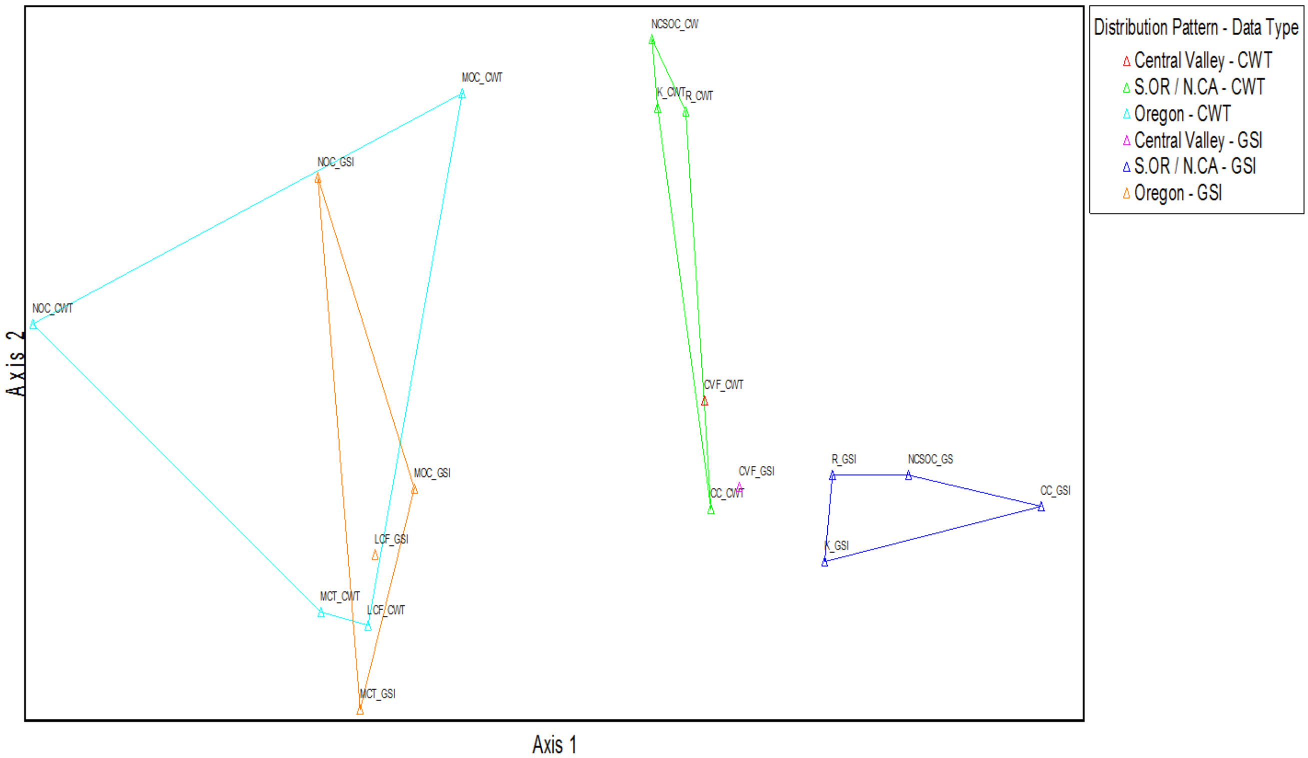

Figure 20. Non-metric multidimensional scaling ordination representing the Sorensen distance between stock specific relative abundance estimates of Chinook salmon calculated from the Early CWT (CWT data collected from 1977 – 1983) and WCSGSI (GSI data collected from 2010 – 2011) aggregates. This analysis arranges stock specific relative abundance estimates in two-dimensional space so that points that are closer together denote greater similarity than those that are further apart. Polygons contain all stocks belonging to a unique distribution pattern – data type group. Stocks: California Coastal (CC), Central Valley Fall (CVF), Klamath (K), Lower Columbia Fall (LCF), Mid-Oregon Coastal (MOC), North Oregon Coastal (NOC), Northern California/Southern Oregon Coastal (NCSOC), and Rogue (R). Points are labeled by stock and data type such that MOC_CWT represents Mid-Oregon Coastal as estimated by CWT data and R_GSI represents Rogue River as estimated by GSI. Final stress = 11.8, r^2 = 0.87

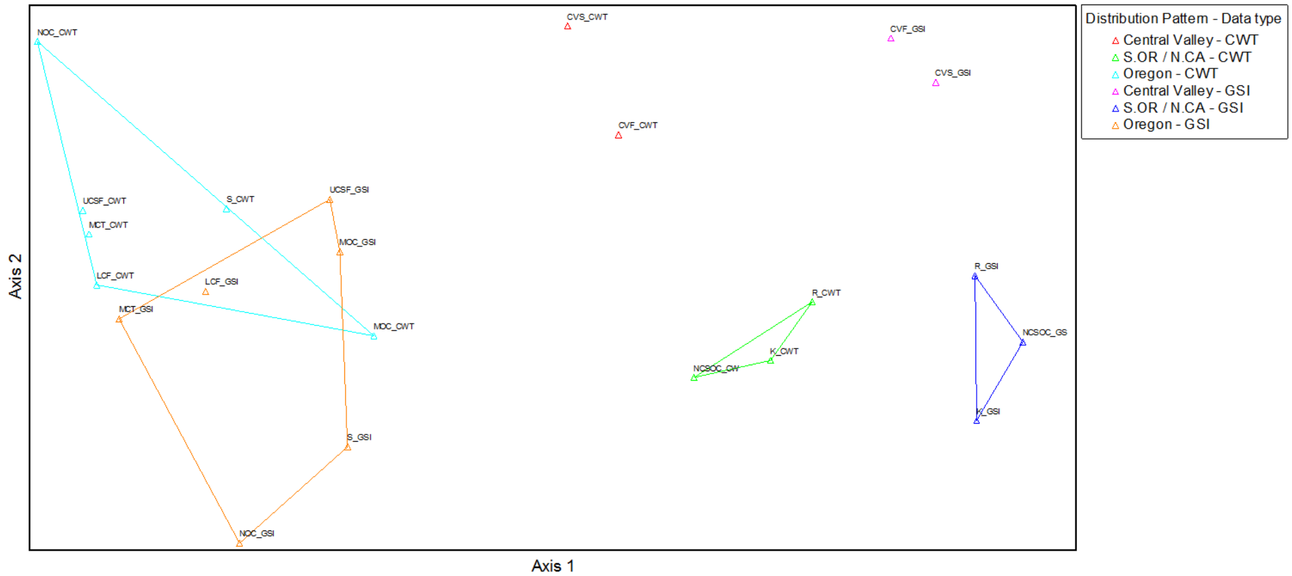

Figure 21. Non-metric multidimensional scaling ordination representing the Sorensen distance between stock specific relative abundance estimates of Chinook salmon calculated from the Mid-Late CWT (CWT data collected from 1987 – 2011) and WCSGSI (GSI data collected from 2010 – 2011) aggregates. This analysis arranges stock specific relative abundance estimates in two-dimensional space so that points that are closer together denote greater similarity than those that are further apart. Polygons contain all stocks belonging to a unique distribution pattern – data type group. Stocks: Central Valley Fall (CVF), Central Valley Spring (CVS) Klamath (K), Lower Columbia Fall (LCF), Mid-Oregon Coastal (MOC), Mid-Columbia Tule (MCT), North Oregon Coastal (NOC), Northern California/Southern Oregon Coastal (NCSOC), Rogue River (R), Snake River (S) and Upper Columbia Summer/Fall (UCSF). Points are labeled by stock and data type such that MOC_CWT represents Mid-Oregon Coastal as estimated by CWT data and R_GSI represents Rogue River as estimated by GSI. Final Stress = 8.67, r^2=0.93

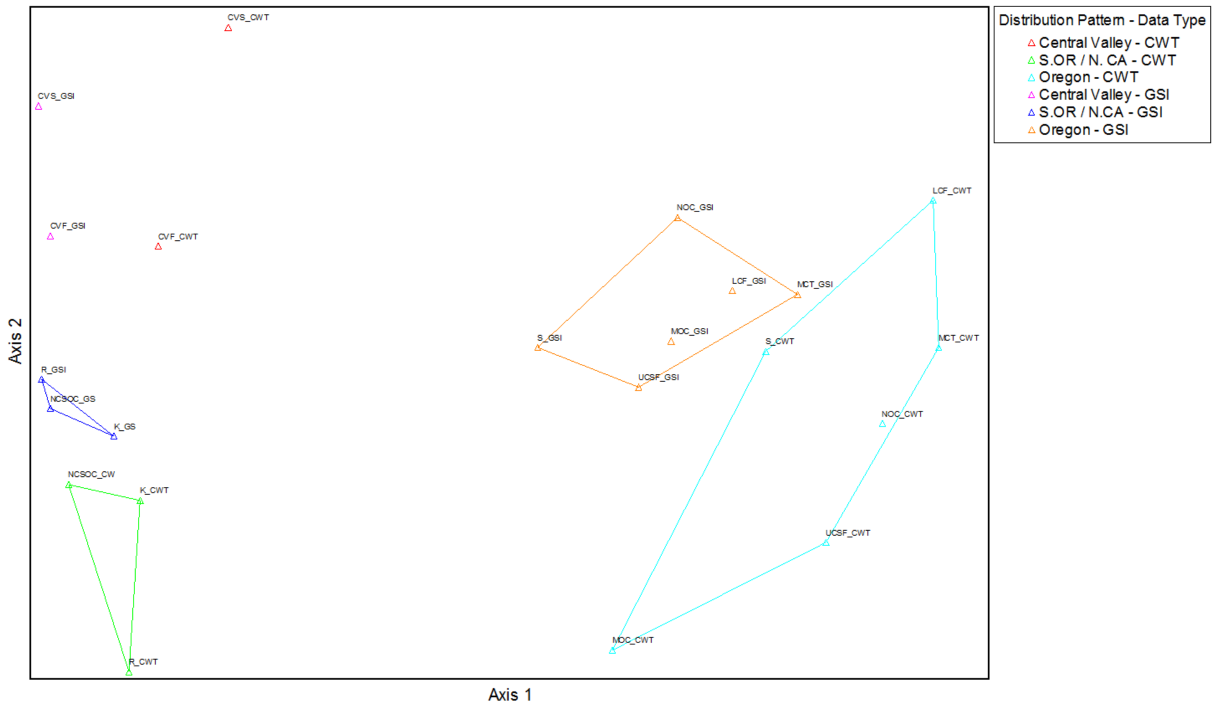

Figure 22. Non-metric multidimensional scaling ordination representing the Sorensen distance between stock specific relative abundance estimates of Chinook salmon calculated from the Late CWT (CWT data collected from 2010 – 2011) and WCSGSI (GSI data collected from 2010 – 2011) aggregates. This analysis arranges stock specific relative abundance estimates in two-dimensional space so that points that are closer together denote greater similarity than those that are further apart. Polygons contain all stocks belonging to a unique distribution pattern – data type group. Stocks: Central Valley Fall (CVF), Central Valley Spring (CVS) Klamath (K), Lower Columbia Fall (LCF), Mid-Oregon Coastal (MOC), Mid-Columbia Tule (MCT), North Oregon Coastal (NOC), Northern California/Southern Oregon Coastal (NCSOC), Rogue River (R), Snake River (S) and Upper Columbia Summer/Fall (UCSF). Points are labeled by stock and data type such that MOC_CWT represents Mid-Oregon Coastal as estimated by CWT data and R_GSI represents Rogue River as estimated by GSI. Final Stress = 8.7, r^2= 0.90.

MRPP was utilized to test the hypothesis of no difference in average within-cluster ranked distances between the clusters of stock-data objects observed in the ordinations above (Table 6). In essence, MRPP was utilized to evaluate if the stock data objects were more similar to other objects in their cluster than would be expected by chance (i.e. is the distribution of Rogue as estimated by WCSGSI more similar to the distribution of Klamath River and Southern Oregon/Northern California Coastal stock than would be expected by chance?). Regardless of whether CWT or WCSGSI data were used to estimate relative abundance, results of MRPP suggested that the distribution of stocks belonging to the S.OR/N.CA group (these stocks were distributed primarily within and between the Southern Oregon and Fort Bragg areas) were significantly different than the distribution of stocks belonging to the Oregon group (stocks distributed primarily north of the OR/CA border). In our nMDS ordinations the polygons outlining CWT and WCSGSI estimates of the Oregon group overlapped, which may suggest there is no difference between those two groups. MRPP indicated that the average within-group ranked distance for the Oregon groups was significantly different only between estimates calculated from the late CWT and WCSGSI aggregates (Table 6; $A = 0.18$, $p = 0.004$). Additionally, MRPP indicated that WCSGSI and CWT (early and mid-late aggregates, but not the late aggregate) estimates for the S.OR/N.CA group were significantly different.

Table 6. Results of Multi-Response Permutation Procedure utilized to test the hypothesis of no difference between groups of CWT- and GSI-based stock specific encounter rate estimates. The groups being compared were comprised either of stocks exhibiting the "Oregon" distribution pattern (encountered primarily off the Oregon coast) or of stocks exhibiting the "Southern Oregon/Northern California" distribution pattern (encountered primarily between Central Oregon and Fort Bragg).

CWT Aggregate	Group comparison	Data comparison	Effect size (A)	p-value
Early (1977 - 1983)	Oregon - S.OR/N.CA	CWT vs CWT	0.28	0.04
	Oregon - S.OR/N.CA	GSI vs GSI	0.42	0.02
	Oregon - Oregon	CWT vs GSI	-0.03	1
	S.OR/N.CA - S.OR/N.CA	CWT vs GSI	0.37	0.028
Mid-Late (1987 - 2011)	Oregon - S.OR/N.CA	CWT vs CWT	0.42	0.008
	Oregon - S.OR/N.CA	GSI vs GSI	0.45	0.004
	Oregon - Oregon	CWT vs GSI	0.09	0.12
	S.OR/N.CA - S.OR/N.CA	CWT vs GSI	0.42	0.008
Late (2010 - 2011)	Oregon - S.OR/N.CA	CWT vs CWT	0.41	0.008
	Oregon - S.OR/N.CA	GSI vs GSI	0.42	0.004
	Oregon - Oregon	CWT vs GSI	0.18	0.004
	S.OR/N.CA - S.OR/N.CA	CWT vs GSI	0.11	0.44

WCSGSI-based fine scale distributions

As part of our overarching goal to explore the respective abilities of CWT and GSI data to characterize distributions of Chinook salmon we explored how the WCSGSI dataset could be used to identify distribution patterns at space-time scales that are difficult or impossible to investigate with traditionally reported CWT data. Using WCSGSI data gathered in 2010 and 2011, we estimated the relative encounter rate of Chinook salmon stocks at three additional space-time scales: area x bi-month, bi-area x month and bi-area x bi-month. As in our comparison of CWT and WCSGSI data, we plotted those estimates on tileplots to illustrate the distribution of relative abundance across the refined space-time strata. To provide a measure of inter-annual variability in the WCGSI data, we used Mantel's method to assess the correlation between distance matrices calculated from 2010- and 2011-based stock specific relative abundance estimates.

Before investigating fine-scale Chinook salmon distributions, tileplots were created to illustrate how WCSGSI sampling effort data can be examined at more refined space-time scales (Bi-Month x Area, Month x Bi-Area and Bi-Month x Bi-Area) (Figure 23). During 2010, sampling effort expended by the WCSGSI collaboration was distributed nearly coast-wide with the largest number of boat days occurring in the Newport and Southern Oregon catch areas. There was also a lesser, but noticeable, concentration of effort in the Fort Bragg and San Francisco catch areas. WCSGSI fishermen were able to cover such a broad scope of space-time strata in large part because the 2010 commercial regulations allowed 475 days of non-retention fishing for research purposes (Table 7). In the areas closed to commercial harvest, fishermen were instructed to fish as they normally would but after collecting biological samples for DNA analysis the fish were released. A comparison of the distribution of 2010 WCSGSI effort across space-time scales revealed that fishermen were able to sample 95%, 86.5%, 91.25%, and 83.125% of the strata available in the month x area, bi-month x area, month x bi-area and bi-month x bi-area scales, respectively. These data allowed us to explore finer space-time scales and reveal patterns which would go unnoticed at the month x area scale. For example, the ability to plot effort at the bi-month x area scale (Figure 23b) enabled us to illustrate that the commercial troll sampling began during the second two weeks of May, and that effort in the Newport and Southern Oregon areas were greatest during the latter halves of June and August. Effort plotted at the month x bi-area scale (Figure 23c) suggested that fishermen sampled the waters of the northern Southern Oregon area more often than the southern area and that fishermen spent significant time in southern half of the Newport area during May, but fished primarily in the northern half of Newport area for the remainder of the season. Finally, effort plotted at the bi-month x bi-area scale (Figure 23d) tied together the patterns observed at each of the two previous scales. For instance, in the Southern Oregon area, the bi-month x bi-area plot shows that effort was greatest in the northern half during the second two weeks of May and June and the first two weeks of August.

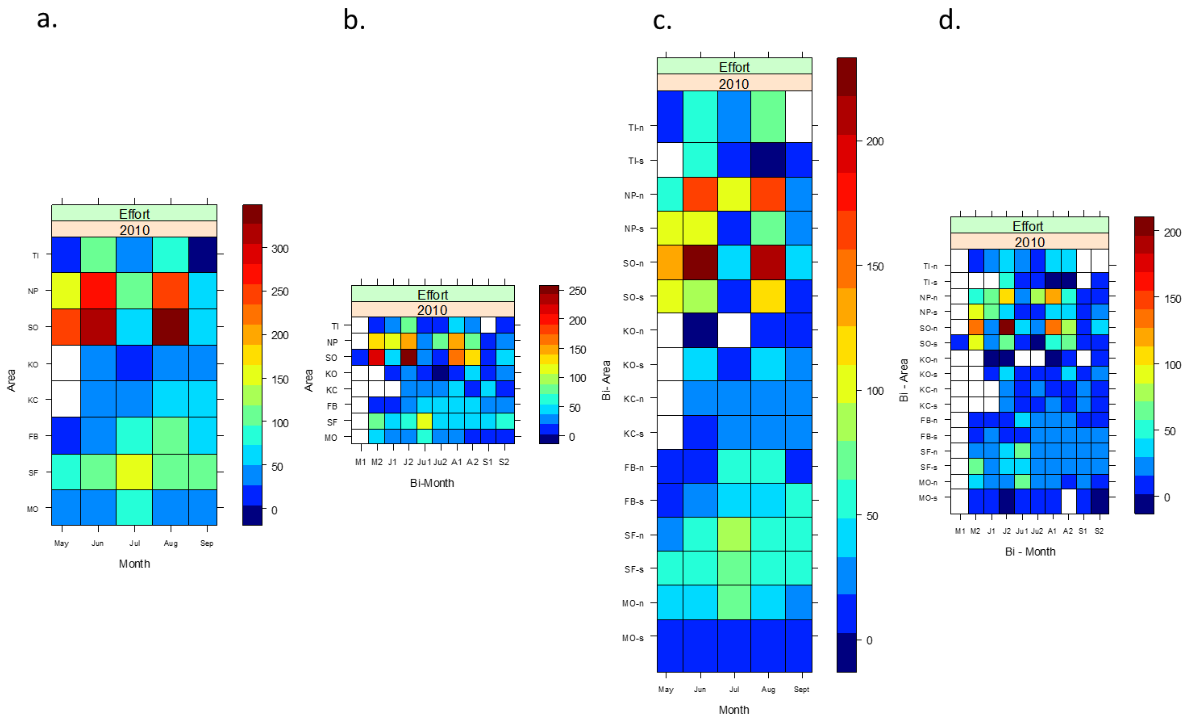

Figure 23. Tileplots illustrating the estimated distribution of WCSGSI sampling effort (boat days) during 2010 at four space-time scales: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep red colored tile represents the space-time stratum where the greatest sampling rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and –n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

Table 7. 2010 Commercial salmon troll fishery regulations in study area. Open to harvest indicates the time periods that the catch area was open for harvest. Non-retention indicates the time periods that were open to catch and release sampling.

Year	Catch Areas	Open to harvest	Days	Non-retention	Days
2010	Tillamook; Newport; Central Oregon	May 1 - July 6; July 9 - 13, 16 - 20, 23 - 27; Aug 1 - 25	107	September 1 - 30	30
	Klamath Oregon	May 1 - 31; July 1 - 31, Aug 1 -31	93	June 1 - 30; September 1 - 30	60
	Klamath California	Closed	0	May 1 - September 30	153
	Fort Bragg	July 1 - 4, 8-11, 15-29; Aug 1 - 31	54	May 1 - June 30; September 1 - 30	91
	San Francisco; Monterey	July 1 - 4, 8 - 11	8	May 1 - June 30; July 13 - September 30	141

In comparison to 2010, the distribution of sampling effort during the 2011 WCSGSI season was considerably less consistent across space and time (Fig. 24). Fishing occurred in 75% of the month x area strata, 66.25% of the bi-month x area strata and month x bi-area strata, and 60% of the bi-month x bi-area strata. Similar to what was observed in plots based on data from 2010, the tileplots suggested that 2011 effort was concentrated in the Newport, Southern Oregon, Fort Bragg and San Francisco areas and that, although we had data for fewer space-time strata, patterns are revealed at finer space-time scales that would not be revealed at the month x area scale. The fine-scale plots (Figure 24b – d) suggested that the greatest concentration of effort in Oregon waters occurred during the first two weeks in June in the northern Southern Oregon area while in California the greatest concentration of effort was in the northern halves of Fort Bragg and San Francisco during the last two weeks of July. Regardless of year, these plots illustrate the advantage of effort data recorded via global positioning units at 5-min intervals. At the bi-month x area scale it would be difficult to replicate these plots with classically reported effort data, and at the month x bi-area and bi-month x bi-area it would be nearly impossible.

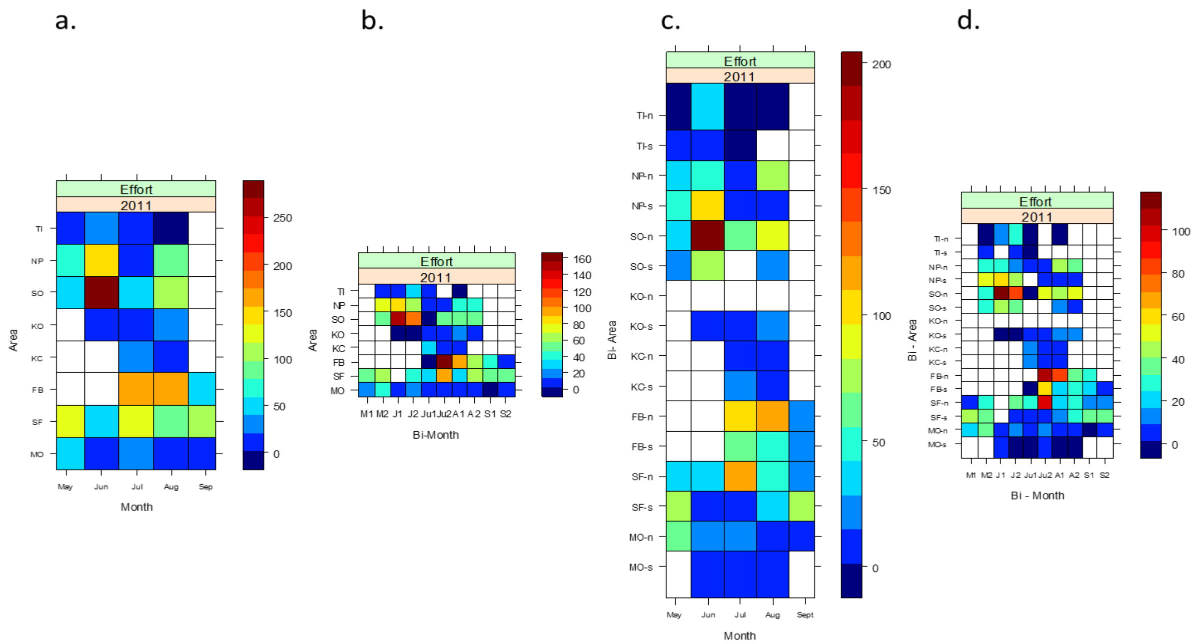

Figure 24. Tileplots illustrating the estimated distribution of WCSGSI sampling effort (boat days) during 2011 at four space-time scales: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep red tile represents the space-time stratum where the greatest sampling rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

The distribution of Chinook salmon encounters by the WCSGSI during the 2010 season is plotted in figure 25. In Oregon waters, the patterns we observed in the distribution of 2010 sampling effort were reflected by the distribution of Chinook encounters with the greatest numbers of salmon being encountered in the same space-time strata where largest amounts of effort were expended. An interesting pattern observed in Oregon was that very few Chinook were encountered by the WCSGSI fishermen during the first two weeks of July (Figure 25b and 25d). One possible explanation is that fishermen may have altered their behavior, switching from targeting Chinook to fishing for highly migratory Albacore tuna. The relative lack of encounters during July was particularly noticeable at refined scales which showed low to zero harvests, particularly during the second half of the month. The number of encounters in California during 2010 rivaled those in Oregon despite there being less fishing effort. The greatest number of encounters in Californian waters occurred in the San Francisco area early in the season, in Fort Bragg during the mid-late portion of the season and in Klamath California during the end of the season, suggesting a possible south – north migration of Chinook as the commercial fishing season progressed from May through September.

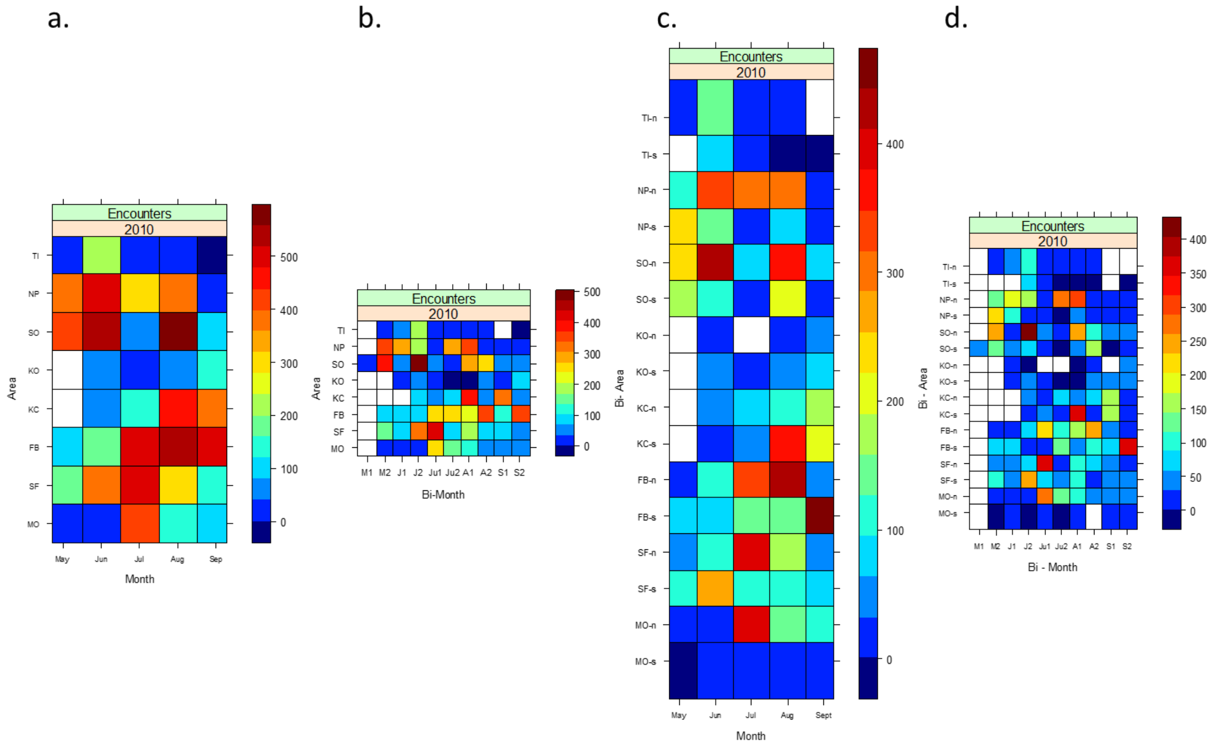

Figure 25. Tileplots illustrating the estimated distribution of WCSGSI Chinook salmon encounters during 2010 at four space-time scales: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep red tile represents the space-time stratum where the greatest number of Chinook salmon encounters occured. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and –n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

In contrast to the relatively even spread of encounters across areas in 2010, encounters in 2011 were largely concentrated in the Fort Bragg area during July and August (Figure 26). The bi-month x bi-area plot revealed that encounters were concentrated in the northern half of the Fort Bragg area during the last two weeks of July and the first two weeks of August. As observed in the 2010 plot, there was evidence of a south – north shift in the number of encounters as the 2011 season progressed.

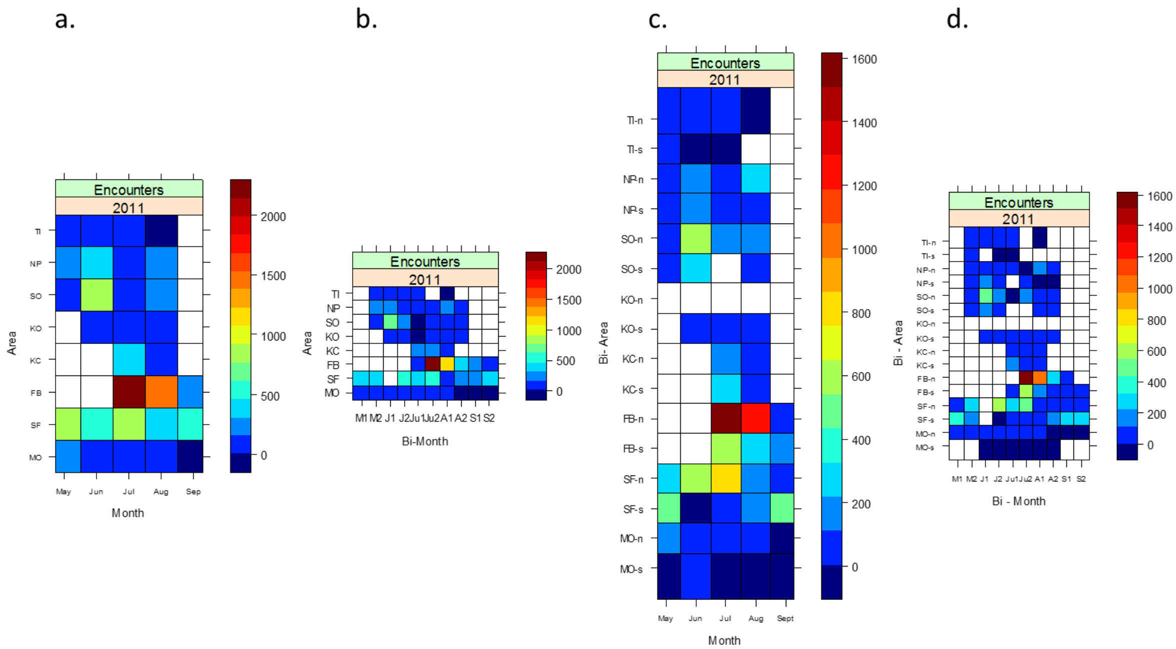

Figure 26. Tileplots illustrating the estimated distribution of WCSGSI Chinook salmon encounters during 2011 at four space-time scales: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep red tile represents the space-time stratum where the greatest number of Chinook salmon encounters occured. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and –n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

We plotted encounter rate estimates (encounters divided by effort) at each space-time scale to illustrate how finer scale WCSGSI data can be used to gain insight into the marine distribution of Chinook salmon at a level of resolution that cannot be achieved with traditionally reported CWT data (Figure 27). While the most effort, and significant numbers of encounters, occurred in areas off the Oregon coast the greatest encounter rates were experienced south of the Oregon – California border during 2010. Estimated encounter rates plotted at the month x bi-area scale (Figure 27b) revealed that encounter rate was more consistent through time in the northern half of Fort Bragg than it was in the southern half. Regardless of the space-time scale, each of the plots supported the notion that the Chinook salmon encountered off California may have undergone a south – north migration during the fishing season.

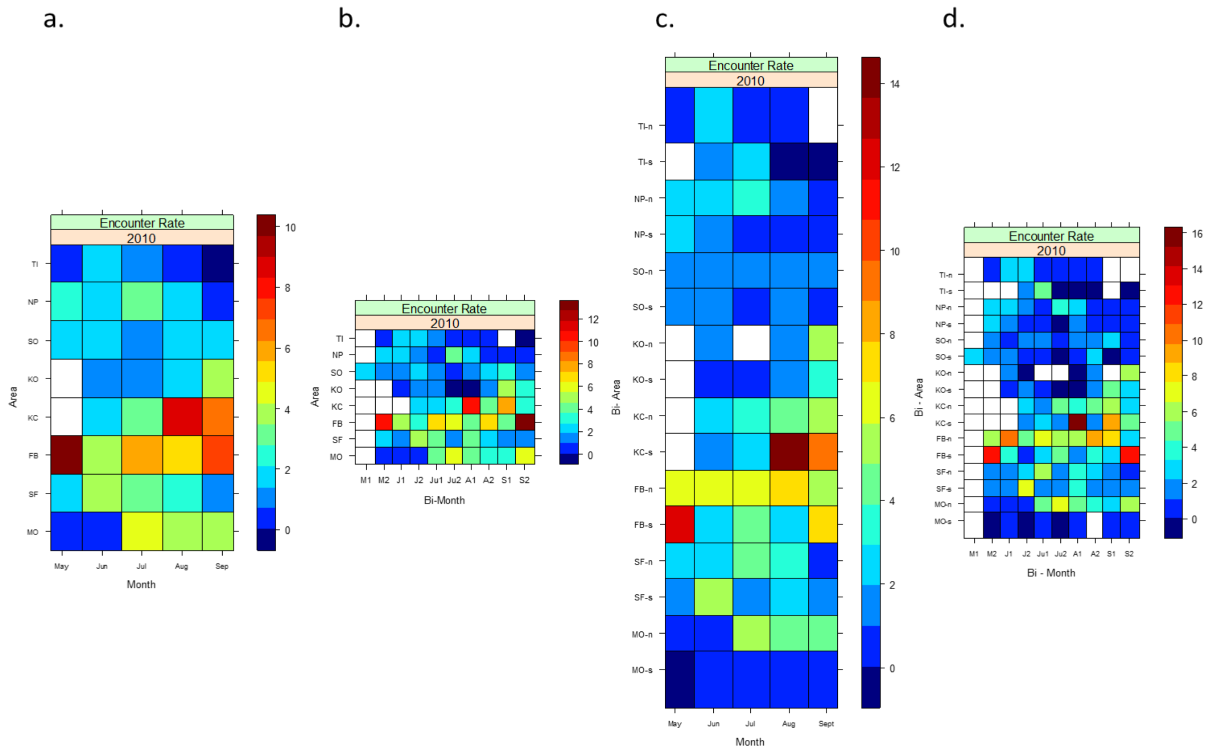

Figure 27. Tileplots illustrating the variation in relative encounter rate through space and time as estimated by WCSGSI data collected during 2010. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the highest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and –n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

In 2011, the estimated encounter rates were also higher south of the Oregon - California border (Figure 28). During the months of May and June, the highest encounter rates were in the northern half of San Francisco (Fig. 28c). Later, in July and August, Chinook were encountered at the highest rates in the Klamath California and Fort Bragg zones. The south – north shift seen in the previous figures was also apparent in our plots of 2011 encounter rates. Comparing the distribution of effort, encounters and encounter rate during 2011 revealed that in the Klamath California area there was very little effort expended and relatively few Chinook encountered, but the relatively high encounter rate identified the Klamath California area as having an abundance of salmon during July and August of 2011.

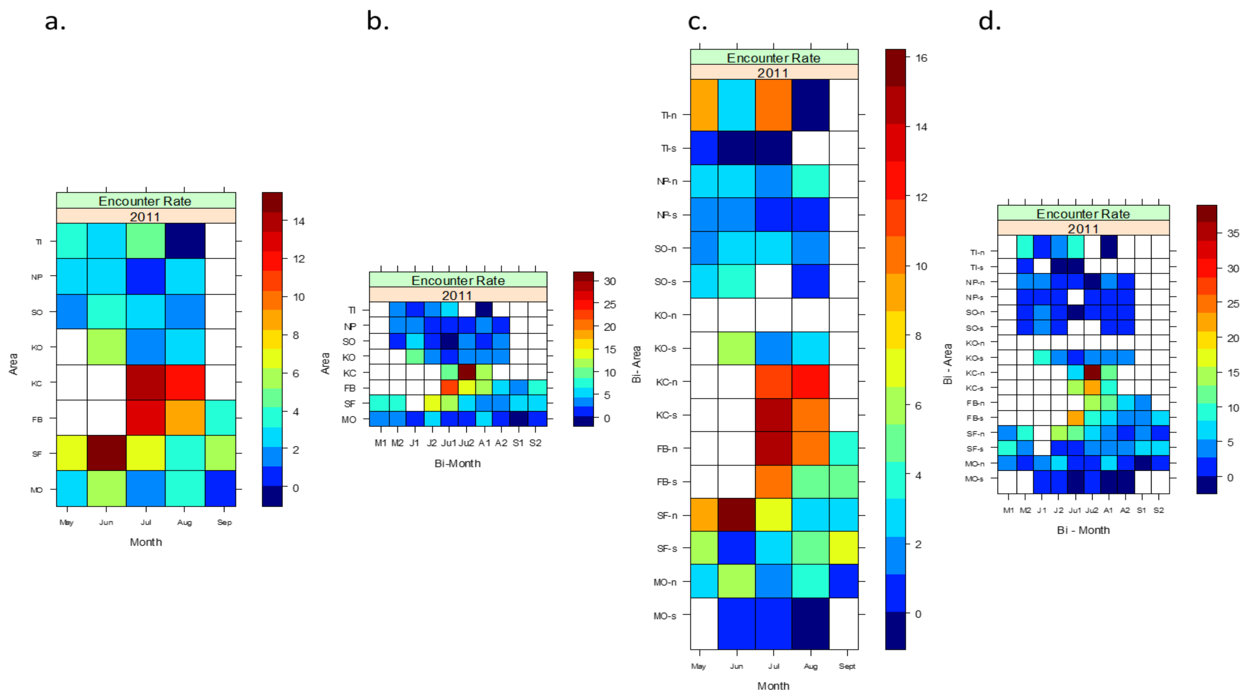

Figure 28. Tileplots illustrating the variation in encounter rate through space and time as estimated by WCSGSI data collected during 2011. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the highest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

WCSGSI: Capability to identify fine-scale stock specific catch patterns

Central Valley Fall stock

In 2010 Central Valley Fall Chinook salmon were encountered in all catch areas but at significantly higher rates south of the Oregon - California border (Figure 29). Encounter rates were consistently high during August. Fishermen trolling the northern section of the Monterey area experienced low encounter rates of Central Valley Fall Chinook during May and June and then high rates for the rest of the season. Fine-scale depiction of encounter rate distribution revealed that encounter rates were consistently higher in the northern half of Fort Bragg, compared to the southern half, from July through the first two weeks of September (Figure 29d). Like 2010, the distribution of Central Valley Fall encounter rates in 2011 also suggests that these fish were significantly more abundant south of the Oregon – California border (Figure 30). In general, it appears that encounter rates were higher earlier in the 2011 season when compared to 2010. In addition the encounter rate in the Monterey area was much lower in 2011 than it was in 2010.

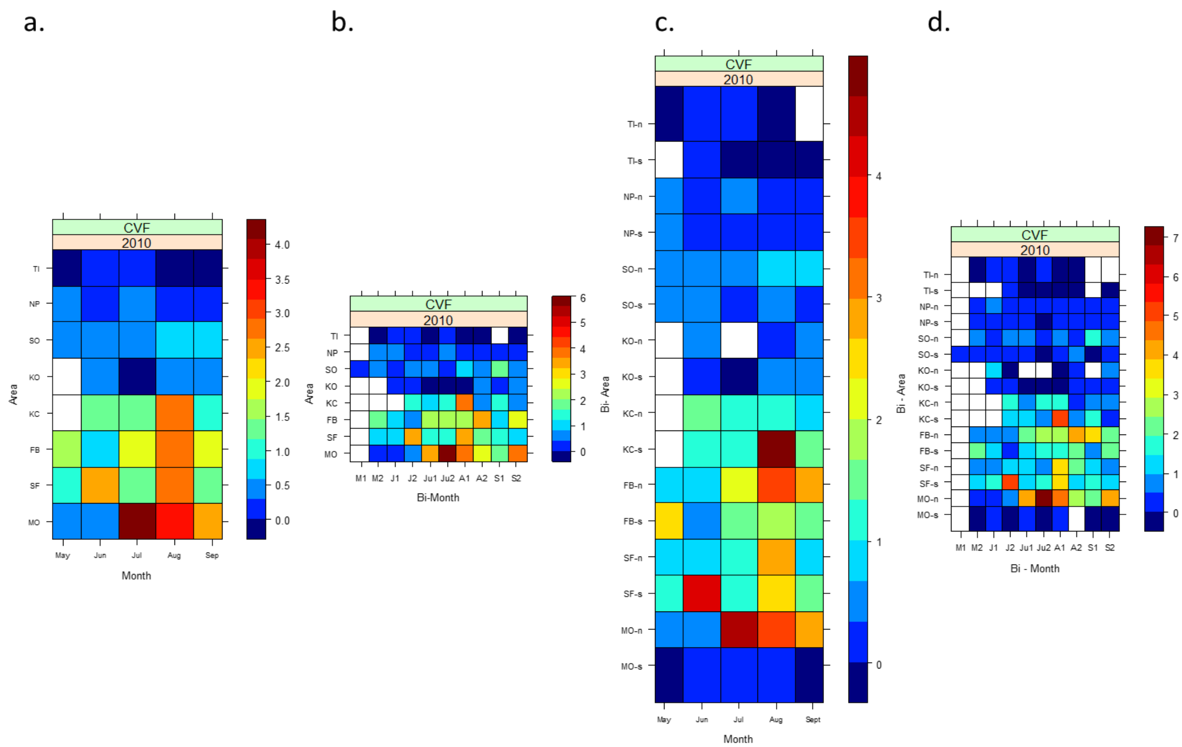

Figure 29. Tileplots illustrating the variation in encounter rate of Central Valley Fall Chinook through space and time as estimated by the WCSGSI data collected in 2010. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

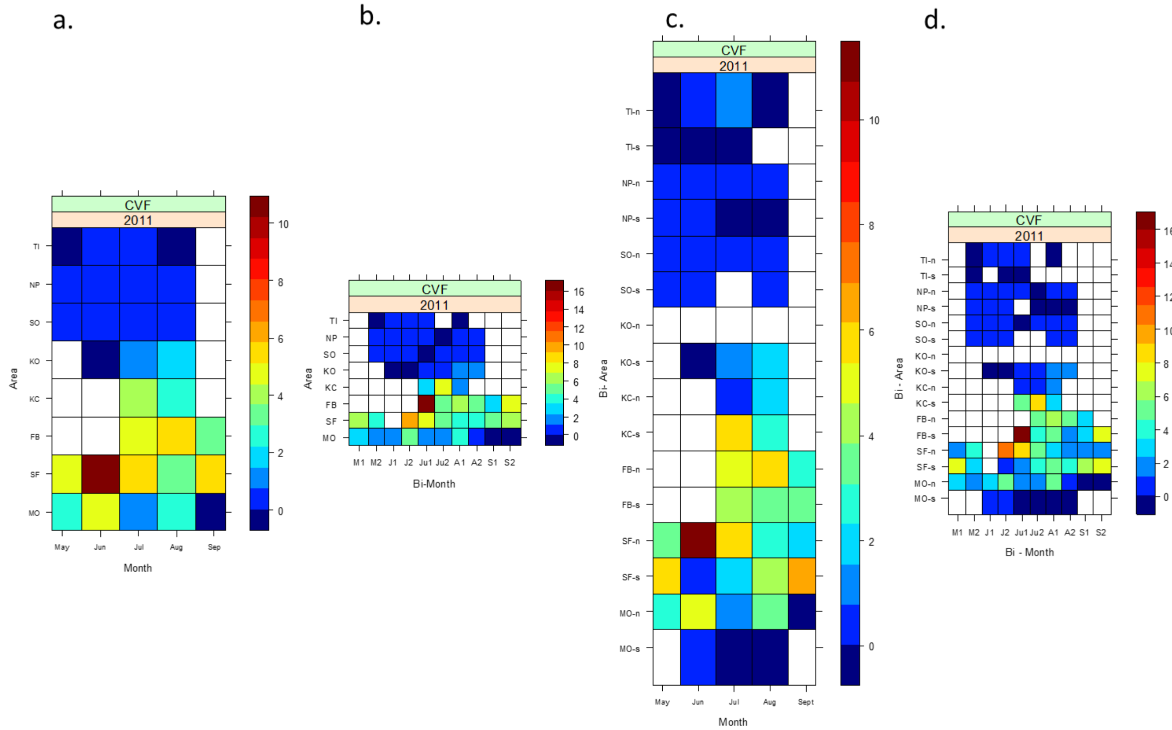

Figure 30. Tileplots illustrating the variation in encounter rate of Central Valley Fall Chinook through space and time as estimated by the WCSGSI data collected in 2011. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

Klamath River Fall stock

Tileplots based on WCSGSI data collected during 2010 suggested that Klamath River Chinook salmon were encountered in all areas between Newport and San Francisco and were most abundant from Klamath Oregon through Fort Bragg (Figure 31). Early in the season the greatest encounter rates occurred in Fort Bragg. In

May the encounter rate of Klamath Chinook was slightly higher in Fort Bragg South. That pattern had switched by June with the higher encounter rate occurring in Fort Bragg North. Beginning in August, abundance appeared to shift to the north as encounter rates were greatest in the Klamath California area. By September, Klamath Chinook were being encountered at similar rates in Klamath Oregon and Klamath California.

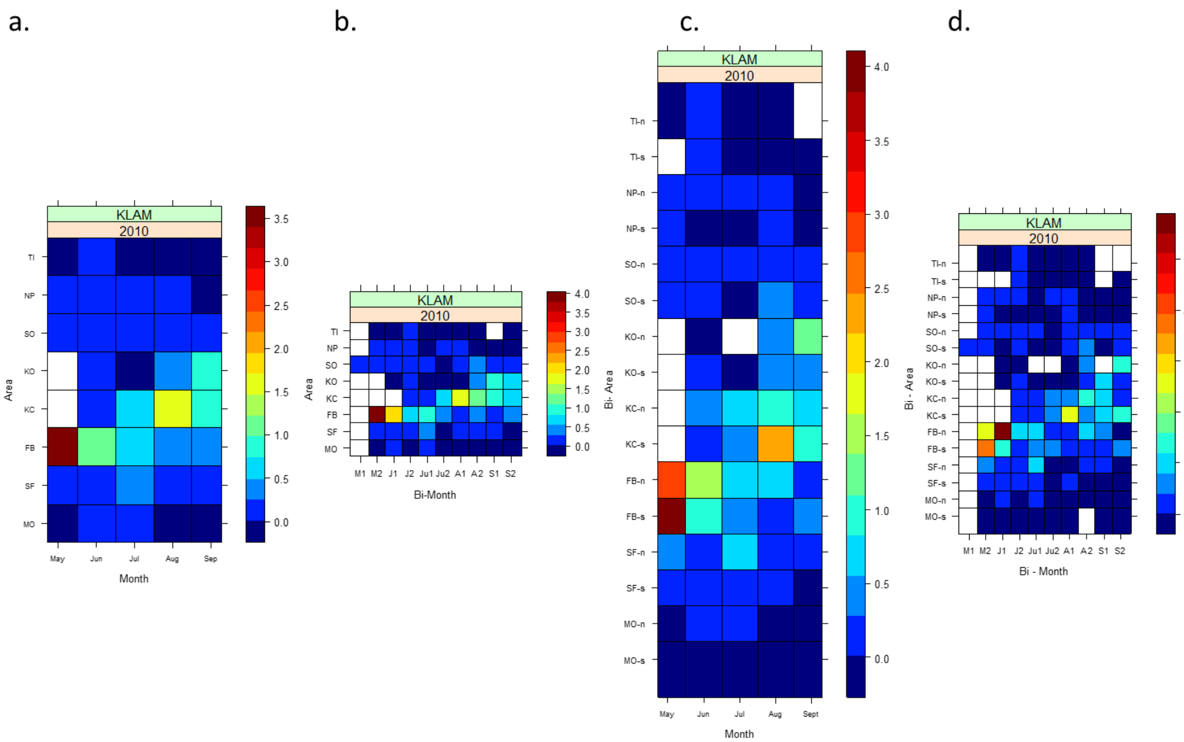

Figure 31. Tileplots illustrating the variation in encounter rate of Klamath River Chinook through space and time as estimated by the WCSGSI data collected in 2010. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

In 2011 the highest encounter rates of Klamath Chinook were again in the Klamath California and Fort Bragg areas (Figure 32). Our coarse scale (Figure 32a) plots suggested that encounter rates in Fort Bragg and Klamath California were very similar during the month of July. However, at finer space-time scales it appeared that during the first two weeks of July the encounter rate was much higher in the Klamath California area. While encounter rates appeared to be uniform throughout the Klamath California area, Fort Bragg North experienced much higher encounter rates than Fort Bragg South. By August of 2011 the highest encounter rate was observed in Klamath California North, which is home to the mouth of the Klamath River were Klamath Chinook return to spawn. The fine-scale plots suggested that Klamath Chinook were encountered at a high rate in Tillamook North during July but this is likely misleading because that value was the result of three Klamath River Chinook being caught in a space-time stratum where only one boat day of effort was expended.

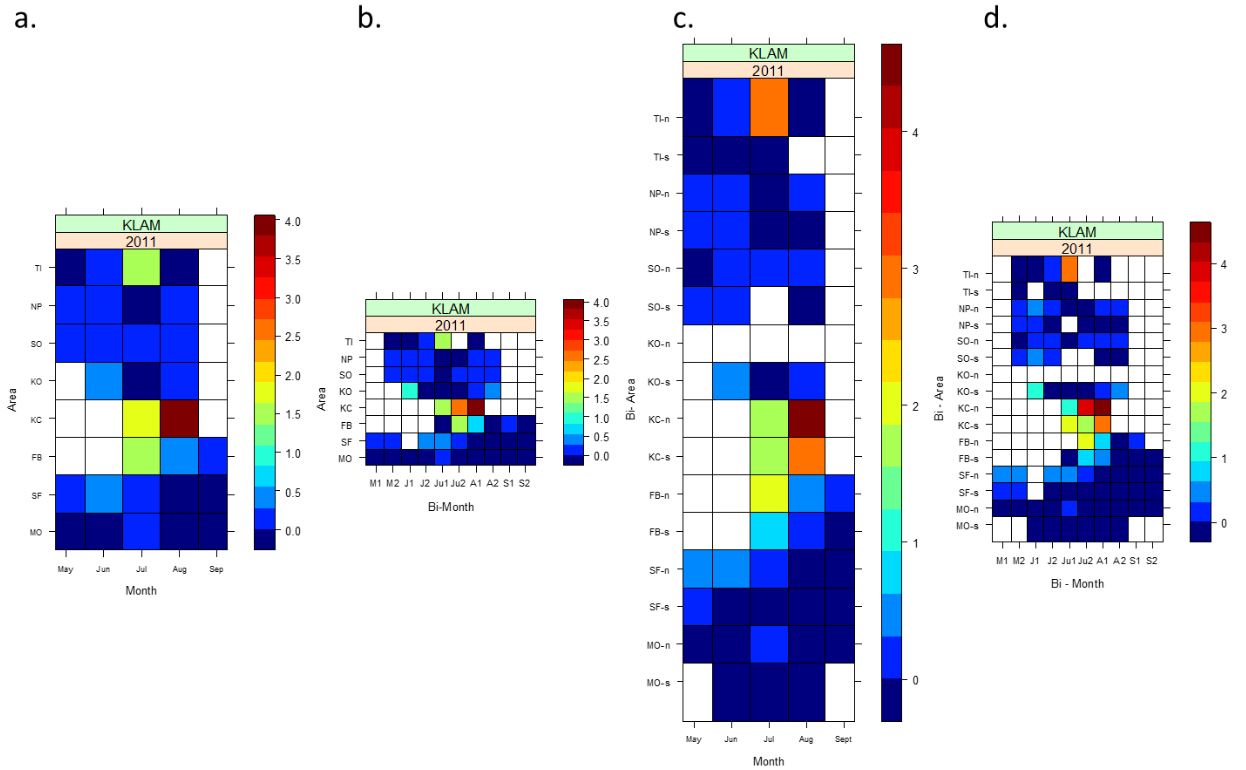

Figure 32. Tileplots illustrating the variation in encounter rate of Klamath River Chinook through space and time as estimated by the WCSGSI data collected in 2011. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

California Coastal stock

The California Coastal Chinook stock was encountered most consistently in the Fort Bragg area in the 2010 season (Figure 33). Beginning in the second two weeks of July these fish were also encountered consistently in the Klamath California area. The tileplots show that by September this stock was being caught from Klamath Oregon through Fort Bragg with greatest encounter rates occurring in the southern halves of Fort Bragg and Klamath California. In 2011, California Coastal were also caught at the greatest rates in Klamath California and Fort Bragg, with the highest rates occurring during the second half of July in Fort Bragg north and Klamath California South (Figure 34). In contrast to 2010, California Coastal Chinook were encountered in San Francisco north early in the 2011 season.

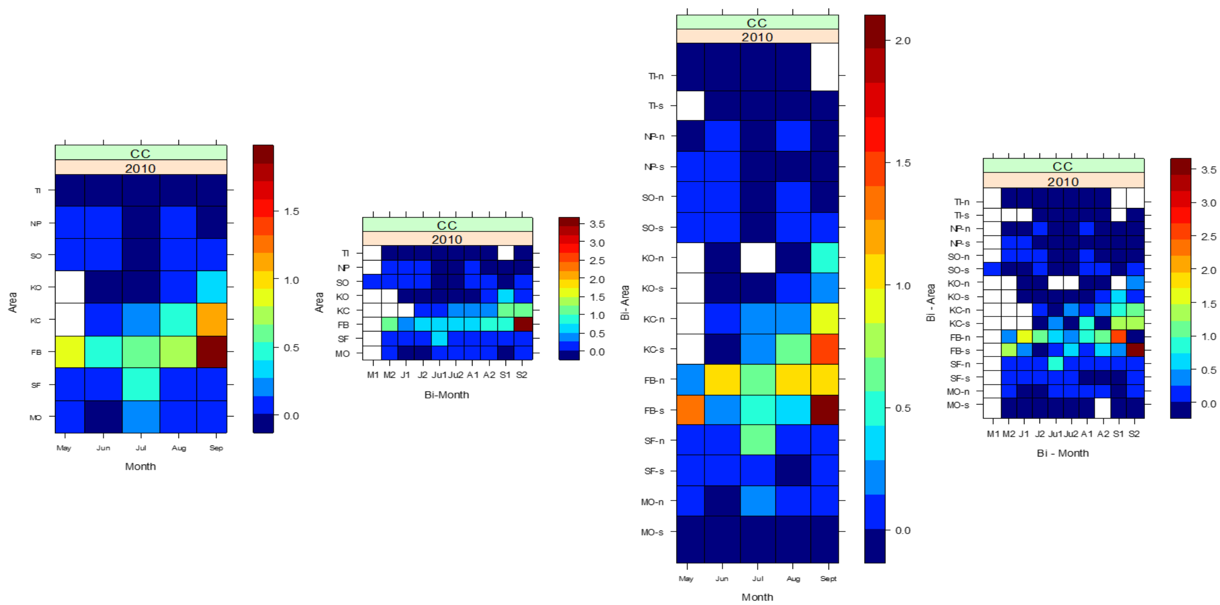

Figure 33. Tileplots illustrating the variation in encounter rate of California Coastal Chinook through space and time as estimated by the WCSGSI data collected in 2011. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

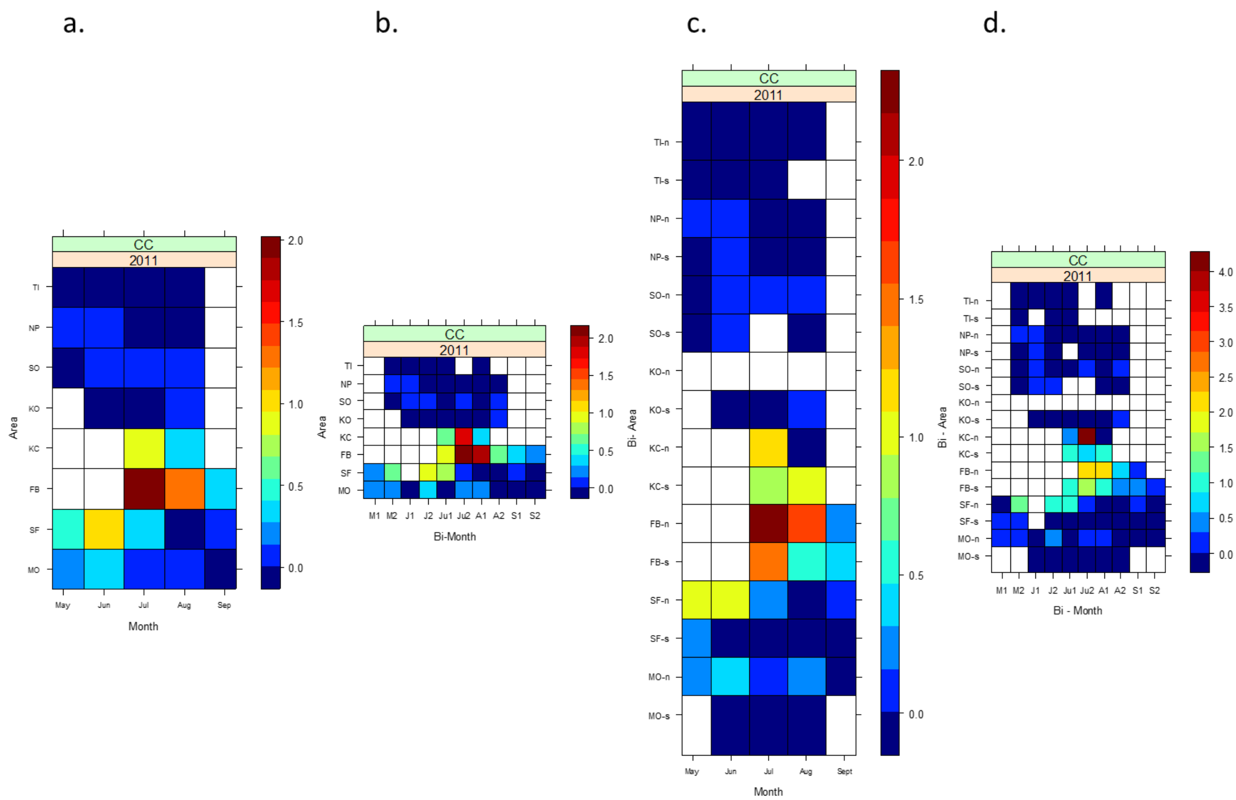

Figure 34. Tileplots illustrating the variation in encounter rate of California Coastal Chinook through space and time as estimated by the WCSGSI data collected in 2011. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

Mid-Oregon Coastal stock

Plotting the estimated encounter rate of Mid-Oregon Coastal Chinook during 2010 suggested that these salmon were present across all areas but were concentrated primarily in the Newport and Southern Oregon catch areas (Figure 35). The plots show an interesting pattern that suggests Mid-Oregon Coastal were widely dispersed across all areas early in the season and then converged from the north and south as the season progressed. By the end of the season, the highest encounter rates occurred in Southern Oregon and Brookings, which is expected since these areas are home to the natal rivers of Mid-Oregon Coastal Chinook. The converging pattern was best illustrated by WCSGSI data plotted at the bi-month x area scale. In 2011, the tileplots indicate that Mid-Oregon Coastal Chinook were distributed primarily between Tillamook and Southern Oregon from May through July and then concentrated in Newport and Southern Oregon during August (Figure 36). Encounter rate appeared to be consistently greater in the northern half of Newport compared to the southern. The overall highest encounter rate occurred in Klamath Oregon during June when two boat days of fishing effort resulted in 3 encounters. The pattern of convergence observed in the 2011 plots was similar to the 2010 results.

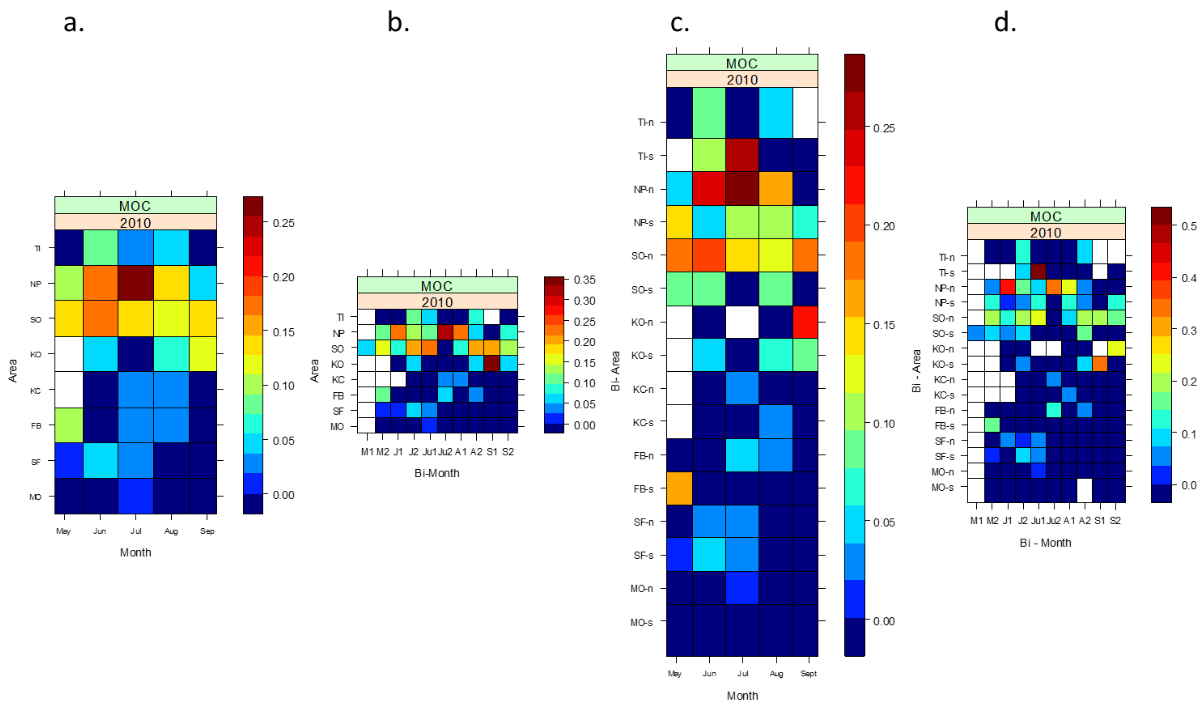

Figure 35. Tileplots illustrating the variation in encounter rate of Mid-Oregon Coastal Chinook through space and time as estimated by the WCSGSI data collected in 2010. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

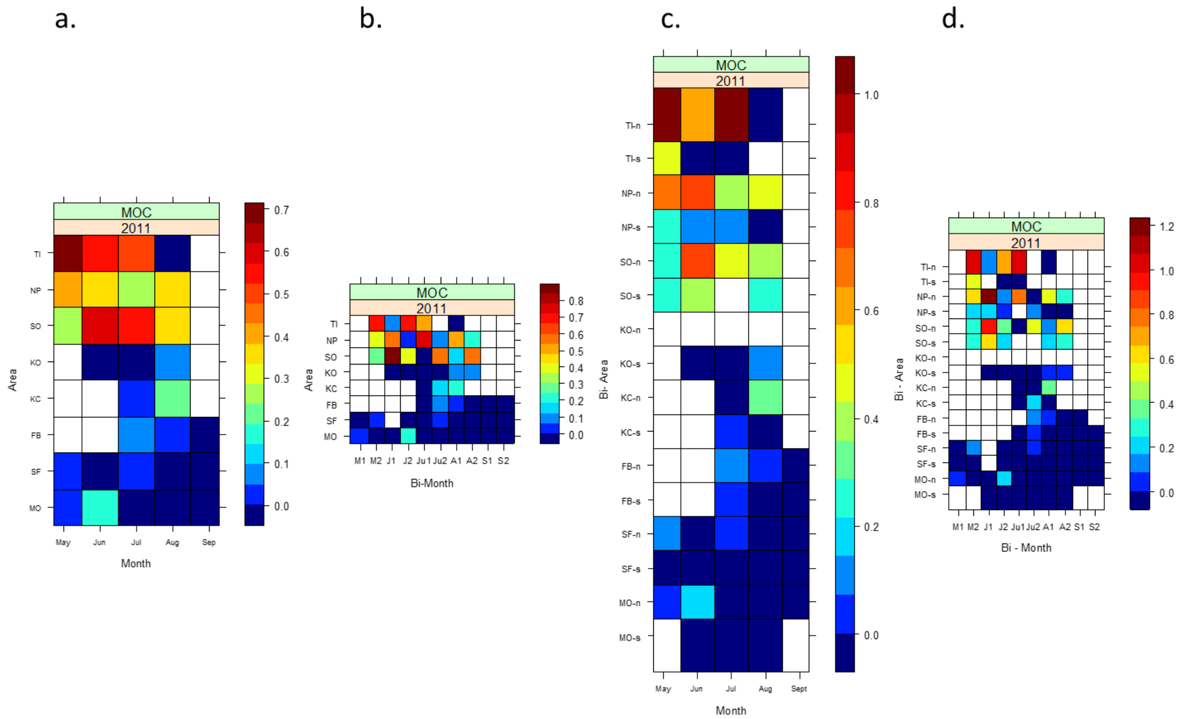

Figure 36. Tileplots illustrating the variation in encounter rate of Mid-Oregon Coastal Chinook through space and time as estimated by the WCSGSI data collected in 2011. Four space x time scales are considered: (a. area x month, (b. area x bi-month, (c. bi-area x month and (d. bi-area x bi-month. The deep-red colored tile represents the space-time stratum where the greatest encounter rate occurred. White tiles indicate strata where no sampling occurred. Area labels: TI – Tillamook, NP – Newport, CO – Central Oregon, KO – Klamath Oregon, KC – Klamath California, FB – Fort Bragg, SF – San Francisco, MO – Monterey; -s and -n denote the northern and southern halves of each area. The numbers (1) and (2) denote the first and second halves of a month.

Correlation between 2010 and 2011 WCSGSI distributions

To determine the consistency of WCGSI between years, Mantel's method was used to evaluate the correlation between pairs of distance matrices calculated from 2010 and 2011 WCSGSI stock specific encounter rates (Table 8). A total of four pairs of matrices were tested, each corresponding to one space-time scale (month x area, bi-month x area, month x bi-area, bi-month x bi-area). Results indicated the presence of a moderate positive correlation between years at each scale. Correlation between years decreased as the space-time scale became more refined. The strongest correlation was between matrices at the month x area scale (r = 0.6, p = 0.001) while the weakest correlation was between matrices containing encounter rate estimates at the bi-month x bi-area scale (r = 0.46, p = 0.001).

Table 8. Mantel's test evaluating the correlation between pairs of Sorensen distance matrices calculated from 2010 and 2011 WCSGSI-based relative abundance estimates. Those estimates were calculated at four space x time scales: month x area, bi-month x area, month x bi-area and bi-month x bi-area. The standardized Mantel statistic (r) is calculated as the Pearson coefficient between the two matrices where higher values denote greater similarity.

Scale	stratum x stock	r	p
Month x Area	29 x 13	0.6	0.001
Bi-Month x Area	46 x 13	0.52	0.001
Month x Bi-Area	46x 13	0.58	0.001
Bi-Month x Bi-Area	70 x 12	0.46	0.001

Discussion

Growing concern surrounding the quality and limitations of CWT data has spurred interest in technologies that can improve stock specific information for Chinook salmon. GSI is one of the rapidly growing technologies with significant potential for generating information that could be used in addition to the CWT data system to improve salmon management. In this research we explored, compared, and contrasted the capabilities of CWT and GSI data to identify fine-scale, stock-specific, distribution patterns of Chinook salmon off the coasts of Oregon and California. We described the marine distribution of the Chinook salmon stocks most commonly encountered in Oregon’s and California's commercial troll fisheries and evaluated the similarity between CWT- and GSI-based estimates of those distributions. Most importantly, we demonstrated how GSI data can provide insight into stock specific distribution patterns at space-time resolutions that cannot be achieved with traditionally reported CWT data.

Coded-wire tags versus Genetic Stock Identification

The key focus of our study was to compare and contrast the capabilities of CWT and GSI technologies for detecting stock specific distribution patterns of Chinook salmon. To our knowledge, this was the first large scale study to explicitly compare the capability of these technologies to estimate adult Chinook ocean distributions. Because CWT data are the most widely used means for determining where and when salmon are encountered in the ocean we expected CWT and GSI data to provide similar distribution estimates at the relatively coarse area x month space-time scale. Generally, our results indicated that CWT- and GSI-based distribution patterns at the area x month space-time scale are moderately to strongly correlated. If we make the assumption that GSI data are representative of untagged stocks, then this finding lends support to the critical assumption that CWT’d fish are distributed similarly to the untagged fish they are intended to represent.

We demonstrated that two years of GSI data can provide much more information pertaining to Chinook salmon distributions than two years of CWT data. From 2010 – 2011 the WCSGSI was able to gather a sufficient quantity of quality data to estimate Chinook distributions for a greater number of stocks, and across a broader spatial-temporal extent, than was possible with CWTs recovered during the same time period. Furthermore, those GSI data appeared to reveal in-season migration patterns of a number of Chinook stocks whereas no clear patterns were apparent using CWT-based estimates (regardless of the number of years CWT recoveries were aggregated). This results suggests that GSI data are a more powerful tool for detecting variance in salmon distributions over short time scales. For instance, our GSI-based distribution estimates of Rogue River, Klamath River and Northern California/Southern Oregon coastal Chinook salmon indicated that the highest encounter rates shifted north as the season progressed. Analysis of GSI data also indicated that Mid-Oregon coastal Chinook appeared to be widely distributed in areas off both Oregon and California early in the season but became concentrated in the Southern Oregon and Klamath Oregon areas late in the season. While these results are consistent with how salmon are managed, this is the first time these patterns have been empirically demonstrated, and they were detected using only two years of GSI data.

Most importantly, we illustrated how fisheries data collected by the WCSGSI can be utilized to estimate Chinook salmon distribution patterns at space-time resolutions that are beyond the capacity of traditionally reported CWT data. Our tileplots illustrated many instances when higher resolution tileplots revealed variation in fishing effort, encounters, and encounter rates that would have otherwise gone undetected at the relatively low resolution area x month space-time scale. A particularly interesting pattern was revealed off the Oregon coast during 2010 where a sharp drop in fishing effort and encounters occurred during the first two weeks of July. This pattern was unusual because both before and after the first two weeks of July fishing effort and salmon encounters were relatively high. However, the encounter rate was relatively low. Examination of the Oregon Department of Fish and Wildlife's commercial harvest records indicated that there was a sharp uptick in the number of Albacore landed between June and July of 2010. One reasonable explanation is that the low encounter rate of Chinook (and ostensibly relatively low profit) caused fishermen to alter their behavior, switching to the Albacore fishery which uses similar fishing gear. This suggests that well designed studies that incorporate GSI and fine-scale effort data may provide insight both into salmon distributions as well as the behavior of fishermen.

CWT-based results compared to previous studies

We expected that the CWT database would allow us to describe broad-scale distribution patterns of Chinook salmon, an expectation founded on earlier works that applied CWT data to gain insights into the ocean ecology of Pacific salmon. For example, Nicolas and Hankin (1988) analyzed CWT recoveries of Chinook salmon originating from Oregon's coastal streams. Their results suggested that Oregon's coastal Chinook salmon exhibit three basic, broad-scale, marine distribution patterns: Chinook from the Elk River and north were distributed from Oregon through Alaska; stocks from the Rogue River and south were distributed off southern Oregon and northern California; and, Chinook from the Umpqua River were distributed both to the north and south. In a more recent study, Weitkamp (2010) utilized CWT data to examine the marine distribution patterns of 77 hatchery and 16 wild populations of Chinook salmon recovered in coastal waters from southern California to the Bering Sea. The results indicated that three broad-scale distribution patterns existed: (1) Chinook from Alaskan hatcheries were largely recovered in Alaska; (2) salmon from hatcheries in northern British Columbia to the Oregon coast were widely dispersed and recovered from the area where their natal stream enters the ocean north to Southeast Alaska; and (3) salmon originating from hatcheries in southern Oregon and California were rarely recovered north of the Columbia River. Furthermore, Weitkamp noted the presence of finer-scale distribution patterns within the three broad-scale distributions. Of interest to this study, Weitkamp's results suggested that salmon from the Oregon coast, southern Oregon-northern California, and the Central California Valley all had unique distribution patterns. It came as no surprised that we were able to utilize CWT data to illustrate distribution patterns of Chinook salmon, however, because the methods we used were dissimilar from Weitkamp, it was not expected that our results would so closely parallel those described in previous studies.

Our methods differed from those used by either Nicolas and Hankin (1988) or Weitkamp (2010), specifically in the years our CWT data were collected and in our incorporation of fishing effort. We aggregated Chinook salmon populations originating from Oregon's coastal streams into three groups: Northern Oregon Coastal, Mid-Oregon Coastal and Northern California/Southern Oregon Coastal. Our Northern Oregon Coastal group was comprised entirely of stocks originating from north of, but not including, the Elk River (see Table 1) and our results indicated that those salmon were recovered primarily in the northern most extent of our study area (Tillamook and Newport catch areas). The Mid-Oregon Coastal group consisted of seven salmon stocks and included salmon originating both to the north and south of the Elk River. The Mid-Oregon Coastal group included salmon from the Elk and Umpqua Rivers. Our results indicated that tagged Mid-Oregon coastal salmon were recovered predominately off of Oregon's coast and to a lesser extent in recovery areas off of northern California. This result is consistent with findings by Nicolas and Hankin (1988) who reported that Umpqua River salmon were recovered in Californian waters, and Weitkamp (2010) who found that Elk River salmon have a more southerly distribution than other stocks originating from the Oregon coast. Finally, our results indicated that Oregon salmon originating from the Rogue River and south were recovered in the ocean off southern Oregon and northern California which mirrored results found in both Nicolas and Hankin (1988) and Weitkamp (2010).

Previous studies demonstrated that CWT data could be employed to examine Chinook salmon distributions at the management area level spatial scale but it was uncertain how well CWT data could be used to estimate salmon distributions at refined temporal scales. There was no evidence in the scientific literature of studies that used CWT data to illustrate how Chinook salmon distribution patterns vary during the commercial fishing season. We were able to utilize CWT data to estimate salmon distributions across months but to do so required a large number of tag recoveries, which limited the number of stocks we could examine to those with a history of tagging and necessitated aggregating CWT recoveries across many years. Furthermore, it was unclear what additional insight was gained by plotting our CWT-based monthly distribution estimates because there were very few instances where there appeared to be a pattern unique to the finer-scale. The exception were plots of Rogue River, Klamath River and Northern California/Southern Oregon coastal stocks of Chinook salmon based on CWT data from the "Early" period which suggested that those fish undertake a south – north migration during the commercial fishing season. Overall, the general patterns we described corresponded closely with the prior studies.

GSI-based results compared to previous studies

The results of this study support previous work conducted by other collaborators in the WCSGSI project. Ireland (2010), utilized GSI data collected during 2007 to examine fine-scale stock-specific Chinook salmon distributions off the Oregon coast. Ireland broke the Oregon coast into 0.25 degree latitudinal bins, a much finer spatial scale than was chosen in the present study, and calculated stock specific relative catch per unit effort for each bin. Ireland's results indicated that three broad distribution patterns existed off the Oregon coast: those encountered primarily off the northern coast (Lower Columbia Fall, Northern Oregon Coastal, Mid-Columbia Tule and Southern Puget Sound stocks), those encountered primarily off the southern coast (California Coastal, Northern California/Southern Oregon Coastal, Klamath River and Rogue River stocks), and those encountered coastwide (Central Valley Fall, Deschutes Fall, Upper Columbia Summer/Fall, Central Valley Spring and Mid-Oregon Coastal). While our study encompassed a broader spatial scope (addressing distributions along Oregon *and* California), utilized a coarser spatial scale (catch areas vs. 0.25 degree bins), and analyzed data collected from a different point in time, our results mirrored the findings of Ireland (2010).

More recently, Satterthwaite et al. (2014), utilized the same WCSGSI data collected during 2010 and 2011 to compare the marine spatial distribution of an untagged stock and its indicator: California Coastal and Klamath River Chinook, respectively. Satterthwaite et al. reported that the two stocks shared similar distributions early in 2010 but by August the highest CPUE for Klamath River Chinook occurred in the Klamath California area whereas highest CPUE for California Coastal Chinook occurred to the south in the Fort Bragg area. Similarly, in 2011 Satterthwaite et al. found that by August CPUE for Klamath River Chinook was again highest in the Klamath California area and CPUE for California Coastal Chinook was highest in the Fort Bragg area. They suggest that there was a northward shift in CPUE of Klamath Chinook as the season progressed. Although we used different methods, our distribution estimates for Klamath River and California Coastal Chinook salmon are nearly identical to those reported in Satterthwaite et al. (2014).

Potential management implications

The primary goal of fisheries management is to prevent overfishing while achieving, on a continuing basis, the optimum yield from the fishery. Optimum yield is defined as “the amount of fish that provides the greatest overall benefit to the

Nation, particularly with respect to food production and recreational opportunities, while taking into account protection of marine ecosystems" (Pacific Fishery Management Council (PFMC), 2014). Commercial salmon fisheries off the coasts of Oregon and California are under the jurisdiction of the Pacific Fisheries Management Council (Council). On an annual basis the Council recommends management measures designed to achieve the stock conservation objectives for each stock or stock complex while simultaneously seeking to achieve their harvest and allocation objectives. The total catch and mortality that results from recommendations made by the Council represents the optimum yield for the salmon fishery.

GSI data have potential to improve salmon management by providing more precise salmon distributions, resulting in higher yield of targeted stocks. Since the 1970s, information from CWT recoveries has helped structure management plans that result in the optimum yield of Chinook salmon stocks and stock complexes. Historically, those management plans have featured large-scale space and time closures that were implemented to help meet conservation goals for salmon stocks. There is no doubt that large-scale space-time closures are an effective means for restricting access to stocks that have failed to meet, or are projected to fall short of, their conservation goals. However, healthy stocks often times intermingle amongst the weak or rebuilding stocks those large-scale closures are designed to protect, resulting in fisheries that fall short of their potential. We illustrated how GSI provides information pertaining to the distributions of specific stocks and stock complexes of Chinook salmon at space-time scales that cannot be achieved with traditionally reported CWT data. Access to those GSI-based high resolution distribution estimates may allow managers to structure space-time closures more precisely, providing better opportunities to access target stocks while simultaneously avoiding harvest of those stocks that are susceptible to overfishing, are overfished, or are projected to fall short of their conservation goals. A more precisely structured fishery may allow for larger harvests to represent the optimum yield.

Access to GSI data in "real-time" could enhance our ability to harvest target stocks by guiding in-season management decisions. A previous study conducted by the WCSGSI collaboration demonstrated that GSI data can be processed and mapped in 24 – 48 hours, providing detailed, stock-specific, Chinook salmon distributions in near "real-time" (Bellinger and Banks, 2008). In contrast, CWT data often take up to a year or longer to process. Access to high resolution, real-time, information could pave the way for dynamic fisheries that could be augmented in-season to focus harvest on specific stocks and avoid those that have potential to constrain the fishery. For instance, during 2010 there were no fall commercial (September – December) fisheries in waters south of Cape Falcon due to concern over the status of Central Valley Fall Chinook and because Klamath River Fall Chinook were in a rebuilding plan which required restricting fall fishing opportunities (Pacific Fishery Management Council (PFMC), 2011). With access to salmon distributions in real-time managers would have been aware that the encounter rate of Central Valley Fall Chinook was relatively low for entire season in waters off the Oregon coast. Our refined GSI-based Chinook salmon distribution estimates indicated that during

September of 2010 Central Valley Fall Chinook were concentrated south of the Fort Bragg North area and Klamath River Chinook were concentrated north of the Klamath California South area. Access to those distribution estimates in real-time may have potentially allowed managers to implement terminal area fisheries designed to target the healthy Oregon Coastal Chinook stocks while avoiding Central Valley Fall and Klamath River stocks. As an added benefit, fish caught later in the season should theoretically be larger, therefore providing greater value to the industry. Finally, real-time salmon distribution estimates could potentially benefit other sectors of the fishing industry by providing them with the means to alter their fishing behavior so as to reduce bycatch of specific salmon stocks. GSI in real-time has the potential to provide benefits to all sectors of the commercial fishing industry.

In contrast to GSI data, CWTs provide the accurate age data which are required for cohort analysis and the models used to help develop and assess the efficacy of fishery regulations. While age data can be obtained via scale analysis, one of the biggest concerns about shifting to GSI for fisheries management has been the lack of reliable age data. A solution to that problem may be the implementation of full parentage genotyping (FPG, also referred to as parentage-based tagging), a genetics-based method that provides both stock of origin and the cohort of the recovered fish (Anderson and Garza, 2005). FPG utilizes a “parent database” which contains the genotypes of all the parents that were used to create a hatchery cohort. This means that under a FPG based system 100 percent of fish originating from a FPG hatchery would be “tagged.” When a fish is harvested it can then be compared to the parent database to determine its exact parents and therefore its origin and age, all the information required to perform cohort analyses. Additionally, FPG can be used in conjunction with GSI to cover both FPG populations as well as naturally producing and non-FPG populations (Anderson and Garza, 2005). Such a system would be able to provide stock of origin for all fish sampled, marked or unmarked, as well as cohort of origin for fish from FPG hatcheries.

GSI has the potential to advance salmon management. Access to more precise salmon distributions could allow us to design more effective management regulations. Knowledge of how salmon distributions vary in real-time would further improve our ability to harvest target stocks, increasing yield from the fishery which would provide greater socio-economic benefits to coastal communities. GSI in conjunction with FPG would provide all the data necessary for cohort analysis allowing current day cohort-based management regimes to no longer rely upon the CWT.

Future work

Future work must include the development of statistical methods that are suitable for identifying significant differences between distribution patterns at varying space-time scales. While our tileplots illustrated that GSI data could be used to estimate distribution patterns at refined space-time scales, we did not provide a statistical analysis that determines if those fine scale patterns provide significantly different information than the coarse scale patterns. Additionally, we will need to determine the quantity of data needed to test for statistically significant differences between space-time scales. The development of these statistical methods will be useful for determining whether the patterns we see at refined space-time scales are significantly different from those at coarser scales.

Conclusion

The Magnuson-Stevens Act states that conservation and management measures shall be based upon the best available science. Coded-wire tags were invented nearly 50 years ago and, while they provided us with unparalleled information about Pacific salmon, relying on technology that is fifty years old does not communicate an up-to-date management plan. Our results clearly demonstrated that GSI can be utilized to identify Chinook salmon distributions at refined space-time scales that are impossible to achieve with traditionally reported CWT data. I believe that CWTs no longer represent the best available science for studying the ocean distribution of Chinook salmon. Today that science is rooted in genetics, not coded-wire.

Bibliography

Anderson, E.C., Garza, J.C., 2005. A description of full parental genotyping. Rep. Submitt. Pac. Salmon Comm.

Bellinger, M.R., Banks, M.A., 2008. Section 2, Genetics. In, Oregon Salmon Commission. 2008. Project CROOS Collaborative Research on Oregon Ocean Salmon, 2007. Final Report to the Oregon Watershed Enhancement Board, 214 p.

Bellinger, M.R., Banks, M.A., Bates, S.J., Crandall, E.D., Garza, J.C., Sylvia, G., Lawson, P.W., 2015. Geo-referenced, abundance calibrated ocean distribution of Chinook salmon (Oncorhynchus tshawytscha) stocks across the west coast of North America. PloS One 10, e0131276.

Candy, J.R., Beacham, T.D., 2000. Patterns of homing and straying in southern British Columbia coded-wire tagged chinook salmon (Oncorhynchus tshawytscha) populations. Fish. Res. 47, 41–56.

Chinook Technical Committee, 1988. Exploitation Rate Analysis: A report of the Analytical Work Group of the Chinook Technical Committee (No. 88-2).

Fisher, J.P., Weitkamp, L.A., Teel, D.J., Hinton, S.A., Orsi, J.A., Farley Jr, E.V., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Trudel, M., 2014. Early ocean dispersal patterns of Columbia River Chinook and coho salmon. Trans. Am. Fish. Soc. 143, 252–272.

Groot, C., Margolis, L., 1991. Pacific salmon life histories. UBC press.

Holt, K.R., Cox, S.P., Sawada, J., 2009. In-Season Forecasting of Coho Salmon Marine Survival via Coded Wire Tag Recoveries. North Am. J. Fish. Manag. 29, 1165–1182.

Ireland, R.R.C., 2010. The distribution and aggregation of Chinook salmon stocks on the Oregon Shelf as indicated by the commercial catch and genetics.

Jefferts, K.B., Bergman, P.K., Fiscus, H.F., 1963. A coded wire identification system for macro-organisms. Washington State Department of Fisheries.

Johnson, J.K., Parker, N.C., 1990. Regional overview of coded wire tagging of anadromous salmon and steelhead in northwest America, in: Am. Fish. Soc. Symp. pp. 782–816.

Legendre, P., Legendre, L.F., 2012. Numerical ecology. Elsevier.

McCune, B., Grace, J.B., Urban, D.L., 2002. Analysis of ecological communities. MjM software design Gleneden Beach, OR.

McCune, B., Mefford, M.J., 1999. PC-ORD: multivariate analysis of ecological data; Version 4 for Windows;[User's Guide]. MjM software design.

Model Evaluation Workgroup (MEW), 2008. Chinook Fisheries Regulation Assessment Model (FRAM) Base Data Development v. 3.0 (Auxiliary Report to FRAM Technical Documentation for Coho and Chinook).

Morris, J.F., Trudel, M., Thiess, M.E., Sweeting, R.M., Fisher, J., Hinton, S.A., Fergusson, E.A., Orsi, J.A., Farley, E.V., Welch, D.W., 2007. Stock-specific migrations of juvenile coho salmon derived from coded-wire tag recoveries on the continental shelf of Western North America, in: American Fisheries Society Symposium. American Fisheries Society, p. 81.

Nandor, G.F., Longwill, J.R., Webb, D.L., 2010. Overview of the coded wire tag program in the greater Pacific region of North America. PNAMP Spec. Publ. Tagging Telem. Marking Meas. Monit. Fish Popul. Compend. New Recent Sci. Use Informing Tech. Decis. Modalities Pac. Northwest Aquat. Monit. Partnersh. Spec. Publ. 2, 5–46.

Nicholas, J.W., Hankin, D.G., 1988. Chinook Salmon Poputlations in Oregon Coastal River Basins: Description of Life Histories and Assessment of Recent Trends in Run Strengths (No. 88-1). Oregon Department of Fish and Wildlife.

Norris, J.G., Hyun, S.-Y., Anderson, J.J., 2000. The ocean distribution of the Columbia River upriver bright fall chinook salmon stocks. North Pac. Anadromous Fish Comm. Bull. 2, 221–232.

Pacific Fishery Management Council (PFMC), 2014. Pacific Coast Salmon Fishery Management Plan for Commercial and Recreationl Salmon Fisheries off the Coasts of Washington, Oregon, and California as Ameneded through Amendment 18.

Pacific Fishery Management Council (PFMC), 2011. Review of 2010 Ocean Salmon Fisheries.

Pacific Salmon Commission, 2005. Expert Panel on the Future of the Coded Wire Tag Program for Pacific Salmon. (Tech. No. 18).

Parken, C.K., Candy, J.R., Irvine, J.R., Beacham, T.D., 2008. Genetic and Coded Wire Tag Results Combine to Allow More-Precise Management of a Complex Chinook Salmon Aggregate. North Am. J. Fish. Manag. 28, 328–340. doi:10.1577/M06-110.1

Pearcy, W.G., 1992. Ocean ecology of North Pacific salmonids. Books Recruit. Fish. Oceanogr. USA.

Pearcy, W.G., McKinnell, S.M., 2007. The ocean ecology of salmon in the Northeast Pacific Ocean: an abridged history.

Quinn, T.P., Fresh, K., 1984. Homing and straying in chinook salmon (Oncorhynchus tshawytscha) from Cowlitz River Hatchery, Washington. Can. J. Fish. Aquat. Sci. 41, 1078–1082.

Satterthwaite, W.H., Mohr, M.S., O’Farrell, M.R., Anderson, E.C., Banks, M.A., Bates, S.J., Bellinger, M.R., Borgerson, L.A., Crandall, E.D., Garza, J.C., Kormos, B.J., Lawson, P.W., Palmer-Zwahlen, M.L., 2014. Use of Genetic Stock Identification Data for Comparison of the Ocean Spatial Distribution, Size at Age, and Fishery Exposure of an Untagged Stock and Its Indicator: California Coastal versus Klamath River Chinook Salmon. Trans. Am. Fish. Soc. 143, 117–133. doi:10.1080/00028487.2013.837096

Seeb, L.W., Antonovich, A., Banks, M.A., Beacham, T.D., Bellinger, M.R., Blankenship, S.M., Campbell, M.R., Decovich, N.A., Garza, J.C., Guthrie, I.I.I., others, 2007. Development of a standardized DNA database for Chinook salmon. Fisheries 32, 540–552.

Shaklee, J.B., Beacham, T.D., Seeb, L., White, B.A., 1999. Managing fisheries using genetic data: case studies from four species of Pacific salmon. Fish. Res. 43, 45–78. doi:16/S0165-7836(99)00066-1

Trudel, M., Fisher, J., Orsi, J.A., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Hinton, S., Fergusson, E.A., Welch, D.W., 2009. Distribution and Migration of Juvenile Chinook Salmon Derived from Coded Wire Tag Recoveries along the Continental Shelf of Western North America. Trans. Am. Fish. Soc. 138, 1369–1391. doi:10.1577/T08-181.1

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C., Beacham, T.D., 2011. Life history and seasonal stock-specific ocean migration of juvenile Chinook salmon. Trans. Am. Fish. Soc. 140, 1101–1119.

Van Doornik, D.M., Teel, D.J., Kuligowski, D.R., Morgan, C.A., Casillas, E., 2007. Genetic analyses provide insight into the early ocean stock distribution and survival of juvenile coho salmon off the coasts of Washington and Oregon. North Am. J. Fish. Manag. 27, 220–237.

Weitkamp, L.A., 2010. Marine Distributions of Chinook Salmon from the West Coast of North America Determined by Coded Wire Tag Recoveries. Trans. Am. Fish. Soc. 139, 147–170. doi:10.1577/T08-225.1

Weitkamp, L., Neely, K., 2002. Coho salmon (*Oncorhynchus kisutch*) ocean migration patterns: insight from marine coded-wire tag recoveries. Can. J. Fish. Aquat. Sci. 59, 1100–1115. doi:10.1139/f02-075