Cruise Report for OS1401, Juvenile salmon ocean ecology
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Vessel: **R/V OCEAN STARR**
Cruise: **OS1401 "summer salmon survey",** July 5-24, 2014
Project: **Juvenile Salmon Ocean Ecology,** Fisheries Ecology Division, NOAA, NMFS, SWFSC

Project Title: Distribution, growth, and condition of juvenile and subadult salmonids in the central California Current Ecosystem.

INTRODUCTION

Fishery managers, modelers, and population ecologists who wish to understand and predict variation in salmon escapement need to utilize a more complete understanding of the mechanisms that control early salmonid growth and survival at sea. Currently predictions of run size are based primarily on counts of precocious early spawners or on the size of a previous year's cohort, but a more sophisticated forecasting approach would also consider the effects of ocean conditions and ocean variability on salmon growth and survival—beginning at the time juvenile salmon first enter the sea. Such an approach would also increase the forecast period for many populations, allowing for improved strategic planning for recovery and enhancement efforts.

The broad objective of our ocean salmon survey is to quantify the spatial distribution and physiological condition of salmonid stocks in the central portion of the California Current Ecosystem. Beginning in 2010 we expanded the scope and range of our existing program through partnership with the NWFSC to develop a unified annual collaborative coast-wide survey of salmon and their ocean habitat. We use a surface trawl to collect juvenile and subadult salmonids (including several ESA-listed populations) and other epipelagic fish and invertebrates that co-occur with salmon. We also collect spatially matched biological and physical oceanographic data to describe the range of conditions in this complex and variable habitat. Data from this continuing time series of ocean salmon condition and distribution are increasingly valuable as California endures a prolonged drought and major changes in freshwater transport and storage are proposed for some of the state's principal salmon rivers in the coming years.

OBJECTIVES

1. Determine the interannual and seasonal variability of growth, feeding, energy status, and spatial distribution of juvenile salmonids in the coastal ocean off northern and central California; determine the migration pathways and spatial distribution/overlap of genetically distinct stocks (ESU or DPS) of salmonids during their early ocean residence.

2. Characterize prominent biological and physical oceanographic features associated with juvenile salmon ocean habitat from shore to the continental shelf break; identify potential links between coastal geography, oceanographic features, and salmon distribution patterns, energy status, and diet; quantify and describe the coastal pelagic fish and invertebrate community associated with juvenile salmon; identify and test promising ecological indices of salmon survival.

3. Quantify seabird distribution, abundance, and foraging activity in the vicinity of salmon and other pelagic fish and invertebrates.

ITINERARY

Cruise OS1401 was conducted over 18 consecutive days at sea (6-23 July 2014) in the coastal ocean approximately 1-20 nautical miles offshore, between Newport, OR (44°39') and Pigeon Point, CA (37°10'). Transects were located off Heceta Head, Five Mile Point, Rogue River, Smith River, Klamath River, Mussel Point, Trinidad Head, Eel River, Big Flat, Albion River, Gualala Point, Fort Ross, Tomales Bay, Bolinas Bay, Pillar Point, and Pigeon Point (Figure 1A). During daylight hours, we used a surface trawl to collect salmon and other epipelagic fish and invertebrates. We also made CTD casts, collected chlorophyll samples, and collected zooplankton using a bongo net and a vertical net. The order of sampling activities at each station was: (1) surface trawl; (2) CTD; (3) bongo; and (4) vertical net; this sequence required about 100 minutes per station, not including transit time between stations. This sequence, in which trawling was the first activity normally conducted upon arrival at each station, attempted to minimize potential interactions with marine mammals in accordance with guidelines developed by the SWFSC. On most days we were able to complete our target of five full stations, starting with the inshore and ending with the offshore station.

At night we traveled to the next sampling line to the south, arriving at about the midpoint of the line (8-9 nautical miles west of the inshore station) before sunrise. Seabird observations commenced as soon as light levels were sufficient and continued for 1 hour running east along the transect line to the day's first trawl station.

Thirteen scientists representing four institutions participated in the cruise (appendix).

METHODS

Since 2010 the Fisheries Ecology Division of the Southwest Fisheries Science Center, National Marine Fisheries Service, has conducted a standardized annual summer cruise in June or July covering the same set of transects and stations, using the same trawl and plankton nets and standardized sampling design (with the exception that trawl samples prior to 2012 were collected without a Marine Mammal Excluder Device installed in the net; see details below). The fishing vessel *Frosti* was chartered for the 2010 and 2011 cruises, and the research vessel *Ocean Starr* for the 2012, 2013, and 2014 cruises. Prior to this, we conducted a similar coastal salmon survey with a more restricted sampling area off central California between Point Arena (38°57') and Pillar Point (37°30') annually from 2000-2005 (Harding et al. 2011) and again in 2007.

Sampling Design

The study area for 2010-2014 summer salmon surveys was a narrow strip of coastal ocean between Heceta Head, Oregon (44°00') and Pigeon Point, California (37°10'), a distance of 754 km north to south. The sampling grid consisted of 16 east-west transect lines spaced an average of 50 km apart, although line spacing was not chosen to be uniform. The locations of transects were selected for their general proximity to coastal geographic features that could potentially influence salmon distribution (e.g. rivers) or affect coastal currents (e.g. headlands and bays). Five fixed stations were located on each transect.

Stations were chosen using criteria for water depth targets and station spacing, or some compromise between the two. The average water depth for positions 1 (closest to shore) to position 5 (farthest from shore) was 33, 57, 124, 215, and 438m. Thus, the shelf break usually occurred somewhere between positions 4 and 5, or between positions 3 and 4 in a few locations with a narrow shelf or where a transect crossed a submarine canyon. The average distance from shore (due west) for positions 1-5 was 4, 8, 15, 25, and 35km, respectively.

Surface Trawl: To collect salmon and their associated fish and invertebrate community, we used a 264 Nordic Rope Trawl (264 NRT; NET Systems, Bainbridge Island, WA) with 3m^2 foam-filled pelagic doors, and each door fitted with 200lb weight shoes. Net dimensions while fishing were approximately 22m wide x 18m high at the mouth and 200m total length with 15mm stretched mesh codend liner. The net was rigged with 70m bridles and fished with 140m of warp out. Six large floats (Polyform A5) attached to the net (two on the headrope kite and two on each upper wingtip) kept the headrope within 0.5m of the surface continuously during tows. Footrope depth was 16-20m (average 18.2m) during tows, and a few meters deeper (average 32m) during layout and haulback. Depth recorders (Reefnet Sensus Ultra dive data recorders) attached to the headrope and footrope verified deployment depths and measured vertical net spread and temperature. A mechanical flowmeter (General Oceanics) was towed alongside the boat for the duration of each tow to measure speed and total distance traveled through water. Sets were 30 minutes in duration, except where jellyfish were very abundant, in which case tow time was reduced according to jellyfish density. Tow speed determined by flowmeter ranged from 3.0-3.8 knots through water (average 3.5 knots STW), and tow distance averaged 3.2km for completed 30 minute tows. To account for differences in tow distance and duration, fish abundance was standardized to a volume of $10^6 m^3$ for all hauls—a standard that is about equal to a tow of 30 minutes at 3.0 knots. Wind and seas permitting, the tow path roughly followed the depth contour and intersected the station coordinates near the midpoint of the tow. Thus, tows usually ran parallel to shore, toward the south or southeast with the prevailing seas and swell.

Mitigating measures for protected species interactions

During final approach to each station, the Captain and all available crew maintained a lookout for marine mammals. When marine mammals were sighted near a station, the Cruise Leaser, in consultation with the Captain and others, determined if trawling operations could reasonably commence without increased likelihood of interaction between the gear and the animals sighted. This determination was based on the species and number of animals sighted, their behavior, their position and vector relative to the path of the vessel, the professional judgment of the Captain and scientists, and other factors.

If marine mammals were observed during this period and were determined to be at increased risk of interaction with gear, then the ship moved on to a new location within the same general area but at least 0.5 nautical miles away from the last position at which the animals were sighted. The visual scan continued during each subsequent move until it was determined that trawling operations could safely commence, or until the station was abandoned. During each trawl tow, the Captain and all available crew kept a continuous watch for marine mammals. When animals were sighted, the Cruise Leader, in consultation with others, determined the best strategy to avoid potential takes. In some situations the decision was made to immediately retrieve the net and move away from the area. At other times the decision was made to continue towing until the animal(s) were clear of the area and away from potential contact with the gear during haulback, when the risk of entanglement was believed to be highest. Finally, two acoustic pingers (Future Oceans 70 kHz Dolphin Pingers) were attached to the net.

These devices emit a 145 decibel signal every 4 seconds for 300 m/s and are believed to repel dolphins and possibly other marine mammals.

In addition to the active avoidance described above, the net was equipped with a Marine Mammal Excluder Device (MMED) to expel any large organisms (e.g. mammals, sharks, turtles) that were unintentionally captured. This device consisted of a rigid aluminum grate affixed at a 45° angle in the intermediate section ahead of the codend. In theory, large animals are deflected by the bars of the grate and expelled from the net through a hole in the webbing, while smaller organisms pass through the grate and are retained in the catch. Throughout cruise OS1401 the MMED was deployed in the "upside-down" position with the escape hole facing down and foam flotation added to the mesh panel covering the escape hole (Weitkamp, L. 2014).

We used several net-mounted video cameras in the intermediate section near the MMED to record organisms entering (and often escaping!) the trawl while it fished. Use of underwater video is becoming common among scientific trawl surveys due to the ready availability of small, inexpensive, durable cameras and housings (e.g. GoPro systems).

Disposition of trawl catch
For each tow, invertebrates and non-salmonid fishes were identified and counted (or counts estimated by subsampling), and 30 individuals of each species measured. All salmonids were identified and measured (fork length, FL). All juvenile salmonids (80-250mm FL) were lethally sampled; these were individually frozen in plastic bags for transport back to shore. Scales, caudal fin clips, and in some cases blood plasma samples were taken from each juvenile salmonid before freezing. Subadult salmonids (>250mm FL) were either kept or released, depending on their condition after capture. Although we immediately placed all subadult salmon and steelhead in aerated seawater live wells after hauling the net, the mortality rate of this size class was about 40% during capture. Those that survived capture were released after we removed a small piece of caudal fin for genotype and a few scales for ageing and growth. Subadult salmon that were lethally sampled were either kept intact and frozen or partially dissected *in-situ* for transport back to shore and subsequent analysis at our lab.

Once on shore, frozen salmon were thawed, weighed, and dissected to remove tissues for studies conducted by Division scientists and our partner agencies. These tissues included otoliths (for age and growth studies), coded wire tags, if present (to identify hatchery and cohort), muscle tissue (for stable isotopes and/or lipid assays), stomachs and contents (diet and feeding studies), and other tissues (heart, liver, intestines, pyloric caeca, kidney) for special studies upon request. Ablated tissues were refrozen for subsequent analysis, except stomachs which were preserved in formalin.

CTD: We used a Sea-Bird CTD (SBE 19-plus profiler) and deck unit (SBE 33) for real-time hydrographic sampling. The CTD and carousel unit was lowered to 10m depth and held for 2 minutes to equilibrate, then raised to just below the surface and lowered at a constant rate of 30m/min for the downcast to a depth of 5m above the bottom, or to a maximum depth of 200m at stations deeper than 200m. The unit was retrieve at a constant rate of 60m/min. Additional sampling instruments attached to the carousel included a PAR sensor, fluorometer, oxygen sensor, and transmissometer.

Water samples: At two stations daily, generally at positions 2 and 4 on the transect line, water samples were collected during the CTD upcast using an Eco55 water sampler and Niskin bottle rosette attached to the CTD carousel. Depths of water samples were determined by observing the fluorometer readings during the instrument downcast and choosing a depth of very low value below the chlorophyll maximum

(Cmax), a second depth at the highest observed value (Cmax, a point that varied in depth from 20-115m), and finally at a depth between Cmax and the surface, usually around 5m depth. The goal of the depth determination was to collect samples that spanned the range of possible values at each location. The CTD was stopped at each sample target depth for about 5sec before closing the bottle to capture the sample. Glass fiber filters (Whatman GF/F number 1825-025) were used to extract phytoplankton from 200ml of water from each bottle. The used filters + phytoplankton were frozen inside lightproof vials for transport back to shore and eventual analysis to measure chlorophyll-*a* concentrations. These samples were used to create a linear regression of CTD fluorometer volts versus chlorophyll-*a* concentration. This equation was used to convert fluorometer voltage values to chlorophyll-*a* concentration for all CTD casts.

Underway fluorometric sampling was done by continuously sampling seawater pumped through the ship's intake located near the bottom of the hull at around 3m depth. A Turner designs SCUFA instrument measured fluorescence values and a Sea-Bird thermosalinometer (TSG) measured water temperature and salinity. The values from these two instruments were merged with date, time, and position every 10 seconds into a continuous data file representing the entire cruise from Newport to San Francisco. Two to four times daily, a water sample was collected from the seawater supply and processed identically to the CTD water samples. The SCUFA instrument failed after the third day of the cruise, although temperature and salinity values from the TSG continued recording throughout.

Vertical net: A 50cm diameter, 200 micron ring net was used to collect zooplankton. While the ship was at a full stop, the weighted net was lowered vertically to a point about 5m above the bottom, or to a maximum depth of 100m at stations deeper than 100m, and then retrieved vertically at a constant rate of 30m/min. A mechanical flowmeter suspended in the mouth of the net (TSK flowmeter, Tsurumi Seiki Co., Japan) was used to measure distance through water and determine sample volume (TSK flowmeters have pins that prevent the impeller from spinning backward during descent when the net is not sampling, so only retrieval distance is measured), and a depth recorder (Reefnet Sensus Ultra) used to verify deployment depth. Net contents were placed in 5% buffered formalin preservative.

Bongo net: Zooplankton were also collected with a bongo net, a weighted pair of 71cm ID anodized aluminum rings connected by a central yoke to which the towing wire is attached. Each ring was fitted with 300 or 333 micron plankton nets and rigid PVC codends, and the bongo was deployed from the starboard hydrographic winch following protocols similar to those of a standard CalCOFI double-oblique bongo tow (Smith and Richardson, 1977). The bongo was lowered at a constant rate of 30m/min to a depth of 30m or to within 5m of the bottom at stations shallower than 30m. Wire angle was measured with an inclinometer attached to the tow wire beneath the block. The ship maintained a slow, steady speed of 1.5-2.0 knots to keep the wire angle at 45° (+/- 5°) throughout the tow. The bongo was held for 30 seconds at its maximum depth, and then raised at a constant rate of 30m/min to the surface. A mechanical flowmeter in the mouth of each net (General Oceanics, Miami, FL) was used to measure distance through water and determine sample volume, and a depth recorder (Reefnet Sensus Ultra) used to verify deployment depth. The entire contents of one of the two nets were placed in 5% buffered formalin preservative. A portion of the contents of the second net were frozen without chemical preservative added.

Seabird observations: A scientist stationed on the bridge recorded seabird sightings each morning while the ship traveled to the day's first trawl station. Seabird observations began just before sunrise at a point about 8-9 nautical miles from shore and continued for one hour as the vessel sailed east along the transect line toward the day's first trawl station. The observer counted, identified, and noted the behavior of all seabirds seen flying or resting on the surface of the water in a 300m radius, 90-degree arc from the bow to the beam of the ship.

Hydroacoustic data: Underway hydroacoustic sampling was conducted continuously over the survey using a multi-frequency echosounder (SIMRAD EK60) configured with down-looking 38, 70, 120, and 200 kHz split beam transducers mounted on the hull 3.3 m below the water line. The strength of volume backscattering from the resulting echograms can be used to measure the abundance and distribution of organisms that generate acoustic signals, such as krill (Hassrick et al, in prep).

RESULTS and DISCUSSION

During 18 days at sea we sampled a total of 70 stations spread over 15 transect lines. We made 69 CTD casts and 68 successful trawl, bongo, and vertical net tows (table 1). One transect line (Rogue River) was abandoned after waiting two days for strong northwesterly winds to subside. Two southern stations (TB01, PP01) were not trawled due to extremely high jellyfish density. Sampling at a few other stations was not attempted due to time constraints or unfavorable weather.

Coastal upwelling was generally weak during cruise OS1401 and surface water temperature was unusually warm, especially in the southern third of the study area from Gualala Point to Pigeon Point. Sea-surface temperature (SST) recorded every 10 seconds by the TSG ranged from a low of 10.3°C near the Rogue River on 08 July during a period of strong northwesterly winds, to a high of 20.9°C at station PP05 in the southern Gulf of the Farallones on 21 July (figure 1B). The water temperatures we encountered on the four southern transect lines (TB, GF, PP, and PI) were up to 8°C warmer than temperatures recorded at the same locations in the previous four year (figure 2). This warm water anomaly expanded and intensified through the summer and fall of 2014 and was notable for its unusual strength and persistence (NOAA Fisheries Ecology Division, News Item 9/8/2014; NASA and California Institute of Technology, Jet Propulsion Laboratory, News Item 9/4/2014), generating considerable interest among oceanographers, marine biologists, and fishermen alike.

Trawl catch

We caught a total of 23 species of fish and 12 species of invertebrates over 68 surface trawls on cruise OS1401 (table 2). The three most abundant species in the catch in 2014 were all invertebrates: market squid (*Doryteuthis opalescens*), lens jellyfish (*Aequorea* sp), and sea nettle jellyfish (*Chrysaora fuscescens*). The species rounding out the top-ten overall most abundant in the 2014 catch were jacksmelt (*Atherinopsis californiensis*), Pacific butterfish (*Peprilus simillimus*), fried-egg jellyfish (*Phacellophora camtschatica*), juvenile Chinook salmon (*Oncorhynchus tshawytscha*), moon jellyfish (*Aurelia labiata*), surfsmelt (*Hypomesus pretiosus*), and blue heteropods (*Carinaria cristata*). As is typical for trawl data such as these, abundance and frequency of occurrence varied dramatically among species. For example, the most abundant species in the catch, market squid, had a mean catch per unit effort (CPUE) of 1,742 individuals per haul and was present in 84% of hauls, whereas the fourth most abundant species, jacksmelt, had a mean CPUE of only 7.2 individuals per haul and was present in just 12% of hauls. Most hauls were sparse—the majority of species were present in fewer than 12% of hauls, the average species richness (number of species per haul) was 5.6, and one haul came up completely empty.

The abundance and frequency of occurrence of many species in the catch varied widely among years from 2010 to 2014. The variation in abundance among stations within years was also very large, as seen by the large standard error bars for mean annual CPUE values for most species. Thus, although interannual differences in total catch may appear substantial for most species, the variation within years makes it difficult to infer actual changes in abundance over time.

Without implying statistical significance, it is still worth pointing out a few notable differences and similarities in mean CPUE in 2014 relative to the preceding four summers. Preliminary analysis of catch rates for several historically abundant or otherwise interesting species captured in the trawl suggests that 2014 abundance was atypically low for at least two salmonids in our five year time series, but not unusually low or high for other species of fish or invertebrates, with one notable exception.

Three species of salmonid were caught in all years of the survey (figure 3). Chinook salmon were the most abundant of these. Chinook salmon catch was lower in 2014 than in any of the previous four years for both juvenile and subadult size classes. Coho salmon (*Oncorhynchus kisutch*) were less abundant than Chinook in all years. Coho CPUE did not appear to differ in 2014 from previous years in the coho series; 2014 juvenile coho catch was down a little from 2013 but higher than 2010 values, when CPUE of both size classes was lowest. Steelhead (*O. mykiss*) were less abundant than the other two salmonid species in 2014 and overall. Steelhead catch was low in 2014 (total of 8 fish), greater than 2010 (1 fish) and down from a high of 59 fish in 2011.

Among the non-salmonid fish and invertebrate component of the catch (figure 4), the abundance of market squid and sea nettle jellyfish in 2014 was well within the range of CPUE values from previous years of the survey. The true abundance of sea nettle jellies was actually higher in all years than our annual estimates suggest because we were unable to trawl at stations where sea nettles are most dense—to do so would damage or destroy the net very quickly. In 2014, two stations (TB01 and PP01) were deemed untrawlable for this reason. Although the overall abundance of sea nettles was not unusual in 2014, the northward spatial distribution of this species (not shown) was unusual. In all previous years of the survey, we encountered very high densities of sea nettles only on the four southernmost transect lines (Gulf of the Farallones region and Tomales Bay line), especially at the stations closest to shore. In 2014 we first encountered high densities of sea nettles further north than in previous years, starting at the Gualala Point line about 70 km north of the Tomales Bay line.

Clupeiform fishes continued to be rare or absent in our catch in 2014. Apart from a few larval individuals, northern anchovy (*Engraulis mordax*) have essentially been absent from our catch for the past five years. Pacific sardine (*Sardinops sagax*) were also entirely absent from samples in 2014, and Pacific herring (*Clupea pallasii*) were almost absent, with both species continuing a trend of extremely low abundance in our survey. Prior to 2010 we recorded catches of sardine in the hundreds and thousands per haul, and catches of anchovy and herring in the thousands and tens of thousands per haul in the southern portion of the study area (Harding et al. 2011). Osmerid fishes such as surf smelt (*Hypomesus pretiosus*) and whitebait smelt (*Allosmerus elongatus*) were also scarce or absent from samples in 2014 but more numerous than clupeids in recent years. Clupeids and osmerids are the principal members of the coastal forage fish community in the California Current and have periodically been very abundant locally (Litz et al. 2014). Their apparent continuing scarcity off southern Oregon and northern California in 2014 may have important implications for many species of fish and seabirds that normally prey on them, perhaps leading to increased reliance on other prey species such as market squid that occupy the same habitat and appear to be vastly more abundant.

Young-of-year rockfish (*Sebastes* spp) were essentially absent in July 2014, although they were caught by us in large numbers in the same region in July 2010 and were reported to be very abundant off central California in May-June 2014 (E. Dick, pers. comm.), a few weeks prior to cruise OS1401. A few common species in our catch, including moon jellies, jacksmelt, and wolf-eels (*Anarrhichthys ocellatus*) were more ubiquitous and were encountered every year from 2010-2014 but in relatively low numbers. Others, such as lens jellyfish, salps (*Thetys vagina*), and Pacific butterfish, had one or two "boom years" with high abundance at a few stations but low abundance or absence at other times.

Perhaps the most conspicuous difference in trawl catch in 2014 was the relatively high take of ocean sunfish (*Mola mola*). We caught thirteen ocean sunfish in the Gulf of the Farallones region in 2014, all on the four southernmost transects where SST was unusually high. No sunfish were captured in the preceding four years of the survey, although 25 were captured by surface trawl during a similar survey in the same area in July 2004. These animals are conspicuous for their unusual appearance and large size (up to 1.5m total length in our catch and reported up to 3.1m and 2500kg). They are common in warm pelagic waters worldwide, but a previous study reported *Mola mola* much closer to shore and in greater numbers off the coast of Oregon in a year with delayed upwelling and unusually warm coastal sea temperatures (Brodeur et al. 2006), similar to the conditions we encountered in 2014 in the Gulf of the Farallones. The capture of these fish is also noteworthy because it demonstrates that the MMED was not entirely effective at excluding all large animals. Most of the sunfish we caught were either pinned against the MMED grate, or tangled in the webbing ahead of the intermediate. Their unusual shape seems to have been a factor in the failure of the MMED to expel them.

The study area for this survey contains headlands, bays, rivers, and even a few small islands. We know that headlands in this area interact with currents and winds to produce large complex eddies and jets, which in turn are known to affect species distributions. A previous analysis of our trawl catch from 2010-2013 using multivariate ordination and cluster techniques found strong gradients in community structure along the two primary spatial axes of our survey—latitudinal and onshore/offshore (Harding, unpublished). On the latitudinal (north-south) axis, salmonids and osmerids contributed strongly to regional diversity in the northern portion, while jellyfish, squid, larval rockfish, and a few other species were more typical of the south. Statistical tests identified four measurably different communities among the 16 transects. These four community groups happened to coincide with the actual position of their lines along the coast, in order from north to south, meaning the biological pattern contained a strong north-south component.

Salmonids contributed strongly to the differences among these four regional assemblages. The proportion of each species and size class varied widely among regions over the five year period 2010-2014 (figure 5). For example, the epicenter of ocean salmon abundance within our study area was the Klamath-Trinidad (KT) region, where the highest proportion of Chinook, coho, and steelhead were caught. Abundance declined sharply in the region to the immediate north (Southern Oregon, SO) for all three species, and also declined to the immediate south (Lost Coast, LC) for coho and steelhead, and to a lesser extent for Chinook. In the southernmost region (Gulf of the Farallones, GF), coho and steelhead were essentially absent from our catch, adult Chinook were uncommon, and juvenile Chinook were again abundant. These patterns of abundance at sea appear to correspond to major sources of salmon production. For example, the Klamath River is a major source for Chinook, coho, and steelhead production, and the Sacramento River is a major source for California Central Valley Chinook production.

Salmonid catch over the five year period 2010-2014 also varied with depth and distance from shore and contributed to significant overall differences in catch composition along the onshore/offshore axis. The majority of Chinook and coho salmon were caught at inshore stations, especially at the second and third positions from shore (figure 6), although juvenile Chinook were taken in similar proportions at all positions except the farthest offshore stations (position 5) where they were rarely seen. Steelhead distribution was shifted farther offshore than the other two salmonids. Juvenile steelhead catch was highest at the third position from shore, and adult steelhead catch was highest further offshore with increasing numbers at positions 3, 4, and 5, respectively.

CONCLUSION

The July 2014 salmon survey conducted off southern Oregon and northern California encountered weak upwelling, unusually warm surface water south of Point Arena, and low numbers of Chinook and coho salmon and steelhead. Catch rates of small forage fish such as osmerid smelts, anchovy, herring, and sardine continued to be very low; for example, not a single anchovy (other than a few larval fish) has been taken in our annual survey since 2010. Although anchovy were absent from our survey in recent years, they have been conspicuously abundant elsewhere, such as in the Monterey Bay in fall of 2013 and 2014. Market squid, another small forage species, was the most abundant organism by far in our catch in 2014 and has been since 2010. The number of sea-nettle jellyfish, another common and abundant species, was similar in 2014 to previous years but their distribution was further north. Several large ocean sunfish were caught in the Gulf of the Farallones region in 2014, in areas where sea surface temperature was unusually high. No sunfish were caught by us in this region in the previous four years.

Based on preliminary viewing of our net-mounted video, we suspect that the MMED significantly reduces the catch of several species of fish and possibly also invertebrates. Recent experimental tests of the MMED compared catch rates in paired tows using the 264NRT with and without the MMED present (Weitkamp, L. 2014) and these comparisons found significant differences in catch of several species of fish and nekton, including coho and Chinook salmon. The catch per unit effort (fish/km towed) of all juvenile salmon groups was roughly twice as high when the excluder was not present in the net. This “excluder effect” has serious implications for any multiyear trawl survey such as ours where consistent fishing effort is required to maintain an unbiased time series and compare catch rates among years.

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Table 1. Transect lines and sampling stations for research cruise OS1401 (6-23 July 2014). A completed station included deployment of a CTD, surface trawl, bongo net and vertical net; successful completion of each operation is indicated by an “x” in the column under each type of equipment.

Line	Station	Latitude	Longitude	Depth (m)	Distance Offshore (km)	CTD	trawl	bongo	vertnet
Heceta Head	HH01	44 00.00	124 10.25	30	2.6	x	x	x	x
Heceta Head	HH02	44 00.00	124 12.70	55	5.9	x	x	x	x
Heceta Head	HH03	44 00.00	124 16.50	80	10.9	x	x	x	x
Heceta Head	HH04	44 00.00	124 23.40	117	20.2	x	x	x	x
Heceta Head	HH05	44 00.00	124 30.40	133	29.4				
Five Mile	FM01	43 13.00	124 26.00	30	3.0	x	x	x	x
Five Mile	FM02	43 13.00	124 28.40	55	6.1	x	x	x	x
Five Mile	FM03	43 13.00	124 33.80	73	13.3	x	x	x	x
Five Mile	FM04	43 13.00	124 39.30	137	20.7				
Five Mile	FM05	43 13.00	124 46.20	340	30.0				
Rogue River	RR01	42 30.00	124 29.50	32	5.6				
Rogue River	RR02	42 30.00	124 32.50	57	9.6				
Rogue River	RR03	42 30.00	124 36.00	82	14.4				
Rogue River	RR04	42 30.00	124 41.80	118	22.4				
Rogue River	RR05	42 30.00	124 48.60	600	31.7				
Smith River	SR01	41 54.00	124 16.30	30	5.4	x	x	x	x
Smith River	SR02	41 54.00	124 21.25	55	12.2	x	x	x	x
Smith River	SR03	41 54.00	124 26.70	91	19.6	x	x	x	x
Smith River	SR04	41 54.00	124 33.40	400	28.9	x	x	x	x
Smith River	SR05	41 54.00	124 40.10	680	38.2	x	x		
Klamath River	KR01	41 35.00	124 09.50	30	5.0	x	x	x	x
Klamath River	KR02	41 35.00	124 15.20	51	13.0	x	x	x	x
Klamath River	KR03	41 35.00	124 20.60	82	20.4	x	x	x	x
Klamath River	KR04	41 35.00	124 26.50	137	28.5	x	x	x	x
Klamath River	KR05	41 35.00	124 33.20	647	37.8	x	x	x	x
Mussel Point	MP01	41 21.00	124 08.50	30	5.4	x	x	x	x
Mussel Point	MP02	41 21.00	124 12.00	55	10.2	x	x	x	x
Mussel Point	MP03	41 21.00	124 16.60	83	16.5	x	x	x	x
Mussel Point	MP04	41 21.00	124 21.90	110	23.9	x	x	x	x
Mussel Point	MP05	41 21.00	124 28.60	250	33.2	x	x	x	x
Trinidad Head	TD01	41 03.50	124 11.40	32	3.1	x	x	x	x
Trinidad Head	TD02	41 03.50	124 14.10	52	6.9	x	x	x	x
Trinidad Head	TD03	41 03.50	124 16.70	87	10.6	x	x	x	x
Trinidad Head	TD04	41 03.50	124 23.30	260	19.8	x	x	x	x
Trinidad Head	TD05	41 03.50	124 29.90	650	29.1	x	x	x	x
Eel River	ER01	40 38.00	124 23.60	30	6.3	x	x	x	x
Eel River	ER02	40 38.00	124 26.80	55	10.7	x	x	x	x
Eel River	ER03	40 38.00	124 30.80	700	16.3	x	x	x	x
Eel River	ER04	40 38.00	124 37.40	700	25.6		x		
Eel River	ER05	40 38.00	124 44.00	1000	34.8				

Table 1. continued.

Line	Station	Latitude	Longitude	Depth (m)	Distance Offshore (km)	CTD	trawl	bongo	vertnet
Big Flat	BF01	40 08.00	124 12.90	30	2.0	x	x	x	x
Big Flat	BF02	40 08.00	124 14.00	55	3.5	x	x	x	x
Big Flat	BF03	40 08.00	124 15.20	91	5.2	x	x	x	x
Big Flat	BF04	40 08.00	124 21.70	400	14.4	x	x	x	x
Big Flat	BF05	40 08.00	124 28.25	600	23.7	x	x	x	x
Albion River	AR01	39 15.00	123 48.20	59	1.5	x	x	x	x
Albion River	AR02	39 15.00	123 49.75	92	3.7	x	x	x	x
Albion River	AR03	39 15.00	123 53.60	130	9.3	x	x	x	x
Albion River	AR04	39 15.00	124 00.00	420	18.5	x	x	x	x
Albion River	AR05	39 15.00	124 06.50	720	27.8	x	x	x	x
Gualala Point	GP01	38 45.00	123 32.70	35	1.7	x	x	x	x
Gualala Point	GP02	38 45.00	123 34.10	55	3.7	x	x	x	x
Gualala Point	GP03	38 45.00	123 37.30	87	8.3	x	x	x	x
Gualala Point	GP04	38 45.00	123 43.70	126	17.6	x	x	x	x
Gualala Point	GP05	38 45.00	123 50.10	300	26.9	x	x	x	x
Fort Ross	FR01	38 30.00	123 14.80	39	2.2	x	x	x	x
Fort Ross	FR02	38 30.00	123 15.60	55	3.3	x	x	x	x
Fort Ross	FR03	38 30.00	123 18.50	81	7.6	x	x	x	x
Fort Ross	FR04	38 30.00	123 24.90	112	16.9	x	x	x	x
Fort Ross	FR05	38 30.00	123 33.80	164	29.8	x	x	x	x
Tomales Bay	TB01	38 08.00	122 58.30	30	1.5	x		x	x
Tomales Bay	TB02	38 08.00	123 00.40	58	4.6	x	x	x	x
Tomales Bay	TB03	38 08.00	123 06.75	76	13.9	x	x	x	x
Tomales Bay	TB04	38 08.00	123 13.20	108	23.2	x	x	x	x
Tomales Bay	TB05	38 08.00	123 19.60	141	32.4	x	x	x	x
Gulf Farallones	GF01	37 50.50	122 41.70	28	12.2	x	x	x	x
Gulf Farallones	GF02	37 50.50	122 48.00	46	21.5	x	x	x	x
Gulf Farallones	GF03	37 50.50	123 01.50	80	41.1	x	x	x	x
Gulf Farallones	GF04	37 50.50	123 11.60	85	55.9	x	x	x	x
Gulf Farallones	GF05	37 50.50	123 23.00	190	72.6				
Pillar Point	PP01	37 30.00	122 31.60	32	2.2	x		x	x
Pillar Point	PP02	37 30.00	122 36.40	56	9.3	x	x	x	x
Pillar Point	PP03	37 30.00	122 45.50	80	22.6	x	x	x	x
Pillar Point	PP04	37 30.00	122 54.30	110	35.6	x	x	x	x
Pillar Point	PP05	37 30.00	123 00.60	400	44.8	x	x	x	x
Pigeon Point	PI01	37 10.00	122 24.20	34	3.7	x	x	x	x
Pigeon Point	PI02	37 10.00	122 26.15	55	6.5	x	x	x	x
Pigeon Point	PI03	37 10.00	122 30.00	83	12.2	x	x	x	x
Pigeon Point	PI04	37 10.00	122 38.30	107	24.4	x	x	x	x
Pigeon Point	PI05	37 10.00	122 44.60	200	33.7	x	x	x	x

Table 2. Summary of fish and invertebrate species or broader taxa captured by surface trawl during cruise OS1401. Catch per unit effort, CPUE, is number of individuals per $10^6 m^3$ trawled, averaged over all stations where trawling was conducted. SD is the standard deviation of the mean CPUE, FO is frequency of occurrence (number of trawls where at least one individual of a species was captured, out of 68 possible trawls), and %FO is percent frequency of occurrence.

common name	**sci name**	**group**	**CPUE**	**SD**	**FO**	**%FO**
market squid	*Doryteuthis opalescens*	invert	1742.45	3297.85	57	83.8
lens jellyfish	*Aequorea sp*	invert	77.18	495.63	32	47.1
sea nettle jellyfish	*Chrysaora fuscescens*	invert	76.86	234.61	30	44.1
jacksmelt	*Atherinopsis californiensis*	fish	7.19	42.30	8	11.8
Pacific butterfish	*Peprilus simillimus*	fish	4.93	26.75	13	19.1
fried-egg jellyfish	*Phacellophora camtschatica*	invert	4.49	14.36	41	60.3
Chinook salmon, juvenile	*Oncorhynchus tshawytscha*	fish	2.24	5.31	21	30.9
moon jellyfish	*Aurelia labiata*	invert	1.32	2.80	25	36.8
surf smelt	*Hypomesus pretiosus*	fish	1.08	6.64	3	4.4
blue heteropod	*Carinaria cristata*	invert	0.81	5.05	8	11.8
alien spaceship salp	*Thetys vagina*	invert	0.77	2.55	16	23.5
coho salmon, adult	*Oncorhynchus kisutch*	fish	0.69	1.55	17	25.0
Pacific herring	*Clupea pallasii*	fish	0.69	2.85	6	8.8
Chinook salmon, adult	*Oncorhynchus tshawytscha*	fish	0.55	1.64	14	20.6
medusafish	*Icichthys lockingtoni*	fish	0.32	1.17	11	16.2
coho salmon, juvenile	*Oncorhynchus kisutch*	fish	0.32	0.93	10	14.7
salp, double-X	*Pegea confoederata*	invert	0.29	1.38	5	7.4
sablefish	*Anoplopoma fimbria*	fish	0.28	2.11	3	4.4
pyrosome	*Pyrosoma atlanticum*	invert	0.28	2.00	3	4.4
flatfish larvae, unid.	*flatfish unidentified*	fish	0.28	0.81	12	17.7
wolf-eel	*Anarrhichthys ocellatus*	fish	0.27	0.68	13	19.1
ocean sunfish	*Mola mola*	fish	0.21	0.53	10	14.7
pipefish, unid.	syngnathid unidentified	fish	0.11	0.56	4	5.9
steelhead, adult	*Oncorhynchus mykiss*	fish	0.11	0.41	5	7.4
pelagic octopus		invert	0.09	0.46	3	4.4
PacMan jellyfish	*Scrippsia pacifica (?)*	invert	0.08	0.45	3	4.4
king-of-the-salmon	*Trachipterus altivelis*	fish	0.06	0.21	5	7.4
purple-striped jellyfish	*Pelagia colorata*	invert	0.06	0.34	2	2.9
jack mackerel	*Trachurus symmetricus*	fish	0.05	0.25	3	4.4
Pacific tomcod	*Microgadus proximus*	fish	0.05	0.25	3	4.4
Pacific hake	*Merluccius productus*	fish	0.04	0.29	1	1.5
rockfish larvae, unid.	*Sebastes sp.*	fish	0.03	0.16	2	2.9
Pacific electric ray	*Torpedo californica*	fish	0.02	0.17	1	1.5
yellowtail rockfish	*Sebastes flavidus*	fish	0.01	0.11	1	1.5
osmerid larvae, unid.	osmerid unidentified	fish	0.01	0.10	1	1.5
shiner surfperch	*Cymatogaster aggregata*	fish	0.01	0.10	1	1.5
steelhead, juvenile	*Oncorhynchus mykiss*	fish	0.01	0.09	1	1.5
Pacific mackerel	*Scomber japonicus*	fish	0.01	0.09	1	1.5

Figure 1. (A) Map of study area for cruise OS1401, showing transect lines and sampling stations. Black circles indicate stations with trawls completed; red circles indicate stations where trawling was not attempted. The ship's track is shown in green, starting in Newport, Oregon (top) and ending in San Francisco, California. (B) Sea surface temperature (C^{o}) in one minute intervals along the ship's track.

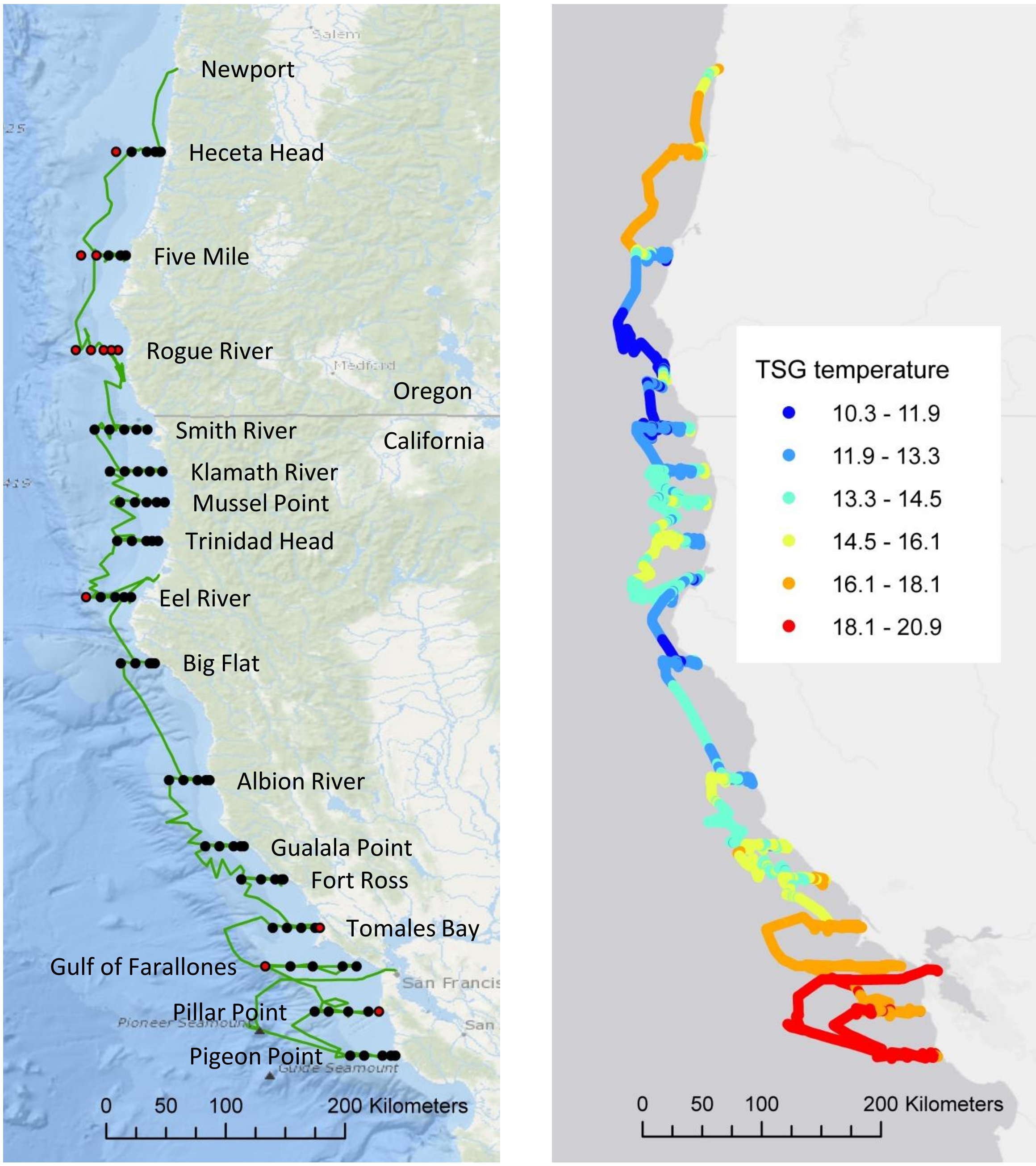


Figure 2. Sea surface temperature (C°) maps derived from CTD measurements made at fixed stations from June-July salmon cruises during the period 2010-2014. Stations north of 44°30' (Newport, Oregon) were sampled by the Northwest Fisheries Science Center, and stations south of 44°30' were sampled by the Southwest Fisheries Science Center. Data analysis and maps provided by C. Morgan, NWFSC.

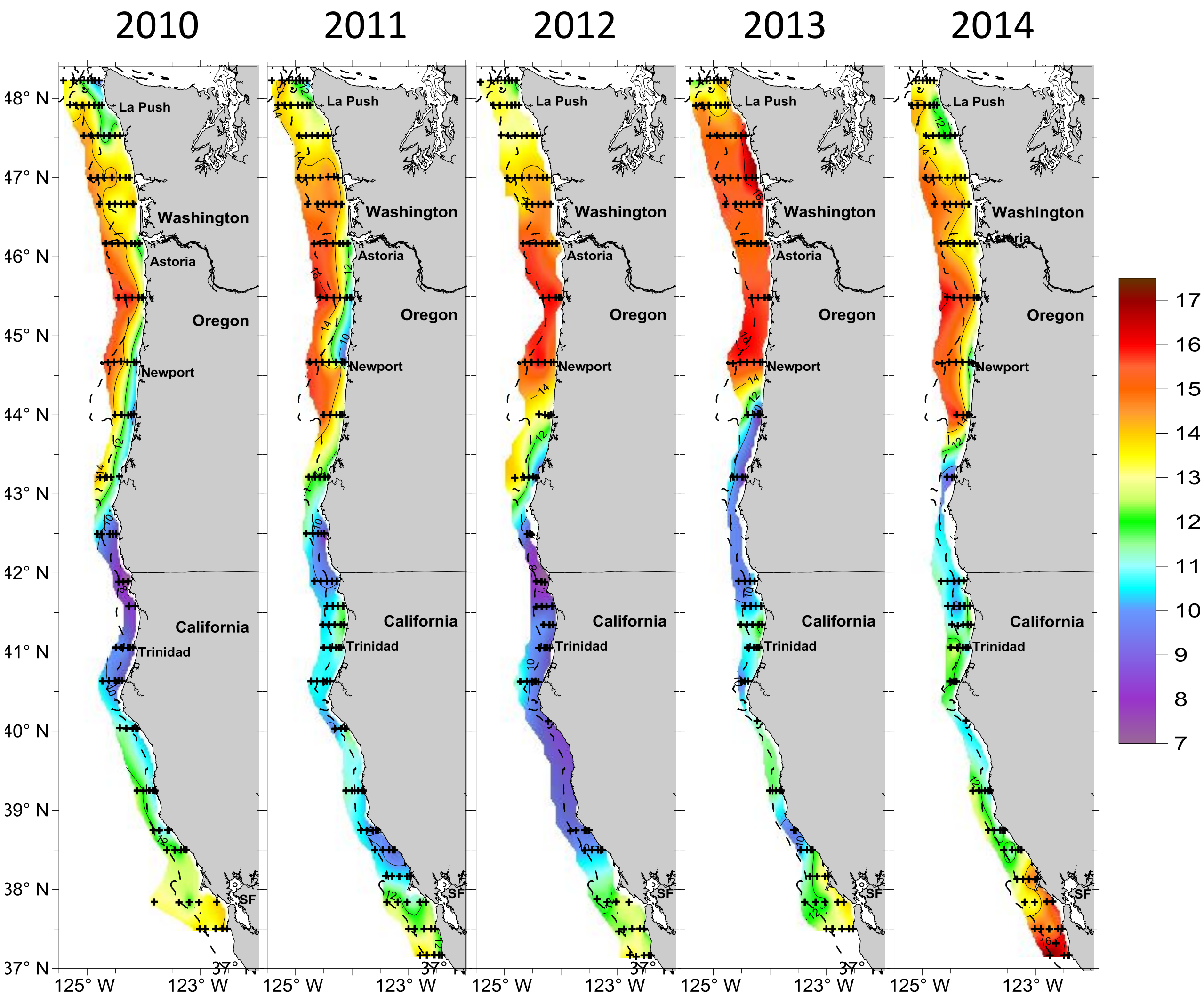


Figure 3. Mean annual CPUE (fish/$10^6 m^3$) of Chinook salmon, coho salmon, and steelhead on summer salmon survey cruises during the period 2010-2014. Error bars are ±1 standard error of the mean. Note different scales used on each graph. "Juveniles" ≤250mm fork length, "adults" >250mm fork length.

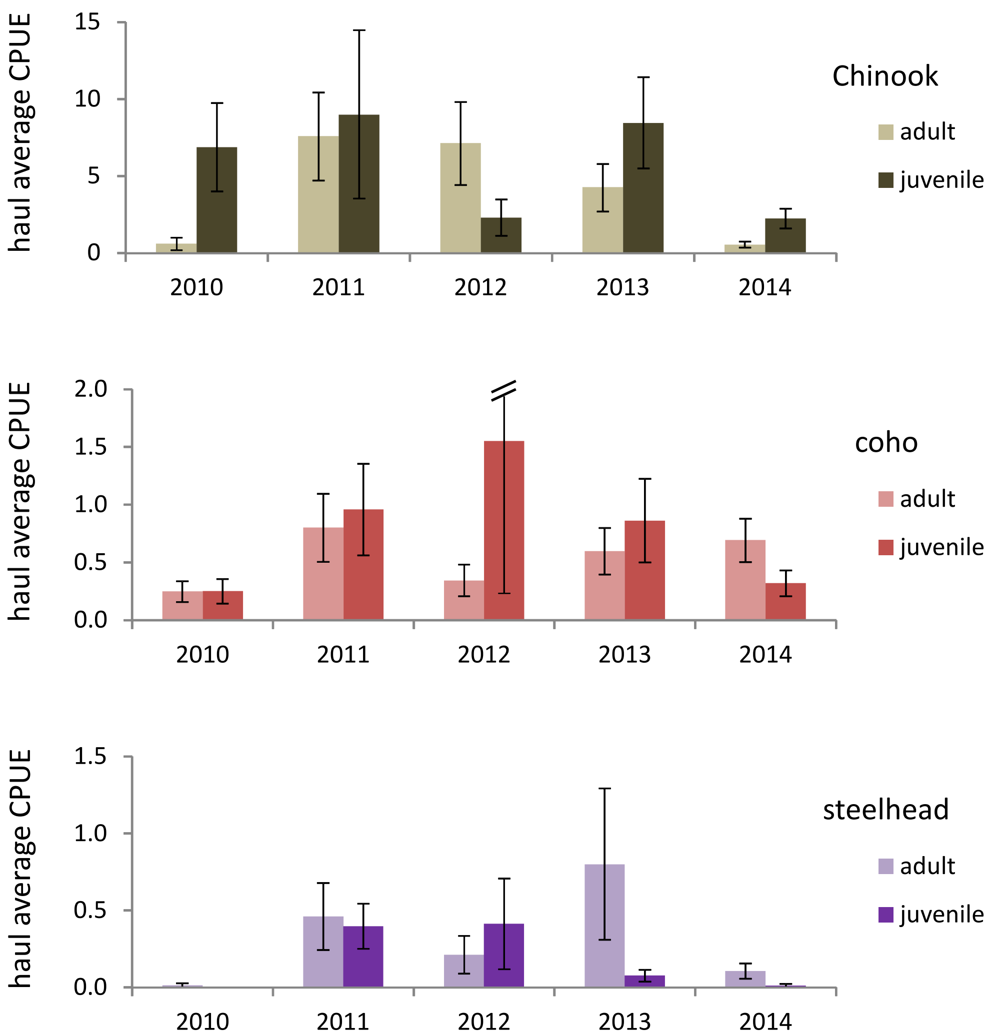


Figure 4. Mean annual CPUE (fish/$10^6 m^3$) of selected invertebrates and fish on summer salmon survey cruises during the period 2010-2014. Error bars are ±1 standard error of the mean. Note very different scales used among the graphs.

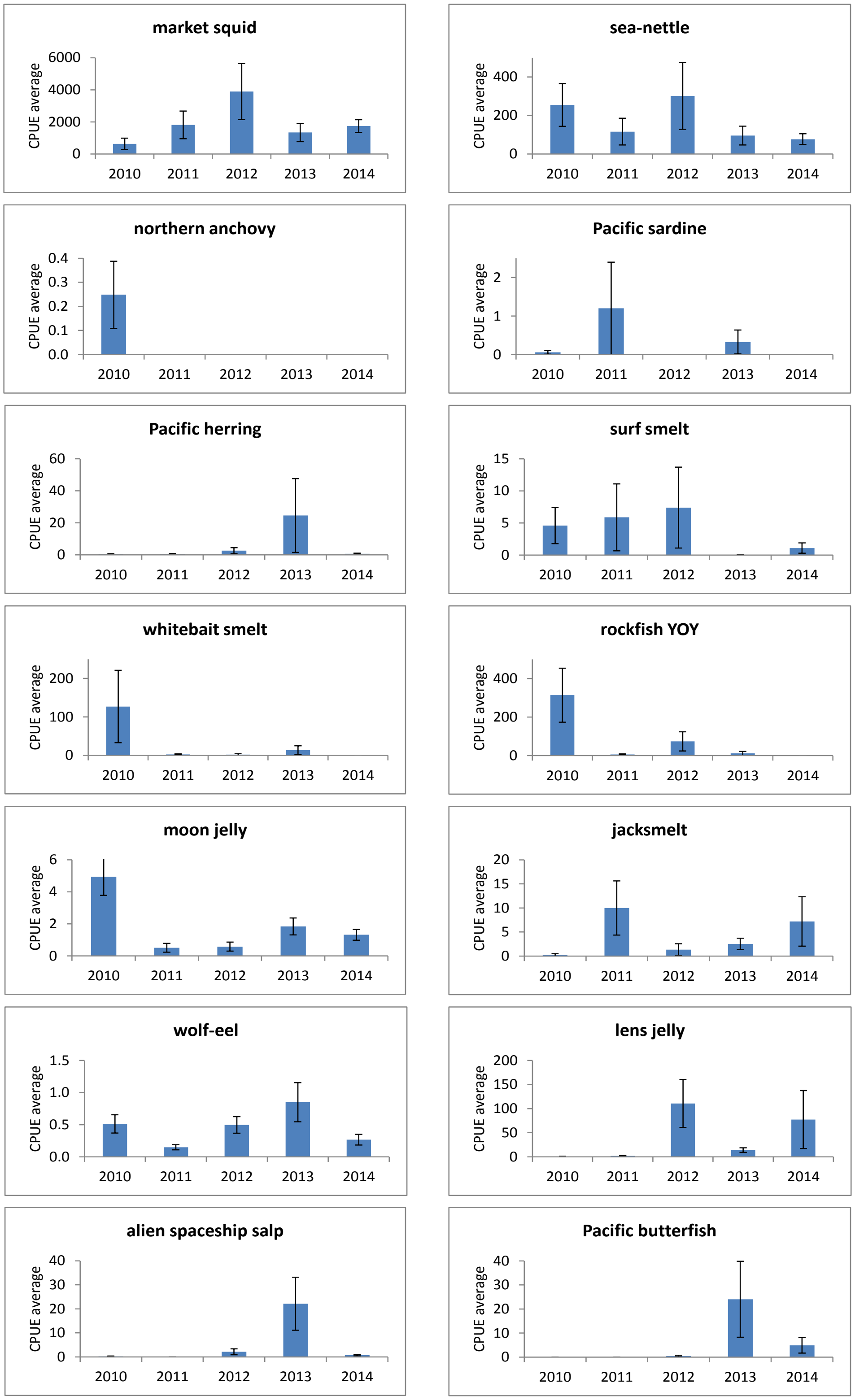


Figure 5. Percent CPUE by size class of steelhead, coho salmon, and Chinook salmon among four community groups (SO, KT, LC, and GF) over the period 2010-2014. Ellipses on the coastal map show the division of the sixteen transects into four statistically different assemblages of fish and invertebrates, based on multivariate analysis of all species in the trawl catch from 2010-2013.

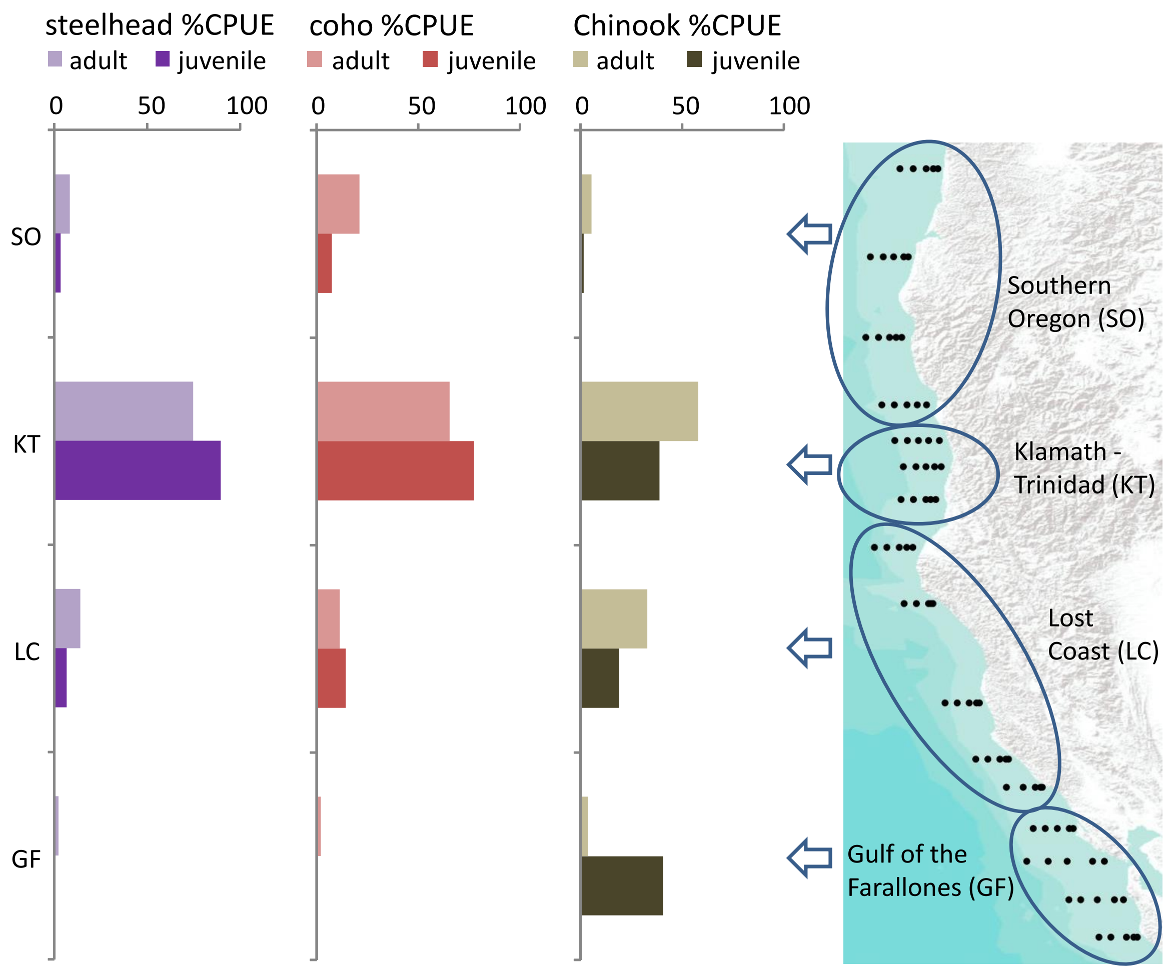
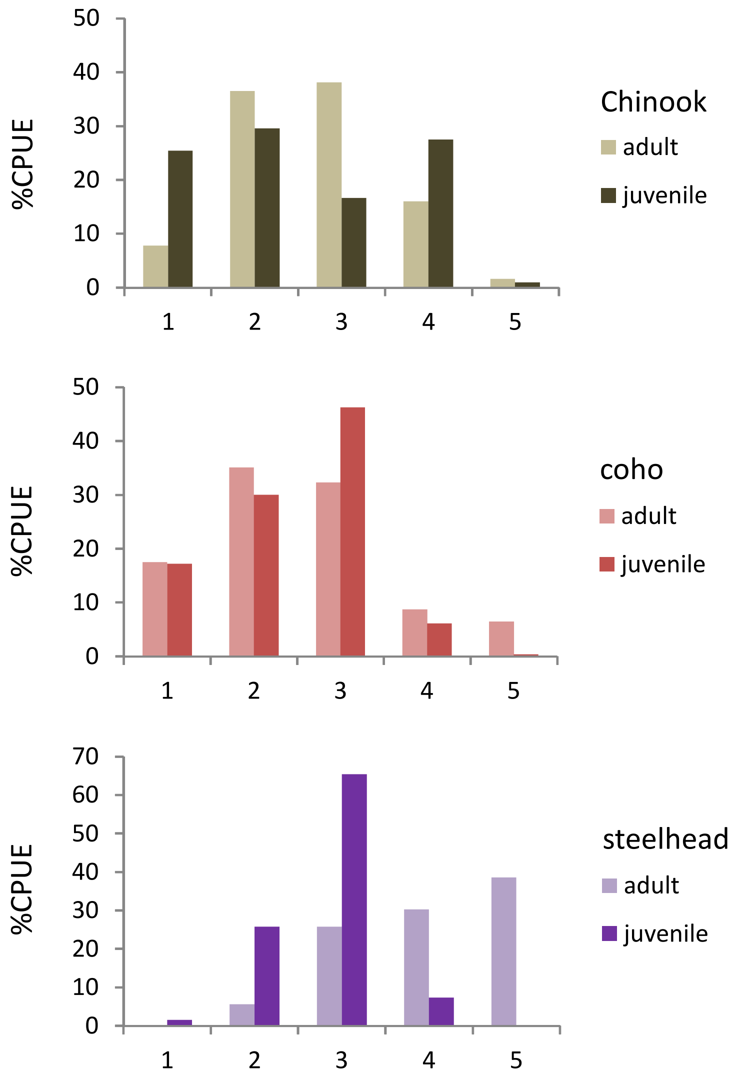


Figure 6. Percent CPUE by size class of Chinook salmon, coho salmon, and steelhead among the five station positions from shallowest (position 1) to deepest (position 5) over the period 2010-2014.



Appendix i: Scientists participating in NOAA research cruise OS1401, July 4-23, 2014.

<u>Leg 1: July 4-14, 2014. Newport, Oregon to Eureka, California</u>

Jeff Harding, Cruise Leader, NOAA SWFSC FED
Theresa Burnham, Hollings Intern, NOAA SWFSC FED
Sarah Abboud, Graduate Student, University of California at Merced
Nic Retford, Graduate Student, University of California at Santa Cruz
Arnold Ammann, Fishery Biologist, NOAA SWFSC FED
Matt Miller, Research Assistant, NOAA SWFSC FED
Emerson Kanawi, Research Assistant, NOAA SWFSC FED
Vanessa Lo, Research Assistant, NOAA SWFSC FED

<u>Leg 2: July 15-23, 2014. Eureka, California to San Francisco, California</u>

Jeff Harding, Cruise Leader, NOAA SWFSC FED
Theresa Burnham, Hollings Intern, NOAA SWFSC FED
Sarah Abboud, Graduate Student, University of California at Merced
Brendan Lehman, Research Assistant, NOAA SWFSC FED
Nick Demetras, Research Assistant, NOAA SWFSC FED
Megan Sabal, Research Assistant, NOAA SWFSC FED
Bryan Begun, Officer and Fishery Biologist, NOAA Corps
Tim Brown, Research Assistant, NOAA SWFSC FED