

A) COVER PAGE

Hatchery Scientific Review Group  
Research Grant Project  
Annual Report

**Marine Distribution and Trophic Interactions of  
Juvenile Salmon in Puget Sound:  
A Synthesis of Trends among Basins**

Elisabeth J. Duffy, David A. Beauchamp, Nathanael C. Overman, Washington Cooperative Fisheries and Wildlife Research Unit, and Raymond L. Buckley, Washington Department of Fish and Wildlife

Interagency Committee for Outdoor Recreation  
Natural Resources Building  
1111 Washington Street  
P.O. Box 40917  
Olympia, WA 98504-0917

**August 29, 2005**

**i) PROJECT STAFF**

**Principal Investigators**

David Beauchamp                      WACFWRU Asst Leader, UW Fisheries Assoc. Professor  
Raymond Buckley                      WDFW Fisheries Research Scientist II

**Graduate Student**

Elisabeth Duffy                      UW School of Fisheries and Aquatic Sciences, PhD Program

**Staff Scientist:**

Nathanael Overman                      Fisheries Research Scientist

**UW and WDFW Field and Lab technicians:**

Angie Lind, Steve Damm, Mistie Hammer, Kenton Finkbeiner, Shannon Stragier, Andre Buchheister, Trevor King, Jim Mattila, Brianna Shrier, Ocean Eveningsong

## INTRODUCTION

The early marine life of juvenile salmon is a critical period when numerous factors influence immediate or long-term survival of these species. Puget Sound, while at the least a necessary migration corridor, may serve as an important rearing environment during this potentially “critical period” of estuarine residence for some or all species of juvenile salmon. As in many areas of the Pacific Northwest, stocks of anadromous Pacific salmon in the Puget Sound basin are experiencing widespread declines. Recent work has focused on determining the distribution, feeding, growth, and sources of mortality for juvenile salmon during and after their nearshore residence in Puget Sound waters in order to understand whether recent declines reflect degraded rearing conditions or changes in temporal-spatial patterns of estuarine use in Puget Sound compared to times of higher marine survival.

Puget Sound is a large glacial fjord that encompasses a wide variety of physical and environmental conditions; therefore generalizations about juvenile salmon ecology are unlikely to apply throughout the entire basin. Localized differences between basins include the size and discharge of associated rivers, the degree of urbanization (e.g., altered habitats, pollutant loads), and the composition of salmon stocks (proportion of natural versus hatchery production). In Puget Sound today, hatchery production accounts for approximately 70% of the harvested salmon (HSRG 2002; Washington Department of Fish and Wildlife, unpublished data) although production varies substantially among the different basins of the Sound (HSRG 2002). These differences likely affect the potential role and quality of these areas as rearing environments for juvenile salmon. For instance, we might expect habitats where salmon first enter Puget Sound (i.e., delta habitats) to offer different foraging and refuge conditions than habitats along nearshore beaches further from freshwater influence. In addition, we might expect rearing strategies to differ between populations dominated by hatchery fish and those with greater natural production.

Recent research efforts by a variety of government and tribal agencies have identified localized timing patterns for entry into Puget Sound waters by various species and stocks of juvenile salmon. Our objectives were to examine whether these localized patterns, including the timing of marine entry, timing and duration of nearshore use, the corresponding size structure of juvenile salmon, and their dietary habits, were similar over time and among regions in Puget Sound.

## METHODS

### Study Area

Puget Sound (Fig. 1) is a deep, elongated glacial fjord composed of underwater valleys, ridges and basins with an average depth of 135m. The central or main basin, from Admiralty Inlet to the Tacoma Narrows, is the deepest basin on average, and contains the deepest point (>280m; Burns 1985). Northeast of the main basin, the Whidbey basin is fed by some of the Sound's largest rivers (the Skagit, Snohomish and Stillaguamish) and receives 60% of the freshwater entering Puget Sound (Burns 1985). The southern basin receives <10% of the freshwater draining into Puget Sound, primarily from the Nisqually and Deschutes rivers plus smaller rivers and streams (Burns 1985).

For this study, we synthesized data from among the main basins of Puget Sound: a northern region (NPS) in the southeastern Whidbey basin, a central region in the main basin (CPS), a southern region (SPS) south of the Tacoma Narrows sill and north of the Nisqually River, and the Nisqually delta region (Nisq) at the mouth of the Nisqually. These sampling regions included significant salt water entry points for both wild and hatchery juvenile salmon, major freshwater inflows (Snohomish, Stillaguamish, Puyallup, Green and Nisqually Rivers), and presumptive marine rearing and migration corridors.

The NPS and SPS regions included 5-6 nearshore sites and 3 neritic (the top 3m of the water column at increasing distances from shore) sites. In the main basin, beach seining was conducted at up to 28 sites. These sites were separated into three regional categories for analysis (Brennan et al. 2004): North Mainland (Golden Gardens to Picnic Point; CPS – N in this document), Island (Vashon and Maury Islands; CPS – IL in this document), and South Mainland (Lincoln Park to Marine View Park; CPS – S in this document). Between 13 and 17 sites were sampled in the Nisqually delta (Nisq) during 2002. The sites were located in the lower portions of McAllister Creek, the Nisqually River and Red Salmon Slough (Hodgson and Brakensiek 2003).

Offshore data was derived from bi-annual mid-water trawling conducted in the main basin of Puget Sound by Department of Fisheries and Oceans, Canada (generally July and September, 1997-2004; (Beamish et al. 1998); R. Beamish, Department of Fisheries and Oceans Canada, Nanaimo, B.C., unpublished data). Sites were separated into two main regions: Admiralty (from Elliott Bay to Port Townsend, roughly CPS – N) and central PS (CPS, from Alki Point to just north of the Tacoma Narrows).

### Data Sources

In addition to results from published reports ((Beamish et al. 1998), Hodgson and Brakensiek 2003, Duffy 2003, Brennan et al. 2004), we also had access to the original datasets including unpublished and unanalyzed data from the same sources (R. Beamish, Department of Fisheries and Oceans Canada, Nanaimo, B.C., unpublished data; J. Brennan and K. Higgins, King County Department of Natural Resources and Parks, Seattle, WA, unpublished data).

### Catch and size distribution

The catches per unit effort (CPUE; average catch per seine haul at each site on each sampling date) and average sizes (FL) were calculated for each salmon species in each region. CPUE for mid-water trawls were standardized as catch per hour.

### Dietary analysis

The proportional wet weight contribution of each prey category was calculated individually for all non-empty salmon stomachs. Sufficient diet data was only available for chinook salmon from central Puget Sound sites. For ease of comparison (Figures 10-13), prey were grouped by the habitats generally associated with them, and were defined as follows: Epibenthic/benthic prey items included cumaceans, fish/intertebrate eggs, gammarid amphipods (*Eogammarus* spp., *Corophium* spp. and others), harpacticoid copepods, isopods (*Gnorimosphaeroma* spp., and others), mysids (*Neomysis* spp.), ostracods, polychaetes, and shrimp (mainly pandalids and hippolytids). Planktonic prey included barnacle “larvae” (cyprids and slough), calanoid copepods, cladocerans, decapod crab larvae (zoea and megalopa), euphausiids, marine gammarid amphipods, hyperiid amphipods, and larvaceans. “Insects” were

associated with neuston or drift and included both terrestrial and aquatic insects (including Coleoptera, Diptera – especially chironomid pupae and adults, Homoptera, Hymenoptera, Lepidoptera, Trichoptera, Plecoptera) as well as spiders and water mites (Arachnida). Nektonic fish prey included mainly larval and juvenile fish species.

## E) FINDINGS

### Timing & Distribution

Overall abundances of all species of salmon were higher in 2002 than in 2001, which may be a result of increased and more experienced sampling regimes. In 2001, timing of chum salmon was synchronized at nearshore sites in CPS and presence of chum salmon was most prolonged in SPS (Figure 2). In 2002, the greatest abundance of pink salmon was in NPS with very few pink salmon caught south of Elliott Bay, mid-Central Sound. Chum salmon persisted nearshore over a few months in most regions and timing was more varied among regions (Figure 2).

The relative proportion of hatchery to unmarked (presumably naturally-produced) chinook salmon increased from north to south in Puget Sound. Timing of hatchery and unmarked fish was slightly offset, particularly in NPS, where there was a higher proportion of unmarked fish (Figure 3). There were May and July pulses of chinook in NPS and in central Puget Sound's Vashon and Maury Islands (Figure 3). In 2002, timing of chinook salmon was synchronized in the main basin (CPS, Figure 3).

Coho salmon had the shortest duration and lowest abundances at nearshore sites, particularly in 2001 (Figure 4). As with chinook, there was a higher relative proportion of hatchery to unmarked (presumably naturally-produced) coho salmon in more southern regions of Puget Sound. Timing was very similar among regions and between hatchery and unmarked coho within each region (Figure 4).

In offshore waters, abundances of all species were highest in July (Figures 5-7). Most coho salmon were gone by September/October, but there were still substantial numbers of chinook and chum salmon, especially in more northern locations (Figures 5, 6; Admiralty, CPS – N; Beamish et al. 1998; R. Beamish, Department of Fisheries and Oceans Canada, Nanaimo,

B.C., unpublished data). Juvenile salmon were caught mainly in the top 30m of the water column, but small numbers were also caught in deeper waters (30-70m, Figures 5-7; R. Beamish, Department of Fisheries and Oceans Canada, Nanaimo, B.C., unpublished data). There were substantial greater numbers of hatchery chinook and coho salmon caught, particularly in southern central (CPS) and south Puget Sound (SPS, Figures 6, 7).

### Size & Growth

Chum salmon were generally slightly larger than pink salmon in all regions, except in SPS (Figure 8) where most pink salmon we caught were thought to be hatchery-reared (Duffy 2003). In SPS, chum salmon were slightly larger in 2001, a year when there were no juvenile pink salmon (Figure 8). Chinook salmon were slightly smaller in NPS and Nisq than in CPS and SPS. Hatchery chinook and coho salmon were slightly larger than unmarked counterparts in all regions (Figure 9). Pink and chum salmon enter nearshore Puget Sound environments at the smallest size, followed by Chinook. Coho, generally a year older, are the largest juvenile salmon found nearshore. Most salmon species were slightly smaller at nearshore sites in NPS than in SPS and CPS (Figure 10). Sizes of pink and chum salmon in neritic waters were similar or slightly larger than those nearshore, and sizes of all salmon species in offshore waters were larger than those nearshore (Figure 10).

In offshore waters, juvenile chum, pink, and chinook salmon are a similar size in July, and by October, chum and pink are larger than the chinook salmon (2004, Figure 11). The smaller chinook and pink salmon are found in the top 15m of the water column, while slightly larger salmon are found in deeper water (Figure 11). As in nearshore catches, hatchery chinook salmon are slightly larger than unmarked chinook (Figure 12).

### Diet

Salmon diets varied seasonally and regionally. In 2002, insects were a dominant food item in NPS for chinook salmon, while planktonic organisms were a more important food source in SPS (Figure 13). Chinook in central Puget Sound foraged more evenly on each major prey category, perhaps representing a food supply that contained a mix of prey available at NPS and SPS sites (Figure 13). Fish prey appeared to be more important for chinook in CPS in the spring

(May-June), while chinook in NPS were more piscivorous in the summer (July-September; Figure 13).

Dietary habits of chinook salmon in May were similar by region in 2001 and 2002 (Figure 14). Within CPS, there were localized differences in diets, with chinook in northern CPS being most piscivorous, although this may be due primarily to their larger size. In June, insects were a more dominant prey item for chinook salmon in all regions, although they were still most prevalent in NPS (Figure 15). The highest piscivory was again associated with the larger chinook, caught at this time in southern CPS (Figure 12). In July, chinook salmon were more piscivorous (especially in NPS and CPS-IL) in 2002 than in 2001 (Figure 16). Insects continued to be a dominant diet item in all regions in both years. Regional dietary differences within central Puget Sound were more apparent in 2002 than in 2001 (Figure 16).

Although there were not many fish caught in neritic waters, some shifts were seen between nearshore and neritic diets. The most pronounced differences were seen for pink and chum salmon as they moved from a more varied nearshore diet (incorporating epibenthic and insect prey) to eating larvaceans almost exclusively (other neritic prey were planktonic or neustonic insects; Figure 17). Offshore diet data was only available from 1997, and it appeared that diets of salmon in offshore waters differed from prey preferences both nearshore and in neritic waters. Chinook were the most piscivorous species of salmon, while chum were exclusively planktivorous (Figure 18). There were some similarities in diets of chum, chinook and coho salmon in offshore habitats. For all three species, euphausiids were an important prey item in the spring, while crab larvae were dominant in July diets, and amphipods became a more important food source in September (Figure 18).

## EVALUATION

This project provided a critical first step at uncovering large-scale patterns, as well as regional differences, in the early marine ecology of juvenile salmon throughout Puget Sound. This work stimulated a series of coordination and planning sessions among scientists and managers from Washington Department of Fish and Wildlife, NOAA-Fisheries, Army Corps of

Engineers, USGS/BRD, King County, City of Seattle, Northwest Indian Fisheries Commission and associated tribes, and Department of Fisheries and Oceans Canada. Our project demonstrates how comparable data sets can be collected, integrated, and used to evaluate factors limiting survival and growth of juvenile salmon during their early life history in Puget Sound.

Recommendations for future sampling include:

- 1) Conduct more intensive sampling in offshore Puget Sound waters to obtain a more complete picture of residence time, growth, and trophic interactions of salmon once they leave nearshore environments.
- 2) Obtain better region and population-specific abundance estimates in order to begin to understand variations in marine survival for salmon species originating in different areas of Puget Sound, and for hatchery and wild populations originating from the same regions.
- 3) Use scales and/or otoliths to evaluate the growth history of juvenile salmon during their residence in Puget Sound to determine whether key (episodic) mortality events occur and whether they are correlated with size.

## ACKNOWLEDGEMENTS

This research was made possible by funding from the Hatchery Scientific Review Group (HSRG), UW Mason Keeler fellowship, Washington Department of Fish and Wildlife (WDFW), Washington Sea Grant, and Washington Cooperative Fish and Wildlife Research Unit (WACFWRU). Thanks to the many hard workers of the Beauchamp lab and others for their tireless efforts during long hours in the field and lab.

## LITERATURE CITED

- Beamish, R. J., M. Folkes, R. Sweeting, and C. Mahnken. 1998. Intra-annual changes in the abundance of coho, chinook, and chum salmon in Puget Sound in 1997. Pages 531-541 in Puget Sound Research '98 Conference Proceedings. Puget Sound Action Team, Seattle, WA.
- Beamish, R.J., R. Sweeting, and C. Cooper. 2001-2004 Puget Sound mid-water trawl (R/V WE Ricker) dataset. Department of Fisheries and Oceans Canada, Nanaimo, B.C. Unpublished data.
- Brennan, J.S. K.F. Higgins, J.R. Cordell, and V.A. Stamatiou. 2004. Juvenile salmon composition, timing, distribution, and diet in marine nearshore waters of central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, WA. 164 pp.
- Brennan, J.S. and K.F. Higgins. King County Department of Natural Resources and Parks, Seattle, WA. Juvenile salmon dataset from 2001-2002 central Puget Sound study.
- Burns, R. (1985). The Shape and Form of Puget Sound. Puget Sound Books. Washington Sea Grant Publication. University of Washington Press. 100 pp.
- Duffy, E.J. 2003. Early marine distribution and trophic interactions of juvenile salmon in Puget Sound. Master's thesis, University of Washington, Seattle, WA. 173 pp.
- Hatchery Scientific Review Group (HSRG) – Mobernd, L., J. Barr, L. Blankenship, D. Campton, T. Evelyn, C. Mahnken, B. Piper, L. Seeb, and B. Smoker. (2002). *Hatchery Reform Recommendations*. Seattle, WA. 163 pp.  
[http://www.lltk.org/pdf/HSRG\\_Recommendations\\_Feb\\_02.pdf](http://www.lltk.org/pdf/HSRG_Recommendations_Feb_02.pdf)
- Hodgson, S., and K. Brakensiek. 2003. Juvenile salmon utilization of the lower Nisqually River and estuary: 2002 beach seine results. Nisqually Indian Tribe and the Northwest Indian Fisheries Commission, WA. 29 pp.

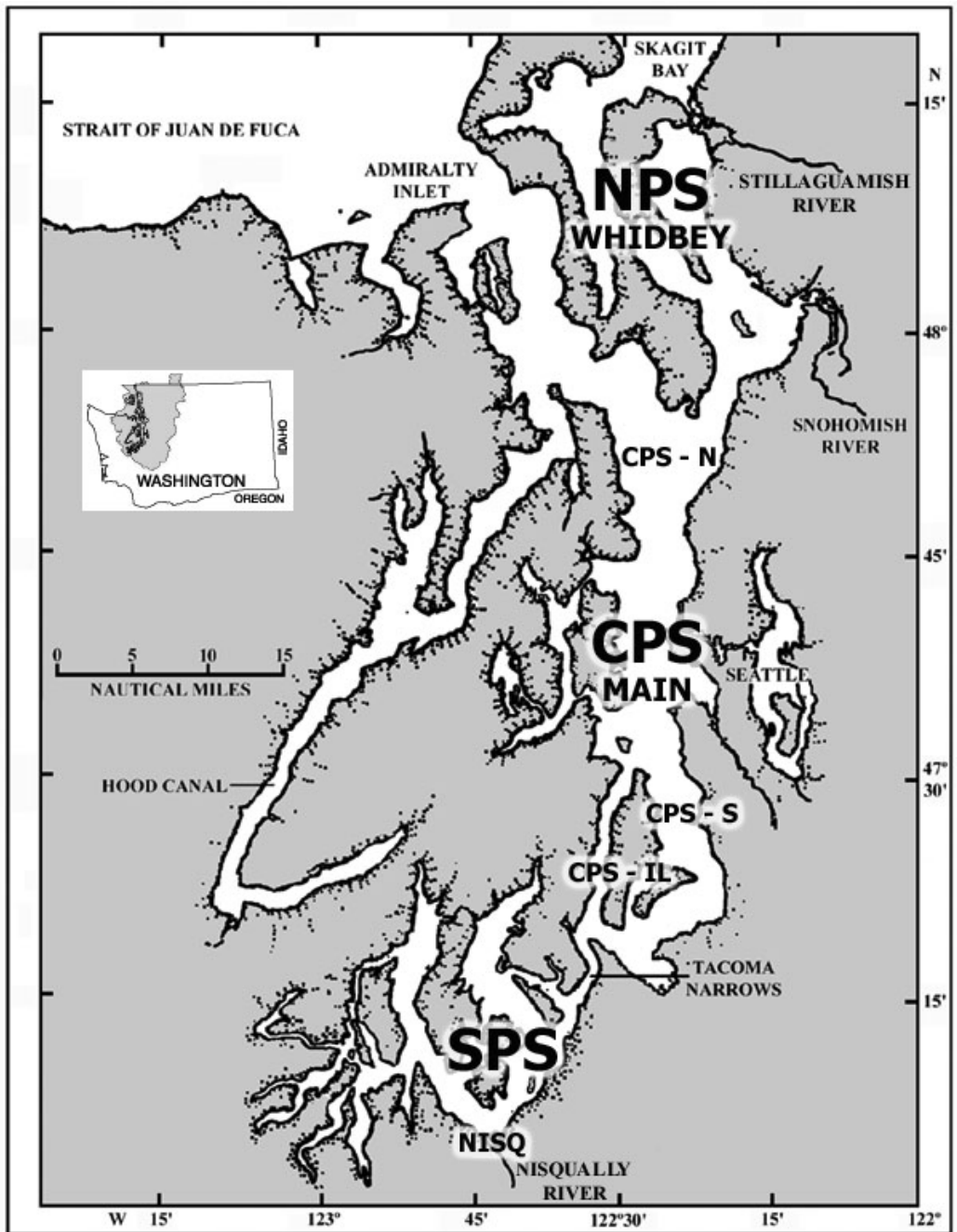


Figure 1. Major regions/basins of Puget Sound.

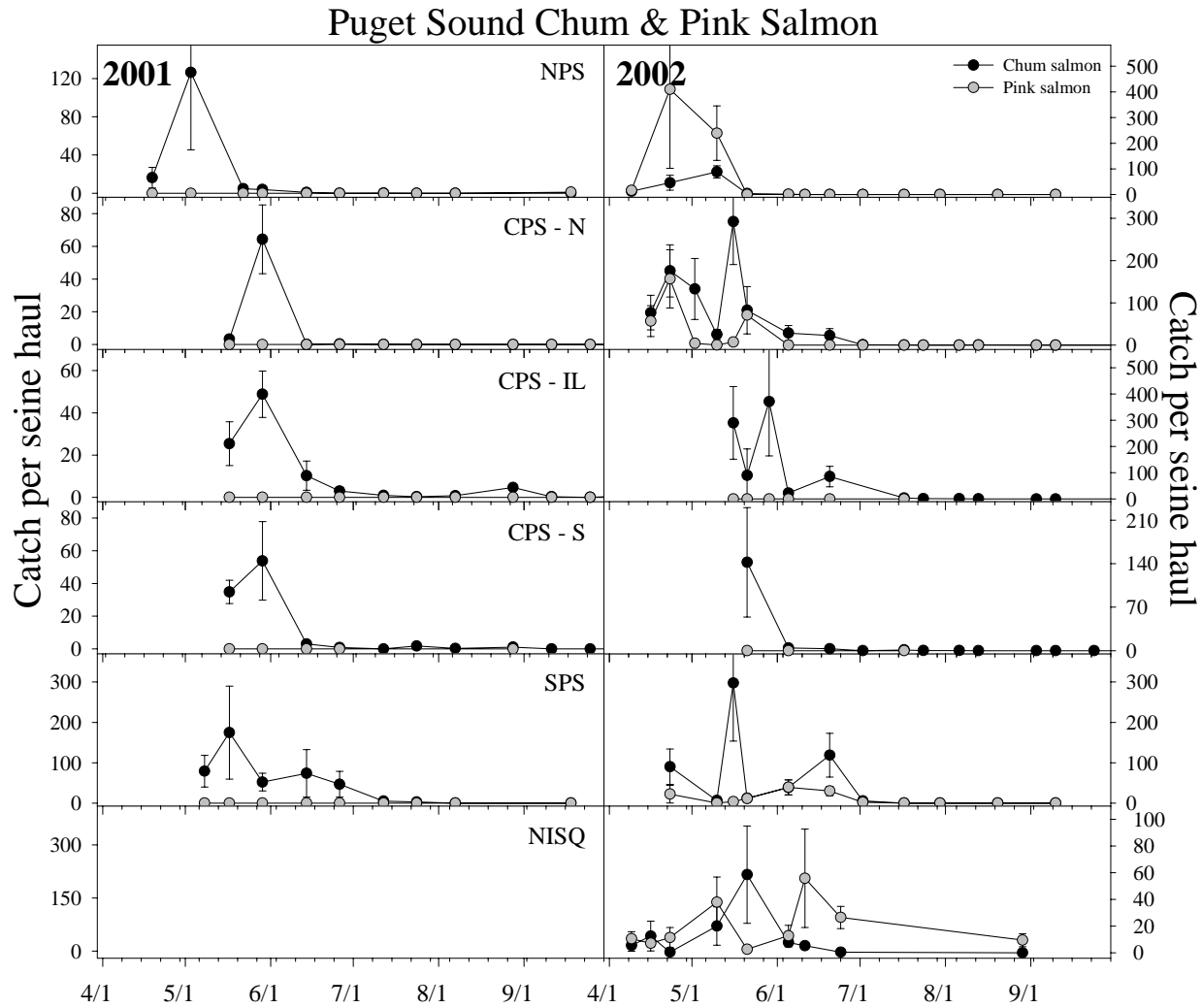


Figure 2. Average catch ( $\pm$  SE) of juvenile chum (black circles) and pink (gray circles) salmon in beach seine hauls. Note that the scale changes by year and region. Points sometimes occlude standard error bars.

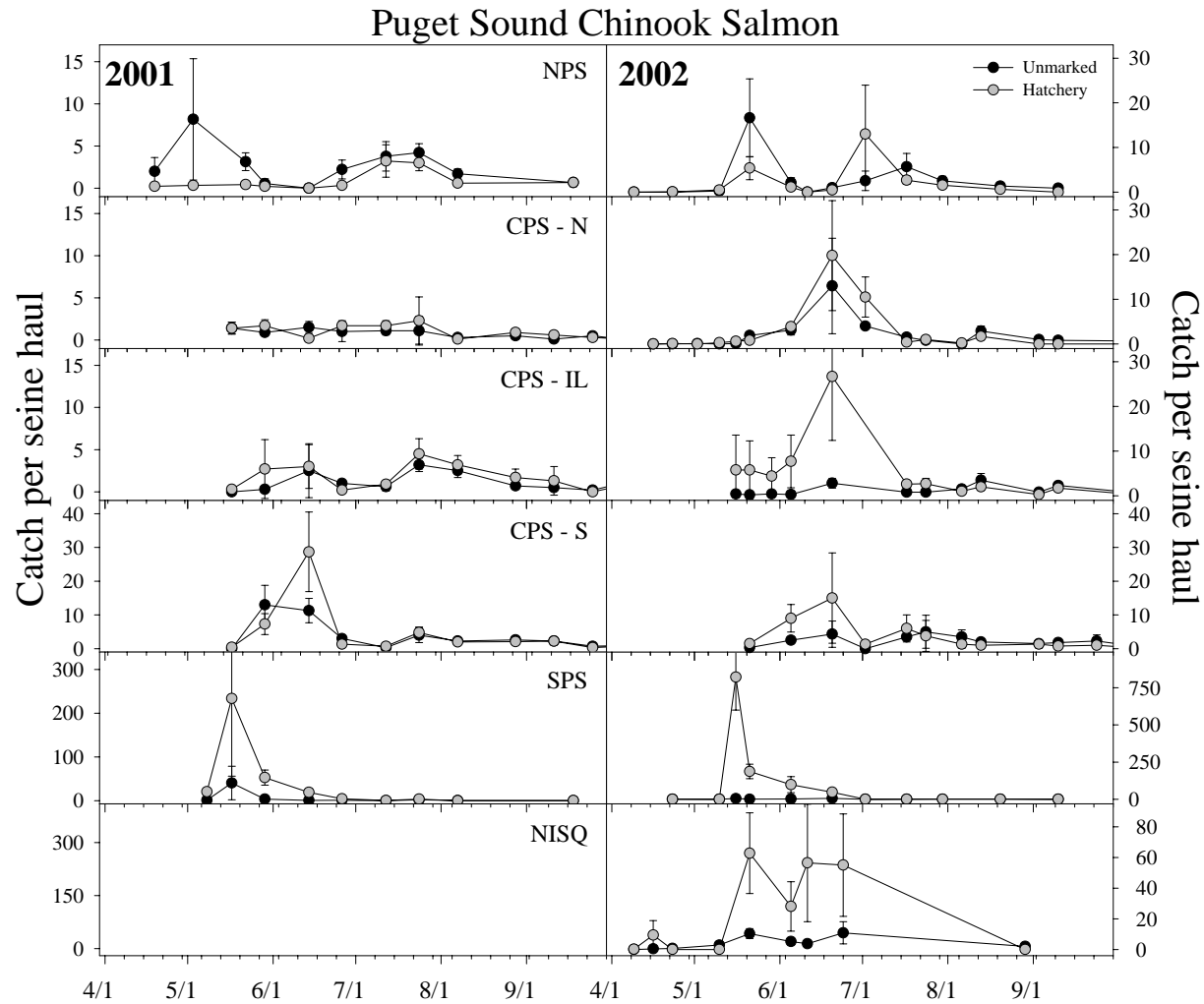


Figure 3. Average catch ( $\pm$  SE) of unmarked (black circles) and hatchery (gray circles) juvenile chinook salmon in beach seine hauls. Note that the scale changes by year and region. Points sometimes occlude standard error bars.

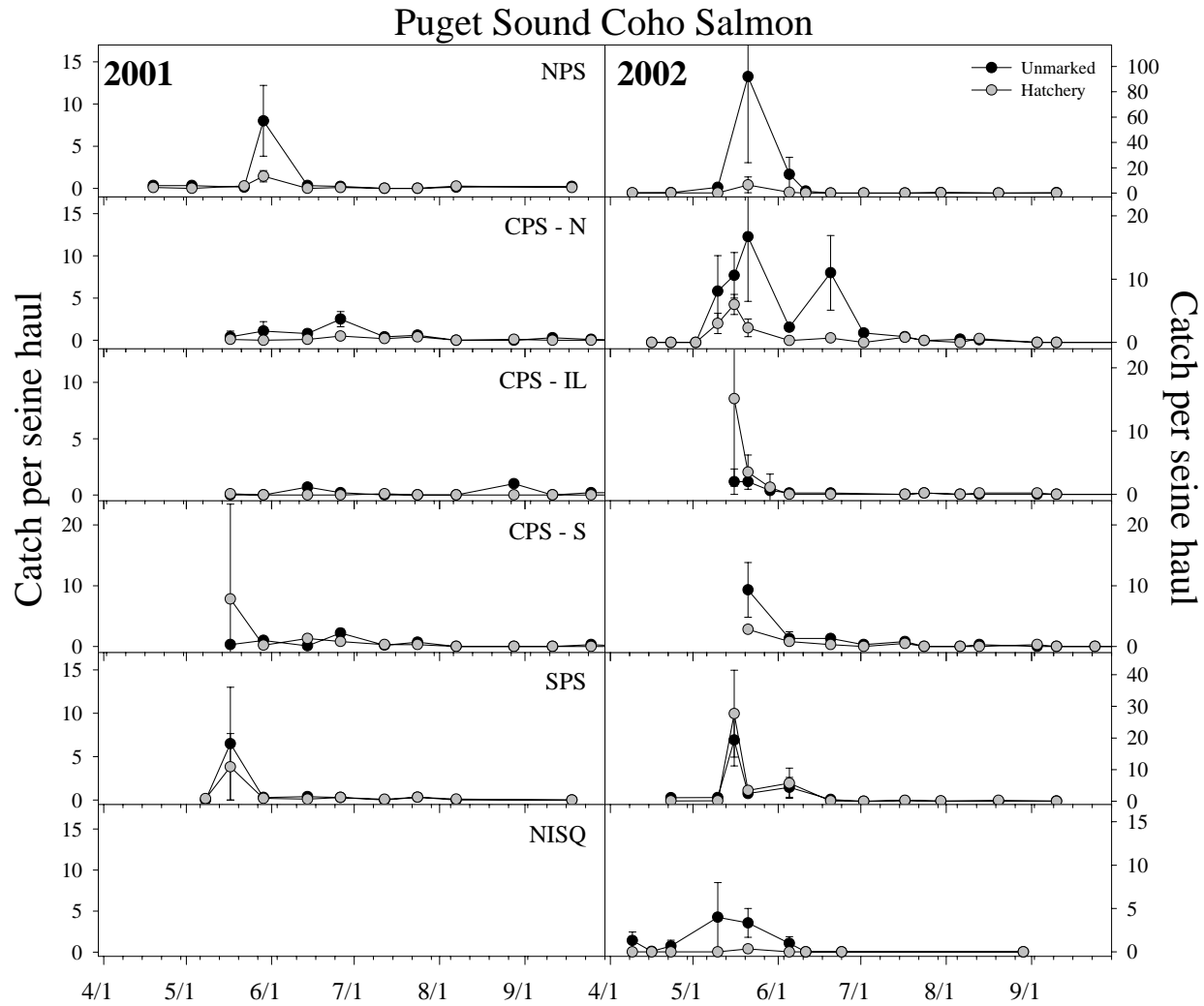


Figure 4. Average catch ( $\pm$  SE) of unmarked (black circles) and hatchery (gray circles) juvenile coho salmon in beach seine hauls. Note that the scale changes by year and region. Points sometimes occlude standard error bars.

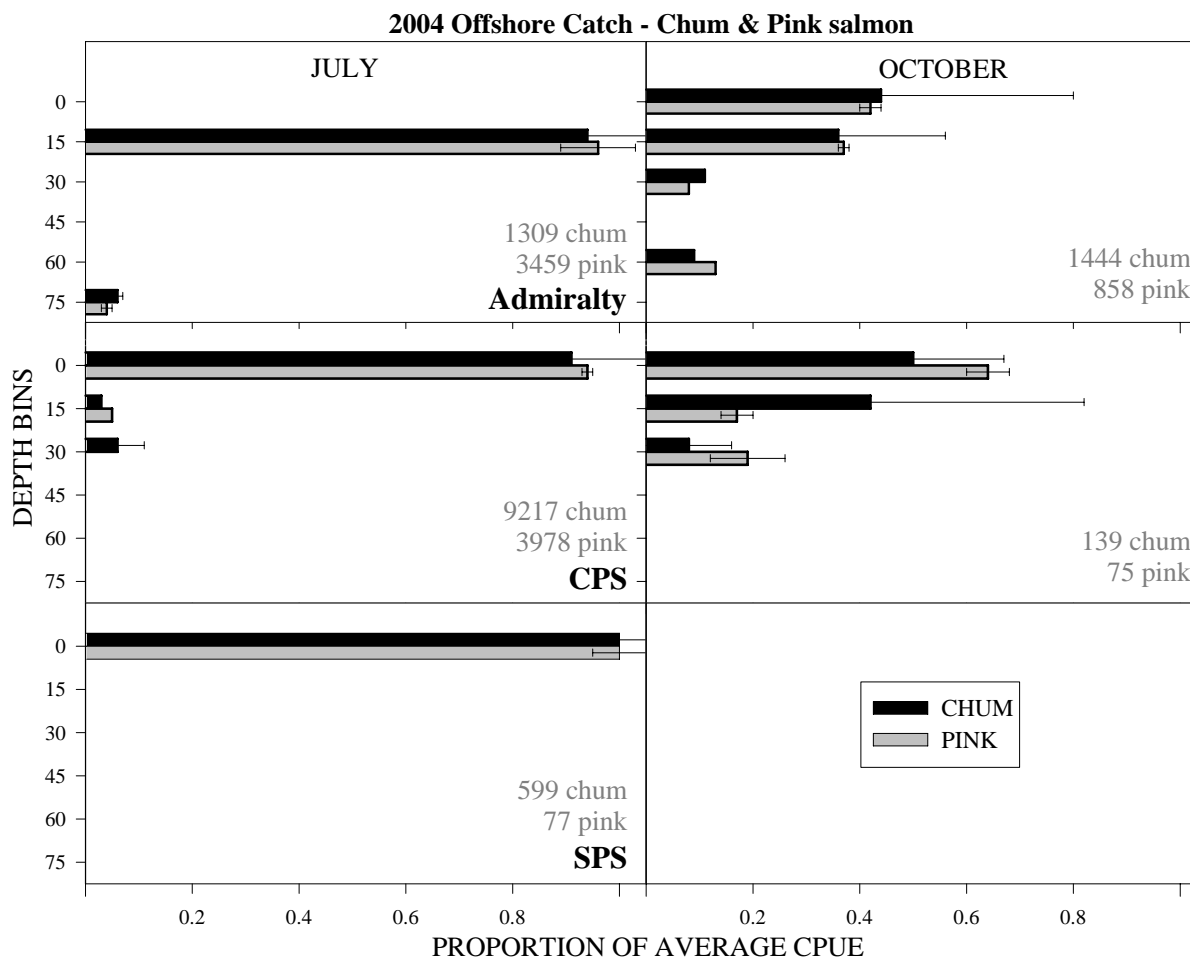


Figure 5. Average catch (proportion of total CPUE  $\pm$  SE), by depth of top rope, of juvenile chum (black bars) and pink (gray bars) salmon in mid-water trawls during 2004. Total catches are listed in gray for each month by region.

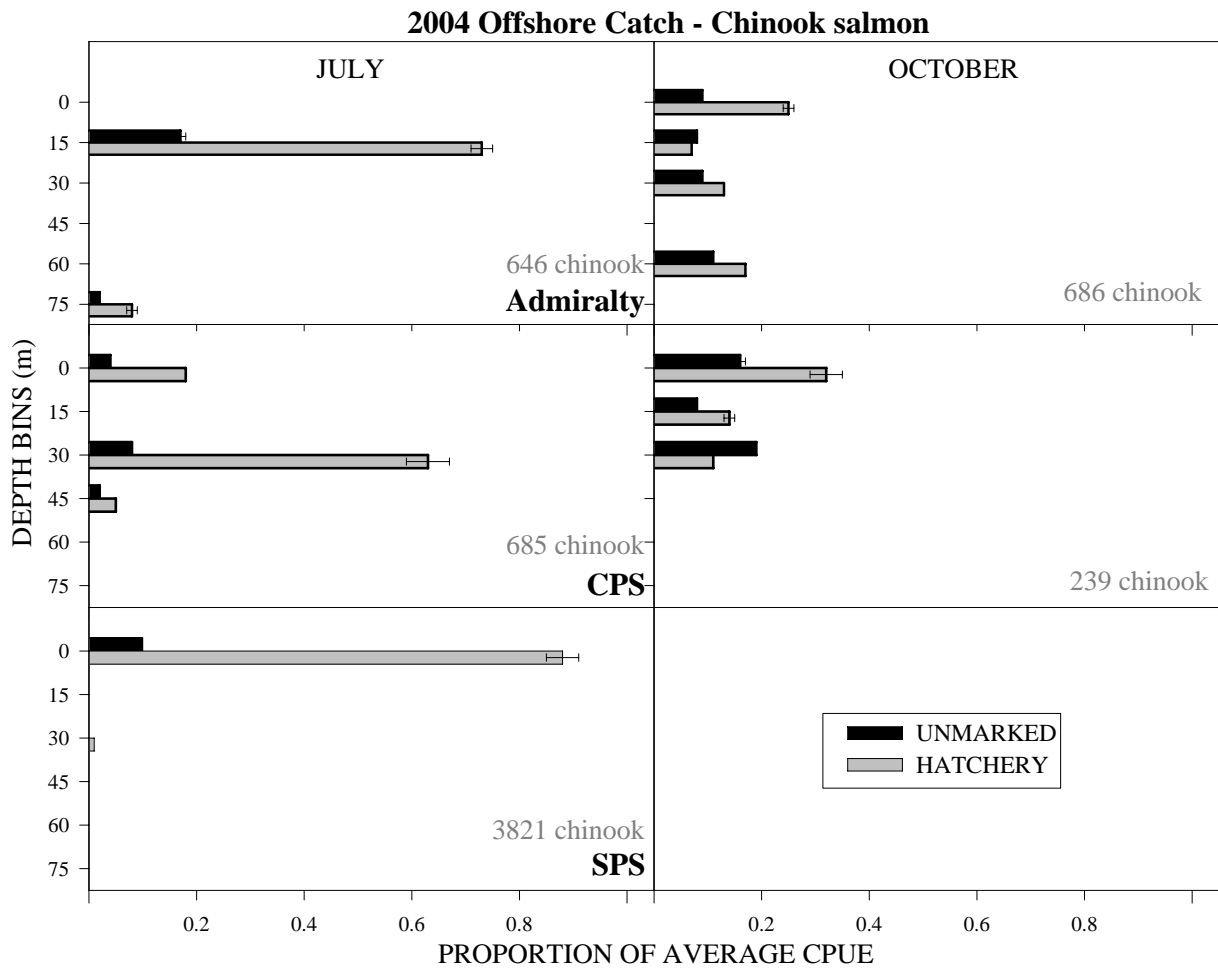


Figure 6. Average catch (proportion of total CPUE  $\pm$  SE), by depth of top rope, of juvenile unmarked (black bars) and hatchery (gray bars) chinook salmon in mid-water trawls during 2004. Total catches are listed in gray for each month by region.

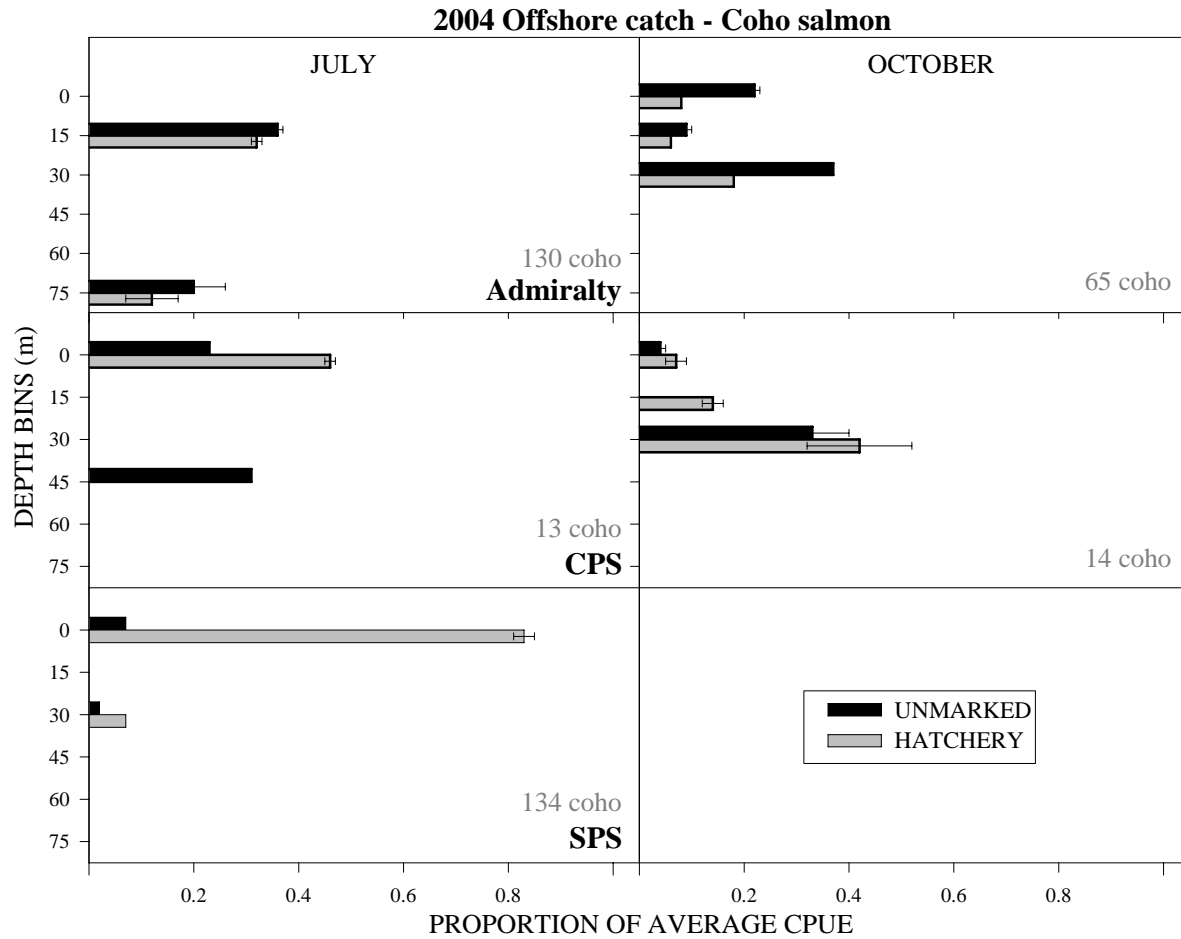


Figure 7. Average catch (proportion of total CPUE  $\pm$  SE), by depth of top rope, of juvenile unmarked (black bars) and hatchery (gray bars) coho salmon in mid-water trawls during 2004. Total catches are listed in gray for each month by region.

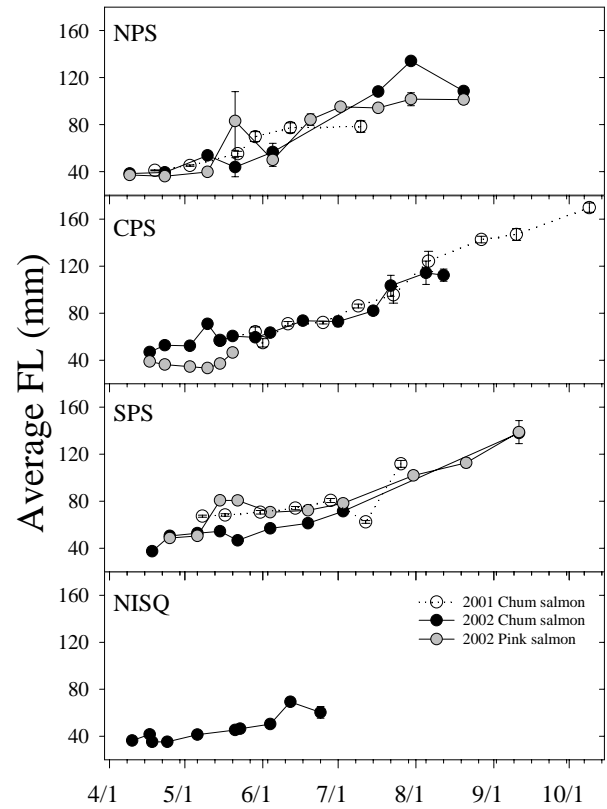


Figure 8. Average fork length ( $\pm$  SE) of chum salmon (2001; white circles, dotted line), and chum (black circles) and pink (gray circles) salmon (2002), caught by beach seine in Puget Sound. Points, in some instances, occlude error bars.

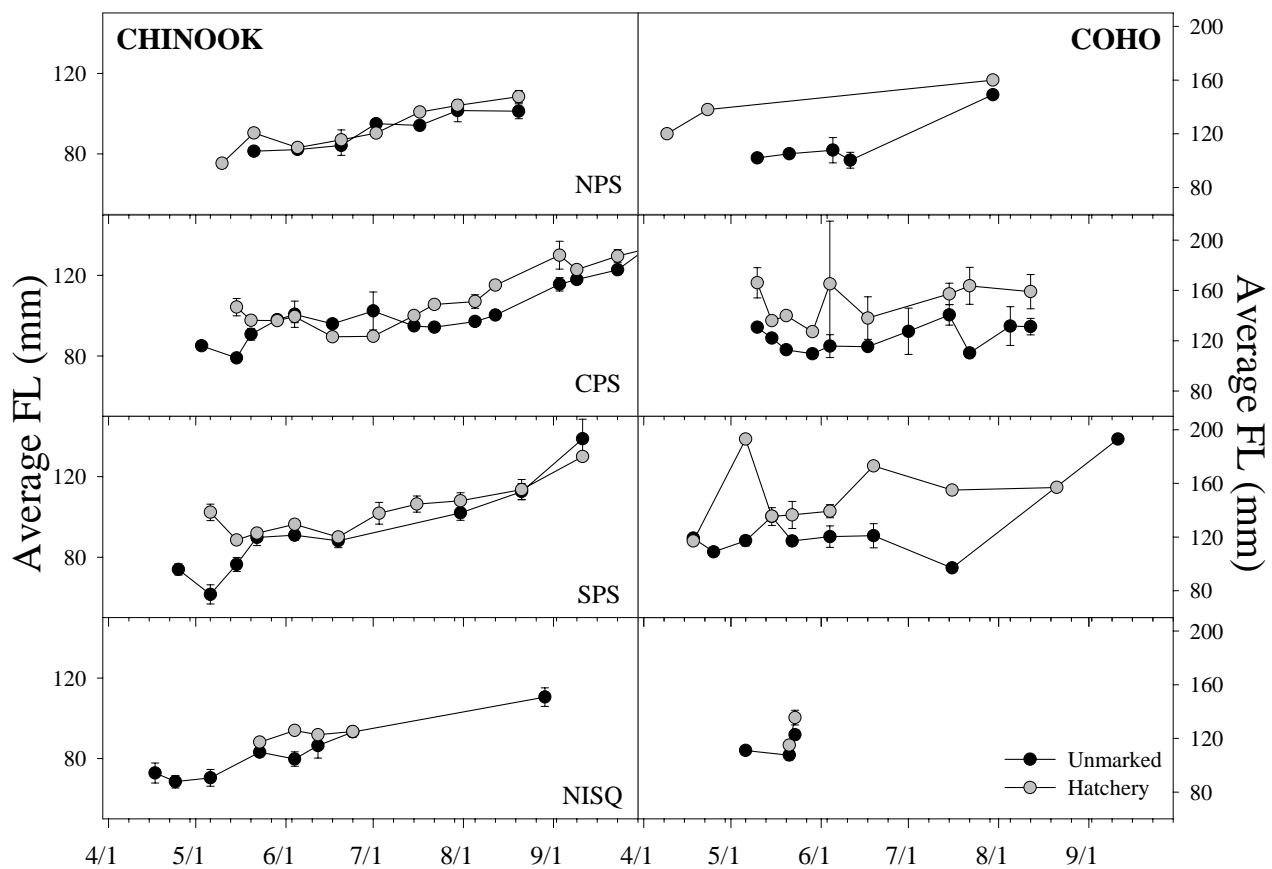


Figure 9. Average fork length ( $\pm$  SE) of unmarked (black circles) and hatchery (gray circles) chinook (left panels) and coho (right panels) salmon caught in beach seine hauls at sites in Puget Sound during 2002. Points, in some instances, occlude error bars.

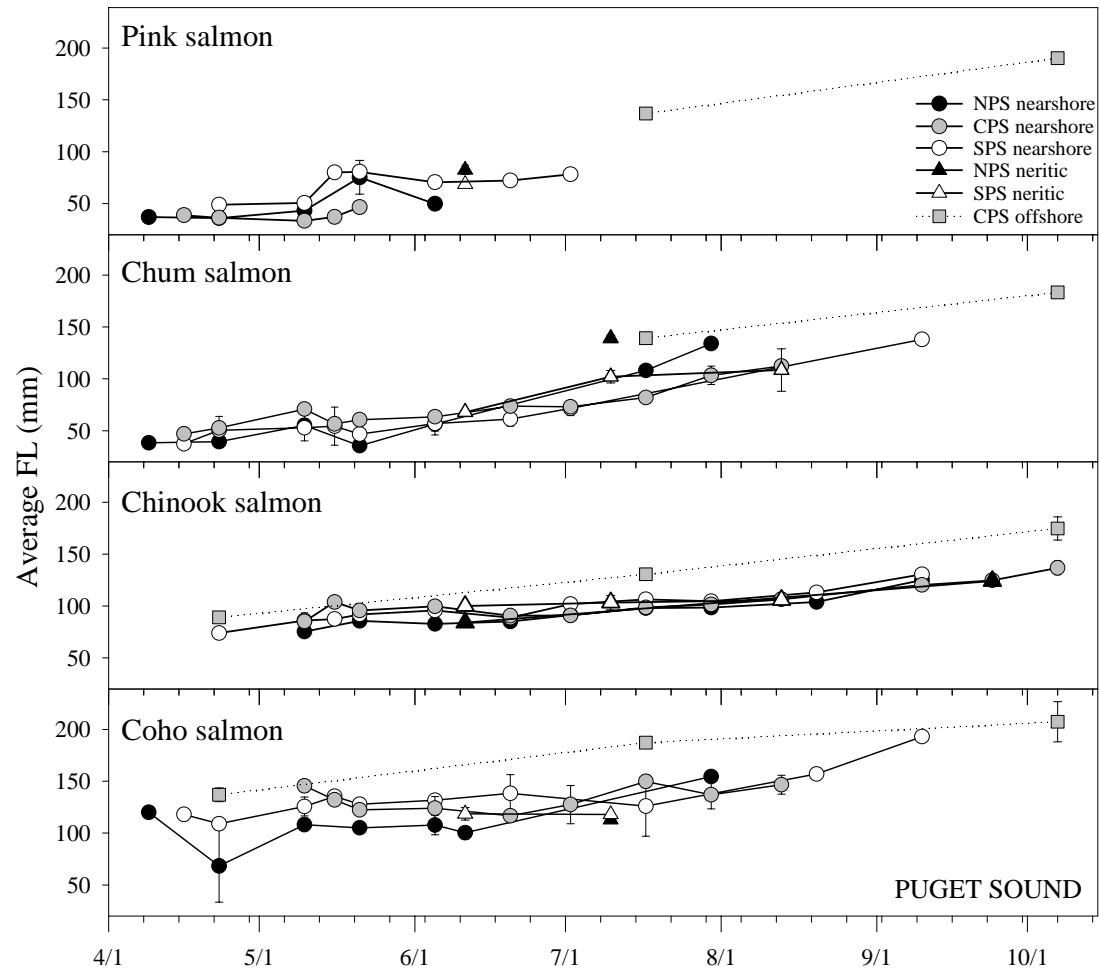


Figure 10. Average fork length ( $\pm$  SE) of juvenile salmon caught in 2002 by beach seine in NPS (black circles) and SPS (gray circles), by surface tow net in NPS (black triangles) and SPS (white triangles) and by mid-water trawl in CPS (gray squares; Apr 1997, Jul/Oct 2004 data). Points, in some instances, occlude error bars.

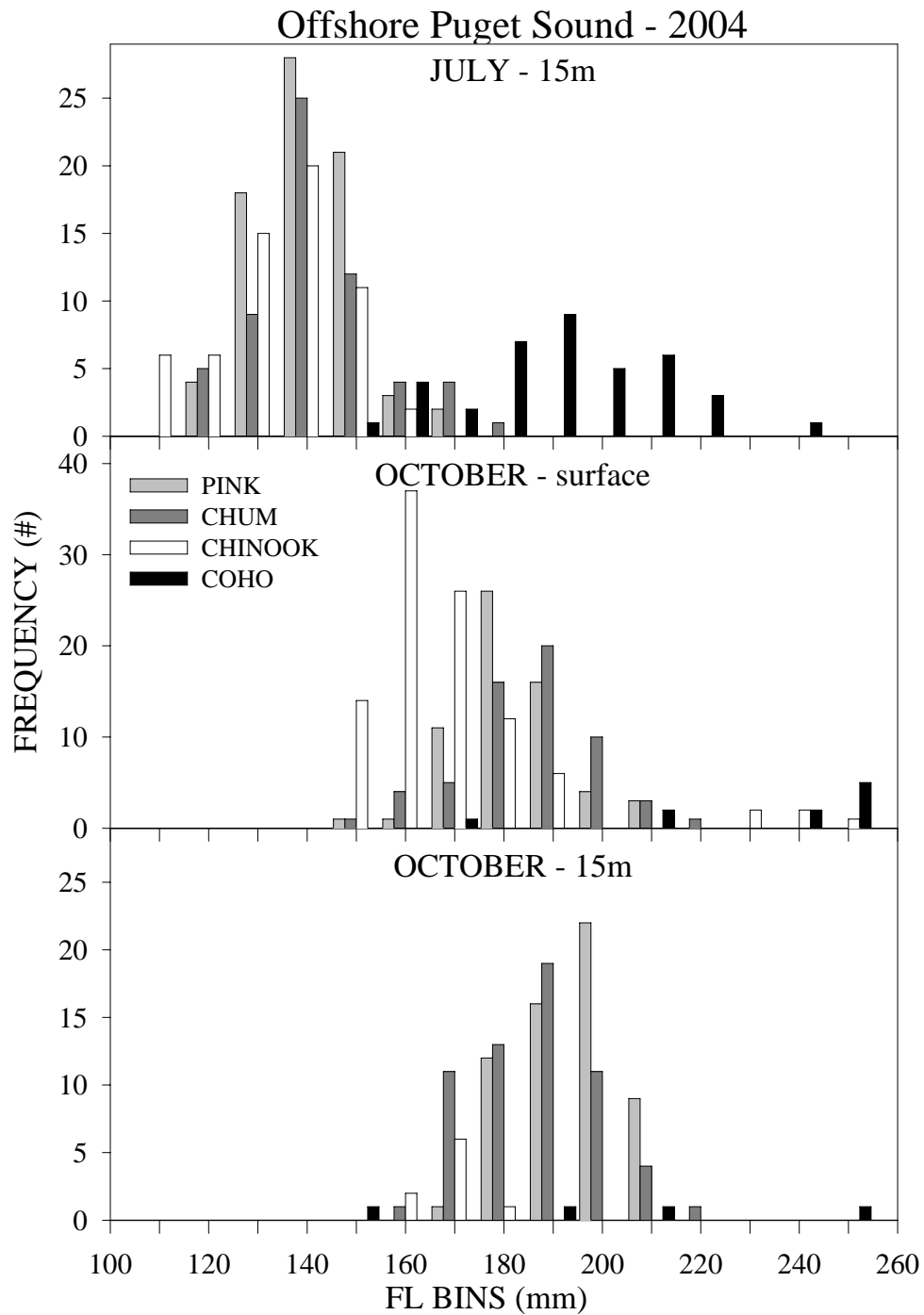


Figure 11. Length frequency histogram of juvenile salmon caught by mid-water trawl in central Puget Sound in July (upper panel) and October (2 lower panels), 2002. Depth of the trawl's top rope is listed with the month.

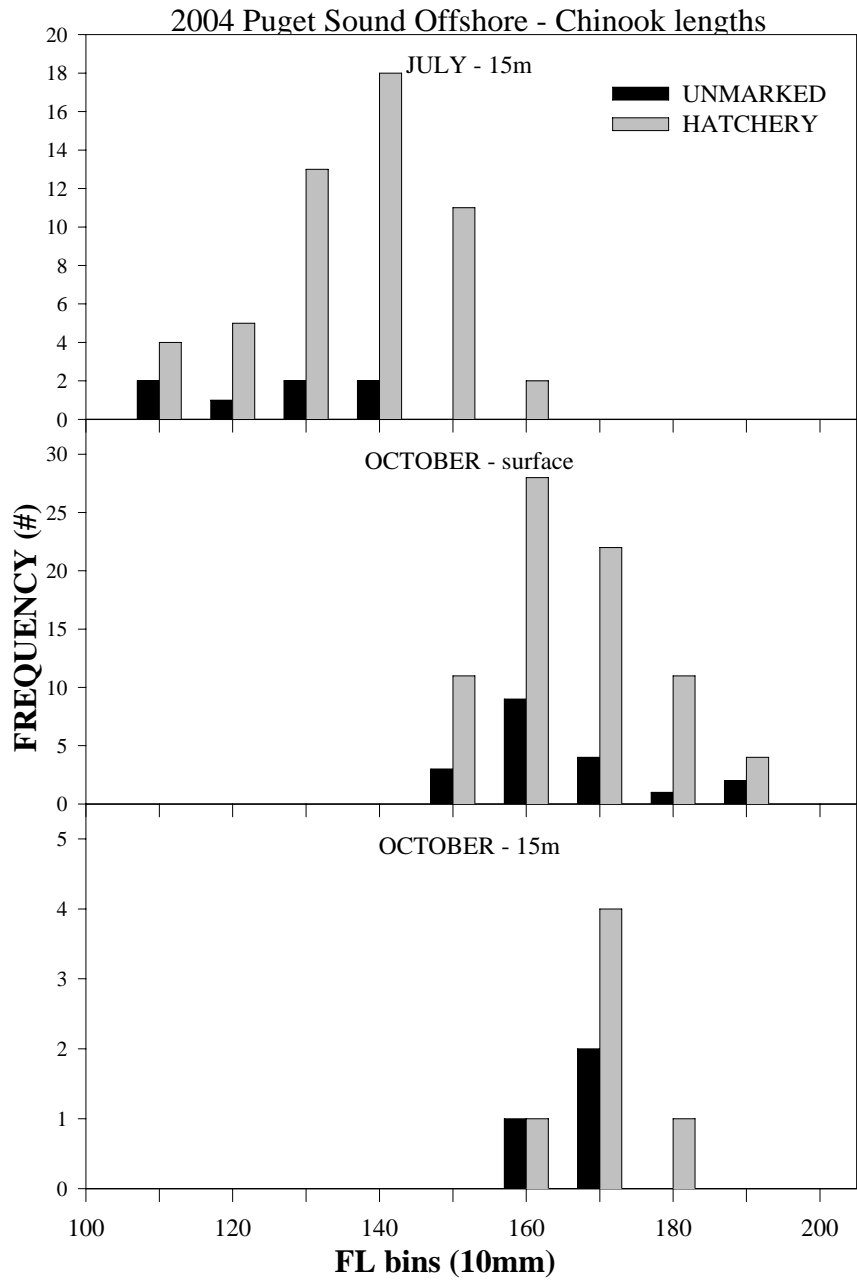


Figure 12. Length frequency histogram of juvenile unmarked (black bars) and hatchery (gray bars) Chinook salmon caught by mid-water trawl in central Puget Sound in July (upper panel) and October (2 lower panels), 2002. Depth of the trawl's top rope is listed with the month.

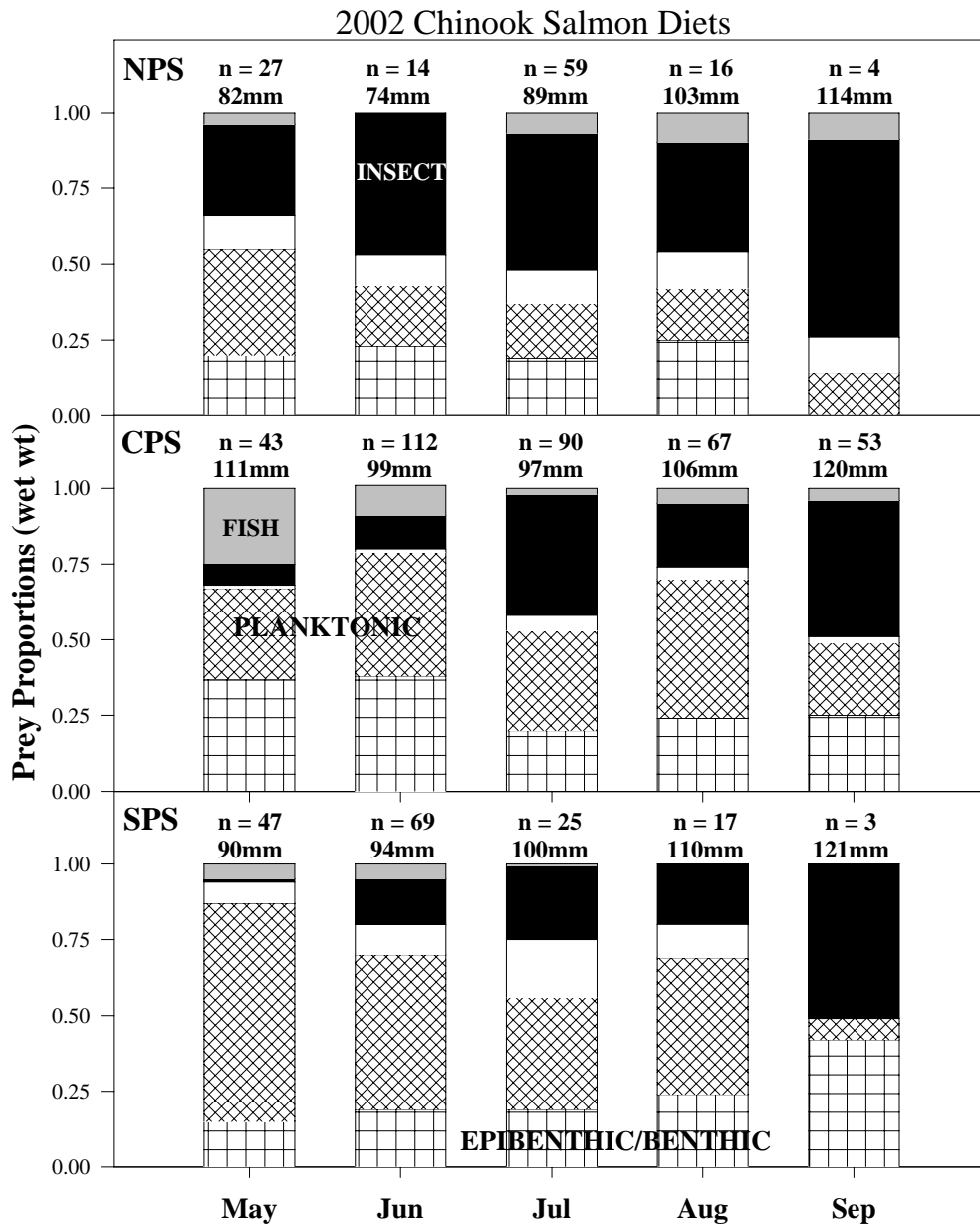


Figure 13. Monthly wet weight proportions of prey items eaten by chinook salmon in northern (NPS, upper panel), Central (CPS, middle panel) and southern (SPS, bottom panel) Puget Sound during 2002. Invertebrate prey types are represented as follows: epibenthic/benthic prey as checked white bars, planktonic prey as checked white bars, and insects black bars. Other invertebrates, mainly unidentifiable, are represented as white bars and fish prey as gray bars. Sample sizes and average lengths (FL) listed above each column.

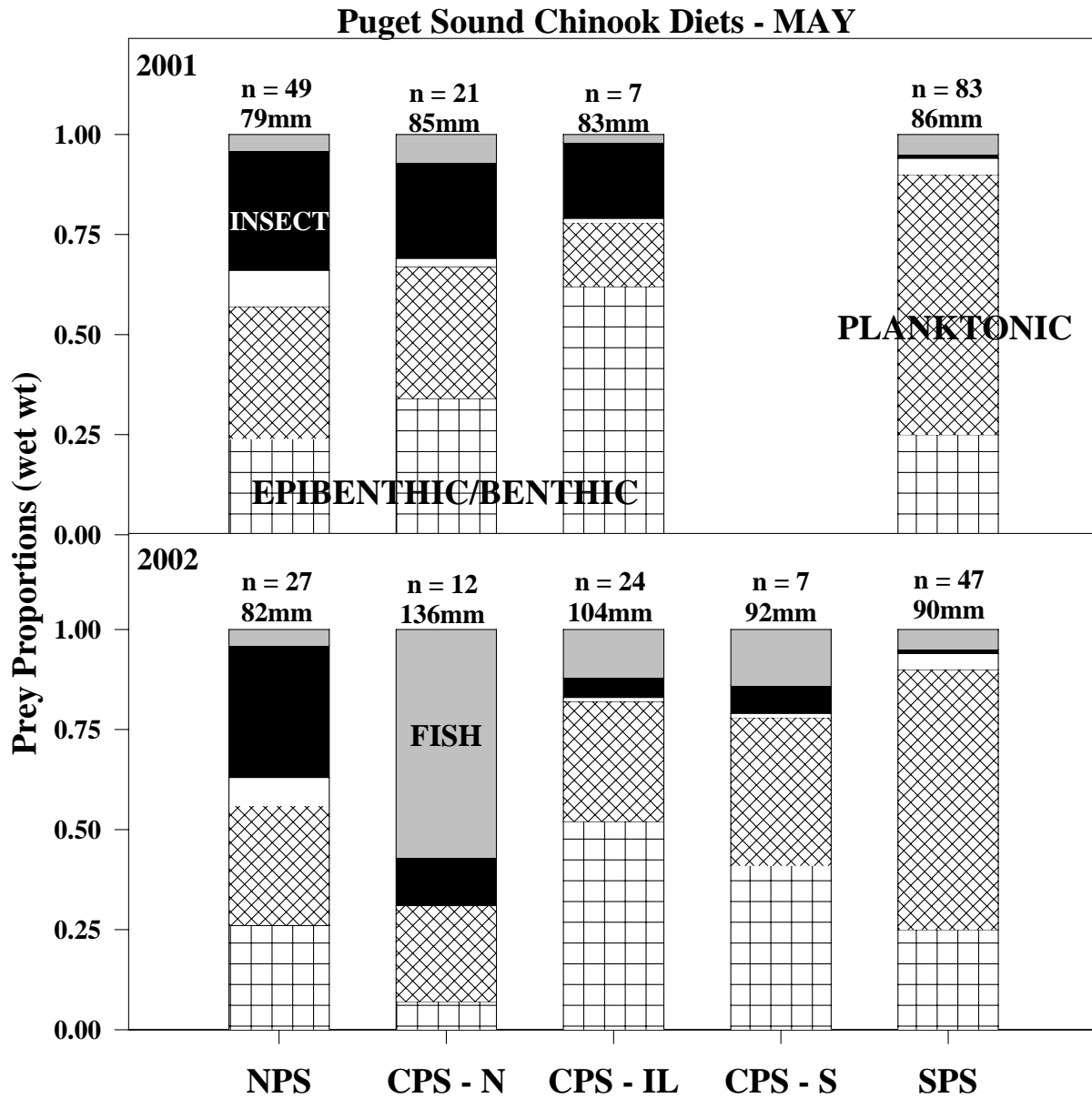


Figure 14. Wet weight proportions of invertebrate prey items (epibenthic/benthic – checked bars; planktonic – cross-hatched bars; other invertebrate – white bars; insects – black bars; fish – gray bars) eaten by juvenile chinook salmon in Puget Sound regions during May 2001-2002.

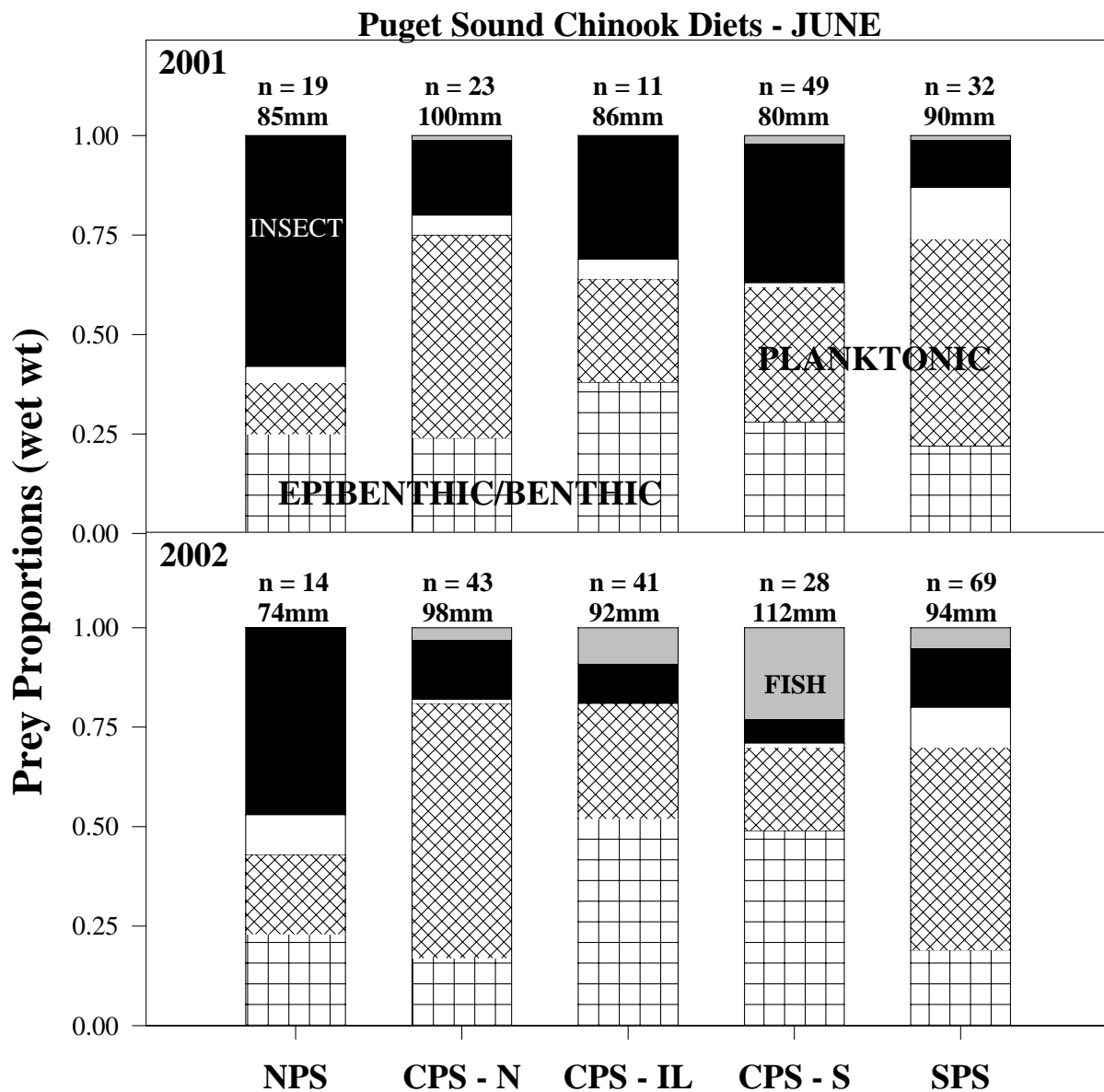


Figure 15. Wet weight proportions of invertebrate prey items (epibenthic/benthic – checked bars; planktonic – cross-hatched bars; other invertebrate – white bars; insects – black bars; fish – gray bars) eaten by juvenile chinook salmon in Puget Sound regions during June 2001-2002.

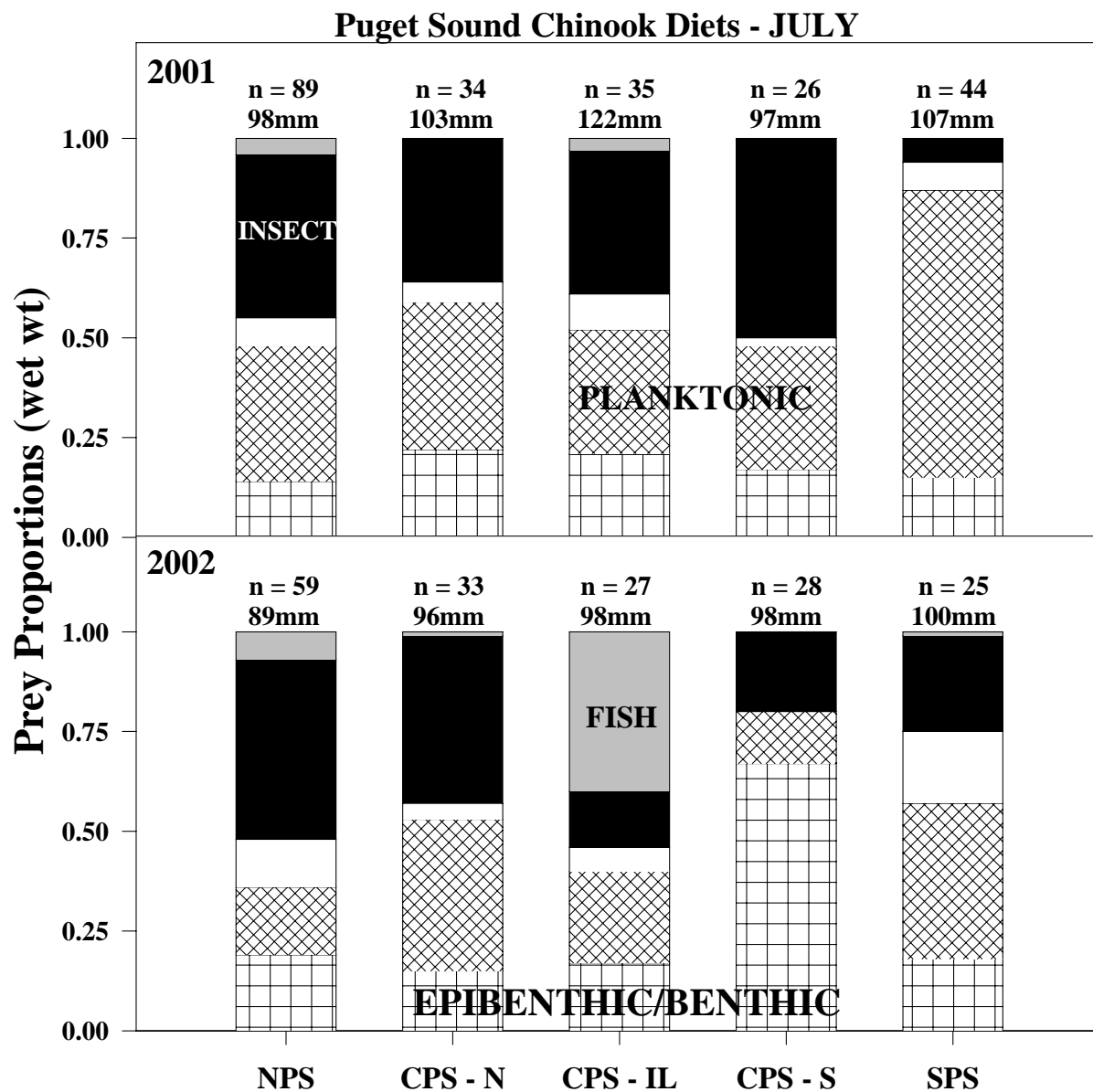


Figure 16. Wet weight proportions of invertebrate prey items (epibenthic/benthic – checked bars; planktonic – cross-hatched bars; other invertebrate – white bars; insects – black bars; fish – gray bars) eaten by juvenile chinook salmon in Puget Sound regions during July 2001-2002.

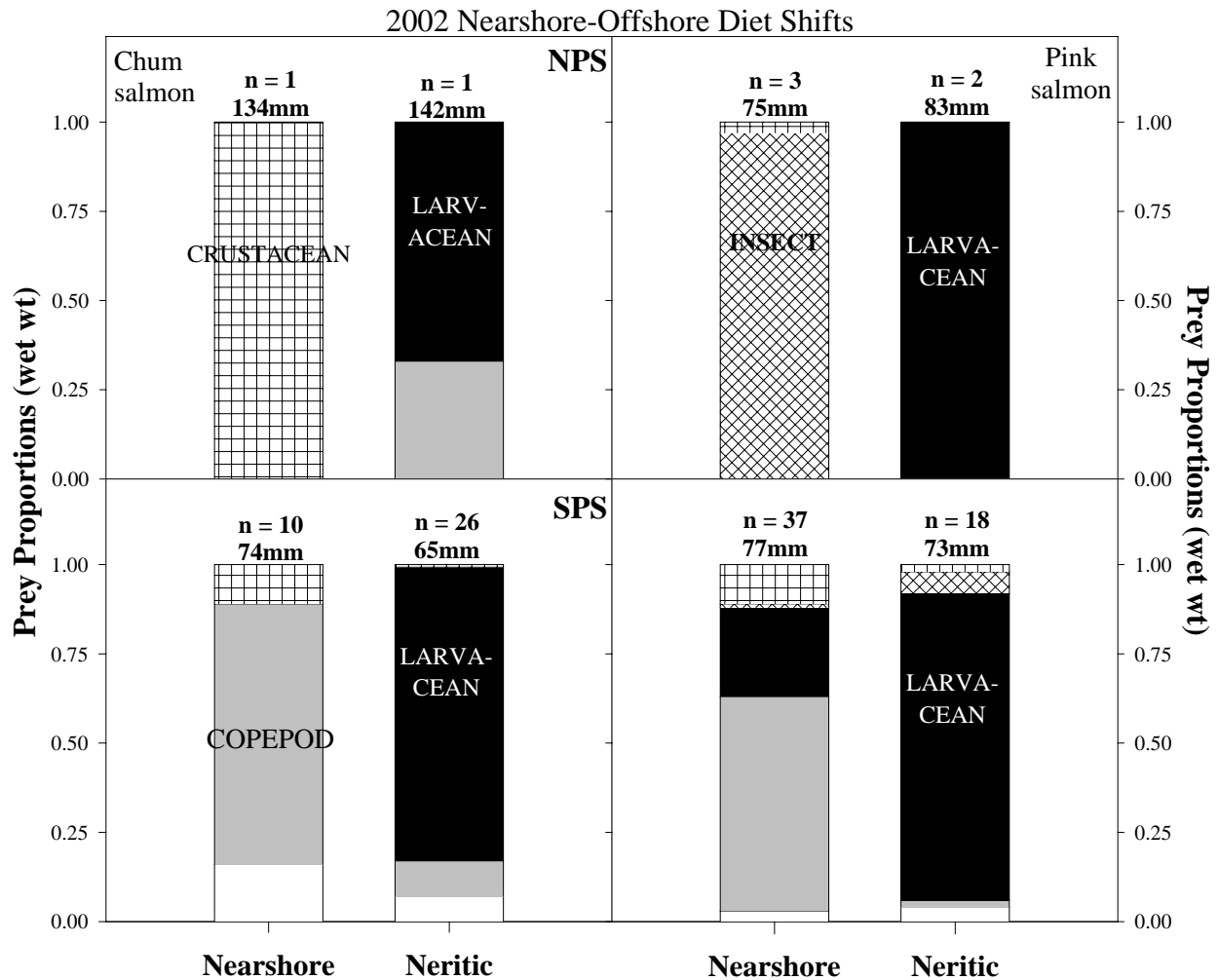


Figure 17. Wet weight proportions of prey items (euphausiids – white bars; copepods – gray bars; larvaceans – black bars; insects – cross-hatched bars; other invertebrates and chyme – checked bars) eaten by juvenile chum (left panels) and pink (right panels) salmon caught by beach seine (nearshore) and surface tow net (neritic) in northern (NPS, upper panels) and southern (SPS, lower panels) Puget Sound during June, 2002 (except July 2002, for chum salmon in NPS). Sample sizes and average lengths (FL) listed above each column.

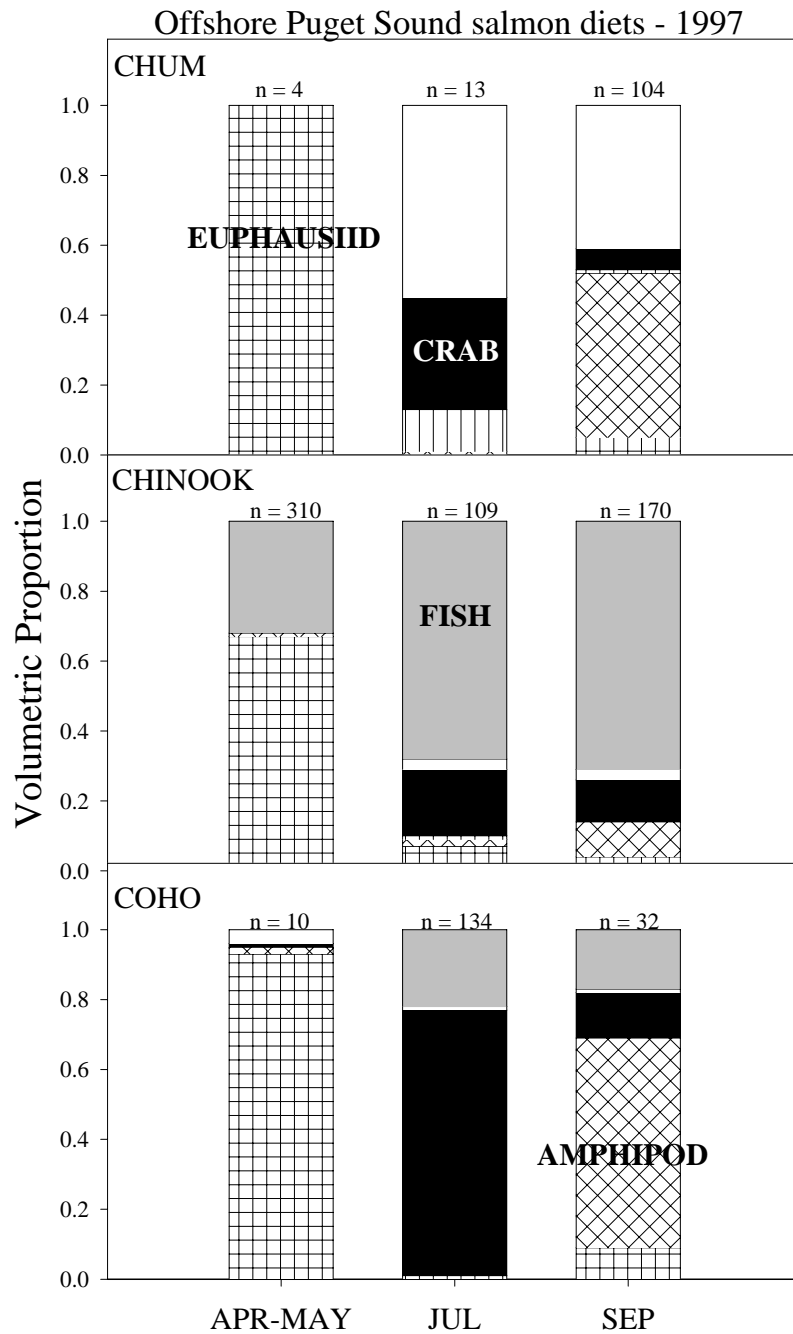


Figure 18. Volumetric proportions of prey items (euphausiids – checked bars; amphipods – cross-hatched bars; copepods – lined bars; crab larvae – black bars; other invertebrates and chyme – white bars; fish – gray bars) eaten by juvenile salmon caught in mid-water trawls in Puget Sound during 1997 (Beamish et al. 1998).