2010-2015 Juvenile Fish Ecology in the Nisqually River Delta and Nisqually Reach Aquatic Reserve

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Introduction

The return of tidal inundation to over 750 acres of the U. S. Fish and Wildlife Service Billy Frank Jr. Nisqually National Wildlife Refuge (NNWR) in fall of 2009 was the crowning moment in the effort to protect and restore the Nisqually Delta. The Nisqually NWR project complemented three earlier restoration projects completed by the Nisqually Indian Tribe (Tribe) on tribal property to restore over 900 acres of the estuary, representing the largest estuary restoration project in the Pacific Northwest and one of the most significant advances to date towards the recovery of Puget Sound (USFWS 2005).

In 2011 the Washington Department of Natural Resources (WADNR) established the over 14000 acre Nisqually Reach Aquatic Reserve (Reserve), complementing the protection and restoration successes in the Nisqually Delta. The Reserve includes all state-owned aquatic lands around Anderson, Ketron and Eagle islands and part of McNeil Island (Figure 1, WDNR 2011). The Reserve also includes a diverse assemblage of nearshore and offshore habitats important to resident and migratory fish including federal endangered species act listed fish like Chinook salmon (*Oncorynchus tshawytscha*) and steelhead (*O. mykiss*). Studies in the Nisqually Estuary (Ellings and Hodgson 2007, David et al. 2014, Ellings et al. 2016) and South Puget Sound (Duffy 2003) have summarized fish use of the area. However, the fish ecology of the reserve had not been systematically surveyed.

The Tribe, U.S. Geological Survey (USGS), NNWR, Nisqually River Foundation (NRF), and others are currently conducting a multi-year, interdisciplinary, hypothesis-based research and monitoring study investigating the impact of delta restoration on estuarine processes, habitat structures, and functions. Our interdisciplinary monitoring framework enables us to link key estuarine processes with habitat development and biological response at multiple scales across the restored footprint, reference marshes, and throughout the Nisqually Reach. Key research components include hydrology and sediment regime, channel and marsh topography and development, vegetation colonization, and invertebrate, bird, and fish abundance, habitat use, and foraging ecology. After the Reserve was established, the WDNR and the research partnership led by the Tribe expanded the existing delta fish ecology assessment to include sampling stations throughout the Reserve. The results of the Reserve fish ecology assessment provide a unique regional analysis of fish ecology from the Nisqually River to McNeil Island.

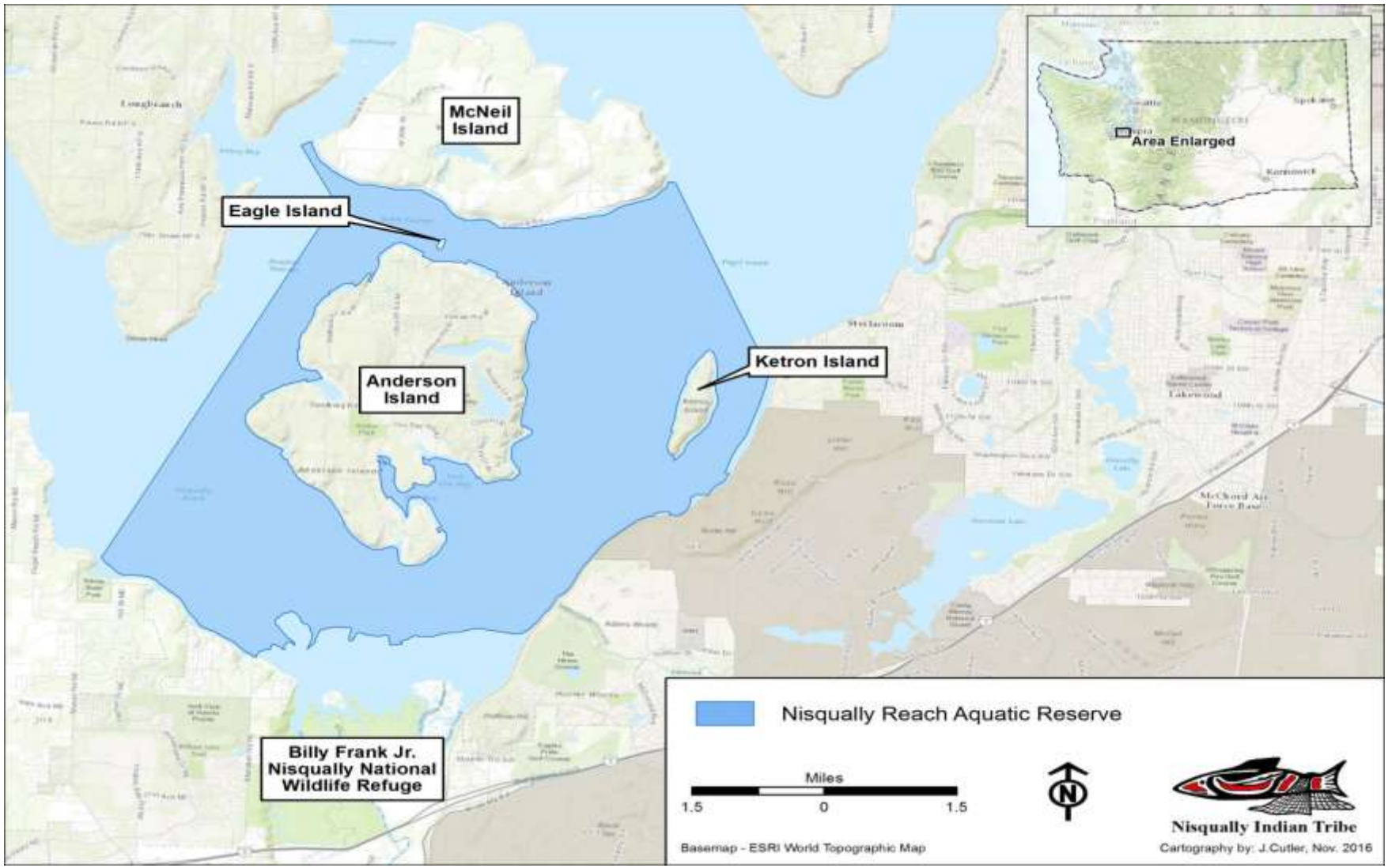

Figure 1. Location of study area.

Methods

We sampled four geographic areas to monitor juvenile fish (Figure 2). One of these areas, the Nisqually River delta, was divided into five habitat zones (Tables 1-2) based on salinity, vegetation, and GIS based habitat mapping (Tanner 1999). The other three geographic areas were all in the nearshore habitat zone. This nearshore habitat zone was grouped into three geographic areas to facilitate comparisons: Nisqually Reach, Cormorant, and North Anderson/ McNeil (Figure 2).

Beach seine sampling field protocols (see Ellings and Hodgson 2007 for more detail) were modeled after similar studies in the Snohomish and Skagit River systems (SRSC Research 2003; Rowse and Fresh 2003) in order to facilitate regional comparisons and compilations. Sites were representative of locations that could feasibly be sampled along channel edges. Extremely complex habitats (e.g. logjams) and locations with fast current (e.g. mainstem Nisqually River) could not be sampled and thus were not represented. Each site was generally sampled once every two weeks from February-October during daylight hours (see Table 1 for annual frequency by site). Fish sampling was conducted using a standard 'Puget Sound seine' measuring 37 m x 2 m with a 2.4 m bag of 6 mm delta mesh, set by boat and hauled to shore by hand (Figure 3). Most sites were sampled between mid to high tide, and generally only one set per site was completed on each sampling occasion. Salinity, temperature, conductivity, and dissolved oxygen were measured at each site immediately after fish sampling using a Yellow Springs Instruments (YSI), Model 85 handheld meter. Measurements were taken near the surface and near the bottom of the water column at the greatest depth within the area sampled for fish.

All captured fish were enumerated and 10 fish of each species were measured (fork length, nearest mm) at each site. On occasions with extremely large catches of fish or especially muddy conditions, a subsample (by volume) was taken and enumerated and then proportionally expanded by species to estimate the unsampled catch. In a few cases, large catches of species such as shiner perch (*Cymatogaster aggregate*) and sculpin (*Cottidae spp.*) made accurate counts unfeasible without causing substantial mortality, so visual estimates were made. All captured coho (*O. kisutch*) and Chinook salmon were examined for a clipped adipose fins. All unclipped and the majority of clipped coho and Chinook were scanned to detect coded wire tags (CWTs). Chinook and coho were called 'unmarked' if they had neither a CWT nor a clipped adipose. The unmarked fish groupings are presumed to be predominantly fish of natural origin but since marking programs are not 100% effective, they likely include some fish that are of hatchery origin. A subsample of the Chinook salmon were euthanized to obtain otolith, CWT, and stomach content data.

A lampara net was also used to sample fish use in areas farther from shore that could not be sampled with a beach seine. The lampara net was set by 2 boats and retrieved in a circle (Figure 4). Sites represented both the delta flats and nearshore habitat zones (and one in the estuarine emergent marsh zone) and were sampled during daytime, twice each month from May to August, and once per month in April and September. Table 3 shows details on site locations and sampling frequency. The standard net size was 50 m long (top rope length 46 m, bottom rope length 40 m) with a 6 m deep bag. The mesh was 102 mm and 51 mm in the wings and 25 mm and 12.7 mm in the bag. The net was designed to fish approximately 4.6 m deep and the bag was 58 cm deep when stretched. Fish examination, enumeration, measurement, and proportional expansion for subsampling were the same as was done for fish captured

by beach seine. Depth to bottom, secchi depth, temperature and salinity at top and bottom of the water column, and current speed were also measured.

Four of the sites sampled with the lampara net were in eelgrass meadows (Figure 5, Table 3). We counted the number of eelgrass shoots in 0.25 m^2 quadrats spaced at 10 m intervals along a 100 m transect at each of these sites in mid-June 2014 and 2015. Data loggers that recorded temperature every 5 minutes were deployed at three of the sites during June-August 2014 and 2015. We excluded temperatures recorded when the data loggers were exposed at extreme low tides.

Table 1. Beach seine sites and number of times sampled by year.

	Habitat Zone	Site	2010	2011	2012	2013	2014	2015	Latitude (^{0}N)	Longitude (^{0}W)
Nisqually Delta	Freshwater Tidal	I-5 Alcove	1						47.069725	122.702361
		I-5 RB	11	12	13	12	9	12	47.070250	122.702818
	Forested Riverine Tidal	Lookout	14	14	16	12	13	12	47.077466	122.707925
	Emergent/Fresh Transition	Nugies	13	12	15	11	10	12	47.085664	122.707978
		Ring Dike Slough	14	12	14	11	11	12	47.086659	122.707346
	Estuarine Emergent Marsh	NEEM 1	13	11	12	12	12	11	47.092041	122.697943
		NEEM 2	13	12	17	13	10	12	47.097652	122.697990
		Leschi	3						47.093078	122.712087
		MCA RB	13	13	15	14	9	12	47.088619	122.725459
		N1	11	10	15	13	10	13	47.096265	122.722657
		RSS LB	11	9	16	12	11	13	47.095004	122.689003
		RSS Point	13	14	16	13	13	13	47.089476	122.691158
	Delta Flats	Breakwater	14	12	15	13	13	14	47.108146	122.674280
		Luhr Beach	14	10	15	13	12	13	47.099601	122.727108
		RSS RB	11	9	14	12	12	13	47.095813	122.686849
		Seal Beach	11	11	15	11	11	12	47.100481	122.699619
Nearshore	Nearshore (Cormorant)	Ketron South			15	12	13	14	47.146671	122.641567
		Riviera			14	12	13	13	47.156180	122.672328
		Sequalitchew	14	14	17	13	12	14	47.118022	122.666206
		Solo Point	13	13	16	13	15	13	47.137688	122.633719
	Nearshore (Nisqually Reach)	Andy	13	12	15	14	15	14	47.145577	122.731982
		East Oro Bay	12	14	12	13	12	15	47.144150	122.697338
		West Oro Bay			9	12	12	11	47.143448	122.707481
		DeWolf Bight	13	13	15	14	12	13	47.110247	122.749301
		Hogum Bay	1	3			1		47.105991	122.741125
		Hogum Bay Spit	11	4	15	13	12	13	47.106089	122.740623
		Tolmie Beach			11	8	5		47.120570	122.773485
	Nearshore (North Anderson and McNeil)	Amsterdam			14	13	13	12	47.161010	122.727039
		Bahamas			14	13	9	10	47.215884	122.647963
		Eagle Island			15	12	12	12	47.187906	122.693520
		Eden Beach			10	11	9	10	47.225254	122.675014
		Hogan Point			12	12	9	10	47.206705	122.728496
		Little Higgins			15	13	13	13	47.183194	122.712789
		Milewa			14	12	8	10	47.196231	122.699460
		Whale Bone			14	12	9	10	47.206385	122.641054

Table 2. Characteristics of beach seine sites with shoreline units classified by the DNR Shorezone database. * indicates data is from the Washington State ShoreZone Inventory (WDNR, 2001) and represents the entire shoreline unit that the site falls in.

Site Name	Habitat Zone	Eelgrass *	Shoreline Type (BC_class) *	Substrate *	Exposure Class *
Amsterdam	Nearshore	Absent	sand beach	Sand	Protected
Andy	Nearshore	Absent	sand flat	Mud and Fines	Protected
Bahamas	Nearshore	Absent	sand beach	Sand	Protected
Breakwater	Delta Flats	Absent	sand beach	Sand	Semi-protected
DeWolf Bight	Nearshore	Absent	sand beach	Sand	Semi-protected
Eagle Island	Nearshore	Absent	sand beach	Sand	Protected
East Oro Bay	Nearshore	Absent	mud flat	Mud and Fines	Protected
Eden Beach	Nearshore	Absent	sand beach	Sand	Protected
Hogan Point	Nearshore	Absent	sand flat	Sand	Protected
Hogum Bay	Nearshore	Absent	sand beach	Sand	Semi-protected
Hogum Bay Spit	Nearshore	Absent	sand beach	Sand	Semi-protected
I-5 Alcove	Freshwater Tidal	Absent	organics/fines	Mud and Fines	Very Protected
I-5 RB	Freshwater Tidal	Absent	organics/fines	Mud and Fines	Very Protected
Ketron South	Nearshore	Absent	sand and gravel beach, narrow	Gravel and Sand	Protected
Leschi	Estuarine Emergent Marsh	Patchy	organics/fines	Mud and Fines	Very Protected
Little Higgins	Nearshore	Absent	sand flat	Sand	Protected
Lookout	Forested Riverine Tidal	Absent	organics/fines	Mud and Fines	Very Protected
Luhr Beach	Delta Flats	Patchy	sand beach	Sand	Very Protected
MCA RB	Estuarine Emergent Marsh	Patchy	organics/fines	Mud and Fines	Very Protected
Milewa	Nearshore	Absent	sand flat	Sand	Protected
N1	Estuarine Emergent Marsh	Patchy	mud flat	Sand	Very Protected
NEEM 1	Estuarine Emergent Marsh	Patchy	organics/fines	Mud and Fines	Very Protected
NEEM 2	Estuarine Emergent Marsh	Patchy	organics/fines	Mud and Fines	Very Protected
Nugies	Emergent/Fresh Transition	Absent	organics/fines	Mud and Fines	Very Protected
Ring Dike Slough	Emergent/Fresh Transition	Absent	organics/fines	Mud and Fines	Very Protected
Riviera	Nearshore	Absent	sand beach	Sand	Semi-protected
RSS LB	Estuarine Emergent Marsh	Patchy	man-made, permeable	Man-Made	Very Protected
RSS Point	Estuarine Emergent Marsh	Patchy	man-made, permeable	Man-Made	Very Protected
RSS RB	Estuarine Emergent Marsh	Patchy	man-made, permeable	Man-Made	Very Protected
Seal Beach	Delta Flats	Patchy	organics/fines	Mud and Fines	Very Protected
Sequalitchew	Nearshore	Absent	sand beach	Sand	Semi-protected
Solo Point	Nearshore	Absent	sand and gravel flat or fan	Gravel and Sand	Protected
Tolmie Beach	Nearshore	Absent	sand flat	Sand	Semi-protected
West Oro Bay	Nearshore	Absent	sand flat	Sand	Very Protected
Whale Bone	Nearshore	Absent	sand beach	Sand	Protected

Table 3. Lampara sites and number of times sampled by year. Sites that were considered eelgrass meadows in analyses are indicated,with three letter site abbreviations used throughout this report also shown.

	Habitat Zone	Site	2010	2011	2012	2013	2014	2015	Latitude (^{0}N)	Longitude (^{0}W)	Eelgrass
Nisqually Delta	Delta Flats	Breakwater T5	4	5	10	10	9	10	47.112641	122.677367	Absent
		Marsh Edge T2	1	1					47.096760	122.721360	Absent
		MCA Eelgrass T1 (MCA)	5	8	10	10	10	10	47.104211	122.725847	Meadow
		Nisqually Flats T2	4	6	10	10	9	10	47.105701	122.716507	Absent
		Nisqually Flats T3	1	2					47.106972	122.705170	Low/absent
		Nisqually Flats T4	4	6	10	10	9	10	47.104691	122.692097	Low/absent
		Nisqually Flats T4 B		1					47.102040	122.693240	Low/absent
		Nisqually Flats T4 C		1					47.102990	122.689140	Low/absent
		Nisqually Mouth T3	5	9	10	10	9	10	47.106771	122.699887	Absent
		RSS Eelgrass T4 (RSS)	5	10	10	10	9	10	47.111021	122.688617	Meadow
		RSS Mouth T5	2						47.101161	122.682227	Absent
	Estuarine Emergent Marsh	Marsh Edge T1	5	6	10	10	8	10	47.097031	122.721607	Absent
Nearshore	Nearshore- Cormorant	Cormorant (COR)	4	3	10	10	10	10	47.143746	122.624932	Meadow
		Cormorant A	1	2					47.147611	122.623147	Abundant
		Ketron East	5	5	9	10	10	10	47.149061	122.636167	Varied
		Ketron West	1						47.155640	122.638750	Medium
		Sequalitchew	7	8	10	10	10	10	47.118161	122.667007	Varied
		Solo	5	7	10	10	10	10	47.139311	122.633397	Absent
	Nearshore- Nisqually Reach	Andy				1			47.145370	122.732380	Absent
		Hogum Bar A (HOG)	4	4	5	5	5	5	47.116712	122.741113	Meadow
		Hogum Bar B (HOG)	2	4	5	5	6	6	47.115731	122.736817	Meadow
		Hogum Bay	6	8	10	10	10	10	47.112911	122.742587	Absent
		Oro Bay	6	7	10	10	9	10	47.141871	122.695267	Absent
		Thompson Cove	5	8	10	10	10	10	47.126791	122.705877	Absent
	Nearshore- North Anderson and McNeil	Amsterdam Inside			6				47.158259	122.721602	Absent
		Amsterdam Outside			9	8	8	8	47.161623	122.730542	Absent
		Bradley Flats			10	9	6	6	47.231889	122.691839	Low/Absent
		Eagle Reef			7				47.189199	122.699216	Absent
		Whale Bone			9	9	6	6	47.208179	122.643351	Absent

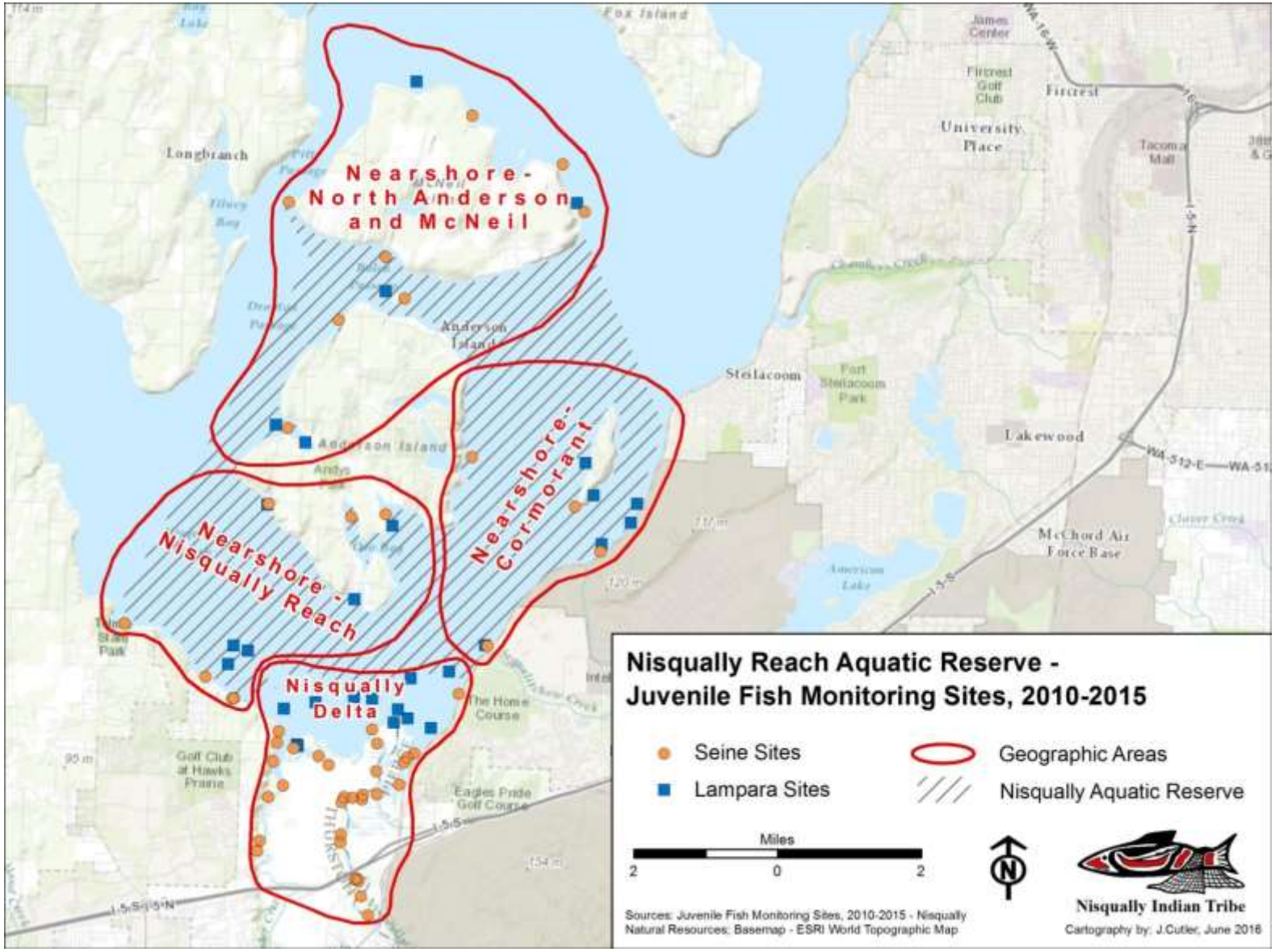

Figure 2. Locations of sampling sites and geographic areas used to summarize data.

Figure 3. Setting a seine net by boat.

Figure 4. Setting a lampara net between two boats.

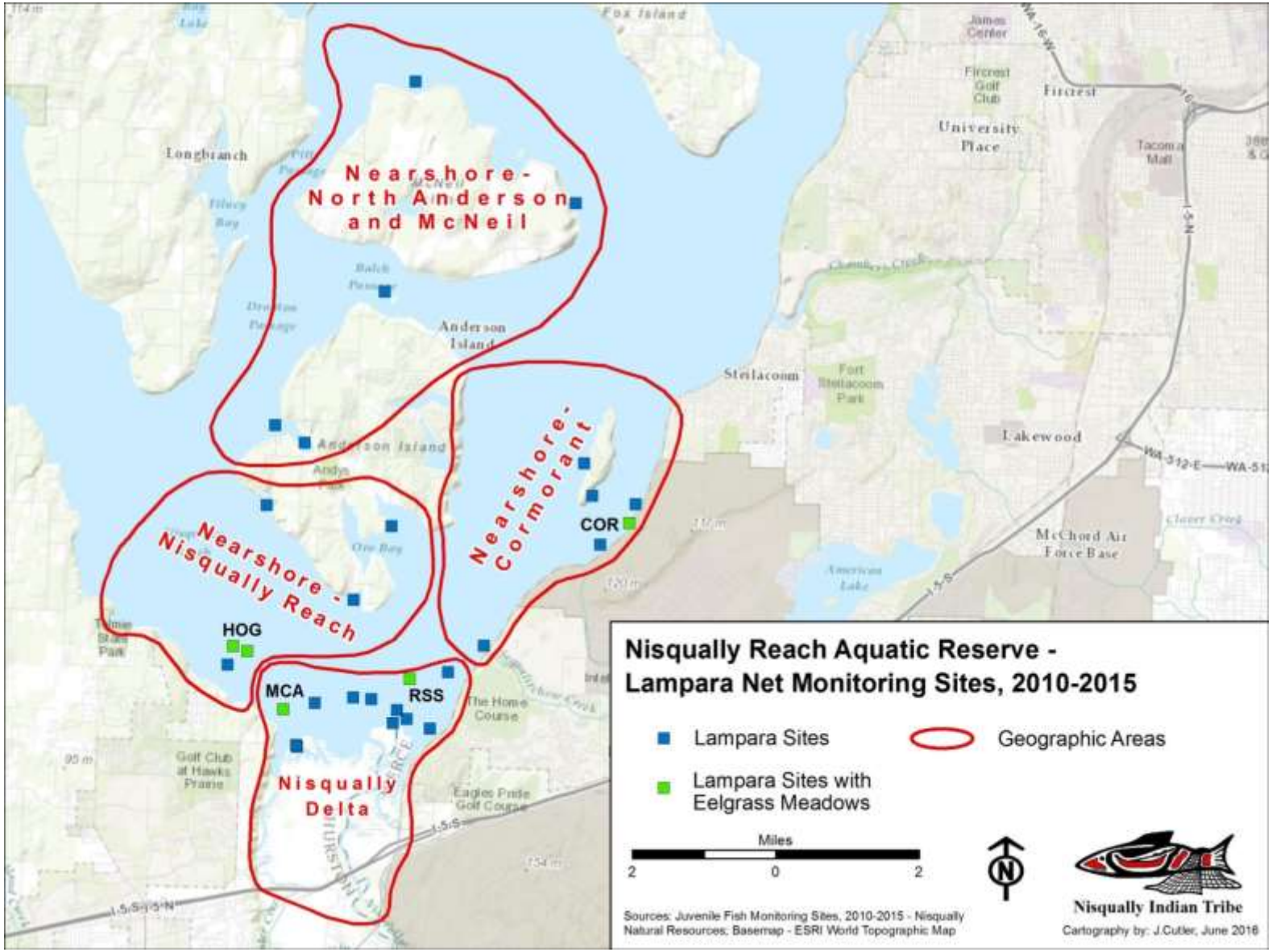

Figure 5. Locations of eelgrass sampling sites with and without eelgrass meadows. Eelgrass meadow sites are labelled: RSS Eelgrass T4 (RSS), MCA Eelgrass T1 (MCA), Cormorant (COR) and Hogum Bar A and B (HOG).

Results

Summaries of surface water quality measurements are shown in Tables 4 and 5 and annual and seasonal patterns of water temperature, salinity, and dissolved oxygen are shown in Figure 6. Water temperature and salinity were generally higher in 2015 compared to the other years. Catch composition in the seine and lampara sampling are shown in Figures 7 and 8 respectively, along with catch per set (CPS) summaries in Tables 6 and 7. The most common species caught included chum (*O. keta*), pink (*O. gorbuscha*), and Chinook salmon, shiner perch, sculpin, and Pacific sand lance (*Ammodytes personatus)*. Hatchery Chinook salmon were abundant in the delta and nearshore (average CPS 5.5-18.8), except in the North Anderson/McNeil area (CPS 0.7). Unmarked Chinook salmon were present but much less abundant than hatchery origin fish (CPS 0.1-2.5). Within beach seined areas, unmarked Chinook salmon were more common in the delta (CPS 2.5) than the nearshore (CPT 0.1 – 0.6), while in the lampara sampled areas, delta and nearshore densities were similar (CPS 0.5 – 0.7) with the exception of lower numbers in the North Anderson/McNeil area (CPS 0.1). Chum and pink salmon were more abundant at the nearshore sites than the delta sites. Pink salmon were especially abundant and dominated the catch in the nearshore North Anderson/McNeil area.

Monthly catch patterns are shown in Figures 9-12. Hatchery Chinook salmon were most abundant in May and June in the delta and nearshore samples, while the timing of unmarked Chinook salmon was more protracted. Pink salmon abundance peaked in March at the beach seine sites and in May-June at the lampara sites. Similarly, chum salmon abundance peaked first in April-May at the beach seine sites and then in May-June at the lampara sites. Herring (*Clupea harengus pallasi*) were most abundant in the May seine sampling in the Nearshore Cormorant area. Pacific sand lance had multiple peaks in abundance, between April and September in the Delta and Nearshore Cormorant areas.

Year to year variation is shown in Figures 13-14. Hatchery Chinook salmon and chum salmon were generally more abundant in even-numbered years when pink salmon were not present. The lampara and seine catch data showed similar interannual variation for chum and pink salmon, while the lampara and seine catches for hatchery Chinook salmon differed more from each other.

Salmon length patterns over time are shown for the different geographic areas in Figures 15-16 Lengths of unmarked Chinook salmon increased steadily over the months sampled. Length patterns show that the beach seine caught more of the smaller pink and chum salmon present earlier in the season while the lampara net caught the larger pink and chum present later in the season.

Utilization of these delta and nearshore areas by hatchery Chinook salmon marked with a CWT is shown in Table 8 and Figure 17 (note that Table 8 also shows information on tagged and total hatchery releases). The majority of the tagged fish originated in the Nisqually basin (75.3%), with the Puyallup (10.9%), Duwamish (5.4%), and Snohomish (6.1%) also being common release basins. Overall, the catch included tagged salmon from the Garrison hatchery on Chambers Creek, Soos Creek hatchery in the Duwamish basin, Grovers Creek hatchery in the East Kitsap Peninsula (North of the Narrows basin), Minter Creek - and Hupp Springs hatcheries in the East Kitsap Peninsula (South of the Narrows basin), Clear and Kalama Creek hatcheries in the Nisqually basin, White River and Voights Creek hatcheries in the Puyallup basin, and the Wallace River hatchery in the Snohomish basin. Fish released from these locations were all present in both delta and nearshore areas, with the Chinook salmon from the Puyallup and Snohomish basins showing greater abundance in the Nisqually delta than in the nearshore areas.

Lampara catch summaries for the four eelgrass sites, and for sites with little or no eelgrass from the same geographic areas, are shown in Figures 18-20. Species composition is shown in Figure 18. Several species showed at least some affinity for eelgrass. Pacific sand lance were more common in the Nisqually Delta than in other geographic areas, and within the Nisqually Delta sand lance were particularly common at the MCA eelgrass site (eelgrass site locations are shown in Figure 5). Shiner perch were common at both of the Nisqually Delta eelgrass sites (MCA and RSS). Herring were more common at two of the eelgrass sites (COR and HOG) than they were at the other two eelgrass sites or at sites with little eelgrass. Tube-snouts (*Aulorhynchus flavidus*), a species known to frequent eelgrass, were more common at three of the eelgrass sites (COR, HOG, and RSS) than they were at the other eelgrass site (MCA) or at sites with little eelgrass. Saddleback gunnels (*Pholis ornate),* another species known to frequent eelgrass, were more common at three of the eelgrass sites (MCA, HOG, and RSS) and at nearshore Nisqually Reach sites with little eelgrass than they were at the COR eelgrass site or at sites with little eelgrass in geographic areas other than the Nisqually Reach. The four salmon species composed varying percentages of the catch across all geographic areas and eelgrass levels but were least common at the MCA eelgrass site.

Mean (across years) monthly catch of hatchery and unmarked Chinook salmon at eelgrass and non-eelgrass sites is shown in Figure 19. Hatchery Chinook salmon were most abundant in May in the Nearshore Cormorant area, and for that month and area they were more abundant at the COR eelgrass site than at sites with little eelgrass. Hatchery Chinook salmon abundance in the other geographic areas peaked in May-June at lower levels. In July-August, hatchery Chinook salmon were nearly absent from the Nearshore Cormorant area but persisted elsewhere, particularly at the HOG and RSS eelgrass sites where catch rates remained above 10 fish per set. The highest abundance of unmarked Chinook salmon in any area or month was achieved at the HOG and RSS eelgrass sites in August, and in July unmarked Chinook salmon abundance was higher at those two sites and at the MCA eelgrass site than elsewhere. Unmarked Chinook salmon abundance in the Nearshore Cormorant area peaked in May-June, dropped to low levels thereafter, and was similar between the COR eelgrass site and sites with little eelgrass.

Mean (across months) annual catch of hatchery and unmarked Chinook salmon at eelgrass and non-eelgrass sites is shown in Figure 20. Abundance of both hatchery and unmarked Chinook salmon was low for all areas and eelgrass levels in 2015, and in 2010 it was low for all areas and eelgrass levels except Nearshore Cormorant sites with little eelgrass. In each year from 2011 to 2014, abundance of hatchery and unmarked Chinook salmon was higher at one or more of the eelgrass sites than elsewhere.

Eelgrass shoot density was much higher at Cormorant (COR) than at the other three sites, and at all sites it was slightly higher in 2015 than in 2014 (Figure 21). Water temperature increased from June to August, was higher in 2015 than in 2014, and was higher at MCA than at COR or RSS (Figure 22).

Table 4. Water quality measurements at beach seine sites (near water surface) and sample size (N) from 2010-2015.

Habitat Zone		Site Name	N	Water Temperature (C)		Salinity (ppt)		Dissolved oxygen (mg/L)	
				Avg.	Range	Avg.	Range	Avg.	Range
Nisqually Delta	Freshwater Tidal	I-5 Alcove	1	14.2	14.2	0.0	0.0	8.5	8.5
		I-5 RB	1017	11.3	4.7 - 16.3	0.0	0.0	10.3	3.0 - 12.9
	Emergent/ Fresh Transition	Nugies	324	12.5	4.7 - 16.4	0.4	0.0 - 2.1	9.7	3.1 - 12.7
		Ring Dike Slough	260	11.5	4.7 - 16.4	0.4	0.0 - 4.3	9.2	2.4 - 12.5
	Forested Riverine Tidal	Lookout	864	11.9	4.6 - 16.5	0.0	0.0 - 0.2	9.3	2.9 - 12.3
	Estuarine Emergent Marsh	MCA RB	1591	13.5	6.2 - 18.4	21.9	0.4 - 30.9	8.2	4.4 - 11.9
		N1	978	13.3	5.2 - 19.7	22.4	5.9 - 30.4	8.7	2.4 - 11.4
		Leschi	30	8.6	8.4 - 11.3	20.6	18.1 - 20.8	8.1	7.8 - 8.3
		NEEM 1	703	12.0	4.6 - 16.6	2.1	0.0 - 5.6	9.2	2.6 - 12.9
		NEEM 2	825	12.7	5.2 - 16.7	6.1	0.1 - 19.0	9.0	5.9 - 12.6
		RSS LB	967	12.7	5.9 - 19.5	15.4	3.5 - 30	8.6	3.2 - 12.3
		RSS Point	653	13.7	5.5 - 18.7	12.7	3.1 - 29.5	8.5	4.2 - 12.1
	Delta Flats	Breakwater	1280	11.6	5.8 - 17.2	20.9	4.7 - 32.0	8.9	5.0 - 12.1
		Luhr Beach	1163	12.8	6.5 - 20.0	20.6	4.8 - 31.6	9.0	5.2 - 12.4
		RSS RB	902	12.3	6.0 - 19.1	14.2	3.4 - 30.5	9.1	3.2 - 12.4
		Seal Beach	967	12.5	5.9 - 17.0	15.9	1.0 - 29.9	9.1	4.3 - 11.9
Nearshore	Nearshore	Amsterdam	743	12.8	7.5 - 17.4	26.6	18.9 - 32.7	9.6	4.5 - 12.5
		Andy	639	12.5	7.4 - 16.2	25.5	12.5 - 32.5	9.0	4.2 - 13.2
		Bahamas	882	13.3	7.6 - 16.3	27.5	20.2 - 32.7	9.9	5.2 - 12.9
		DeWolf Bight	991	12.6	7.2 - 17.0	24.9	6.6 - 32.5	9.8	5.4 - 14.1
		Eagle Island	214	10.8	7.6 - 15.4	27.1	20.4 - 32.6	9.2	5.9 - 11.3
		East Oro Bay	928	12.7	7.3 - 15.8	26.9	10.6 - 32.6	8.5	3.2 - 12.1
		Eden Beach	485	11.7	7.6 - 15.3	26.7	16.0 - 32.9	9.9	4.7 - 11.5
		Hogan Point	265	11.4	7.6 - 15.7	26.1	19.6 - 32.8	9.4	5.0 - 12.2
		Hogum Bay	33	7.9	6.4 - 9.3	23.9	10.5 - 26.1	7.3	6.5 - 11.1
		Hogum Bay Spit	860	12.9	6.1 - 18.6	25.6	3.4 - 32.3	9.4	4.9 - 12.6
		Ketron South	580	11.4	7.4 - 17.2	25.6	12.0 - 32.5	8.7	3.1 - 11
		Little Higgins	522	12.2	7.4 - 15.9	26.0	19.0 - 32.7	9.8	3.7 - 12.7
		Milewa	622	13.8	7.6 - 19.9	27.1	20.0 - 32.8	9.8	4.4 - 12.2
		Riviera	721	12.6	7.3 - 16.5	26.6	19.6 - 32.6	8.4	3.0 - 11.6
		Sequalit-chew	692	11.8	7.3 - 15.8	25.1	11.5 - 32.2	8.8	3.4 - 12.7
		Solo Point	1101	11.8	7.4 - 16.5	25.4	13.6 - 32.4	8.6	3.4 - 11.2
		Tolmie Beach	295	11.8	7.1 - 17.5	24.9	13.4 - 26.8	9.3	6.6 - 11.2
		West Oro Bay	661	13.7	5.8 - 17.0	26.6	7.0 - 32.6	8.8	2.8 - 13.7
		Whale Bone	585	13.2	7.6 - 16.8	27.2	19.6 - 32.7	10.1	4.3 - 12.7

Table 5. Water quality and site measurements at lampara sites (near water surface) and sample size (N) from 2010-2015.

Habitat Zone		Site Name	N	Water Temperature (C)		Salinity (ppt)		Current (m/s)	Depth (m)	Secchi depth (m)
				Avg.	Range	Avg.	Range	Avg.	Avg.	Range
Nisqually Delta	Delta Flats	Breakwater T5	455	12.6	8.7 - 17.9	25.4	16.4 - 32.1	0.0	2.1	0.8 - bottom
		MCA Eelgrass T1	608	13.8	8.8 - 18.0	22.2	7.6 - 32.4	0.2	2.0	0.3 - bottom
		Nisqually Flats T2	287	13.3	8.1 - 18.1	20.0	5.7 - 32.4	0.2	1.7	0.5 - bottom
		Nisqually Flats T3	8	12.4	11.9 - 14.3	13.0	9.5 - 28.6	0.1	1.7	bottom
		Nisqually Flats T4	381	13.4	8.9 - 16.4	23.8	4.0 - 32.3	0.1	1.5	bottom
		Nisqually Flats T4 B	12	13.2	13.2 - 13.2	15.2	15.2 - 15.2	0.0	1.1	bottom
		Nisqually Flats T4 C	1	13.2	13.2 - 13.2	15.2	15.2 - 15.2	0.0	1.1	bottom
		Nisqually Mouth T3	318	12.7	8.0 - 16.5	19.6	3.6 - 32.5	0.2	2.7	0.5 - bottom
		RSS Eelgrass T4	675	13.1	8.6 - 16.9	25.1	12.5 - 32.4	0.2	2.2	0.6 - bottom
		RSS Mouth T5	2	12.5	11.5 - 13.5	27.9	27.7 - 28.0	0.1	2.4	bottom
	Estuarine Emergent Marsh	Marsh Edge T1	437	13.7	8.8 - 19.3	22.8	3.5 - 31.9	0.3	1.6	0.2 - bottom
		Marsh Edge T2	11	12.5	11.8 - 12.6	24.6	11.5 - 25.9	0.1	1.1	bottom
Nearshore	Nearshore	Amsterdam Inside	22	11.6	9.0 - 15.6	25.4	25.1 - 26.4	0.0	3.0	0.8 - bottom
		Amsterdam Outside	115	13.3	9.1 - 16.6	27.1	25.1 - 32.2	0.1	1.7	bottom
		Andy	1	10.4	10.4 - 10.4	21.9	21.9 - 21.9	0.0	2.2	bottom
		Bradley Flats	173	13.2	9.3 - 18.0	26.9	25.5 - 32.2	0.0	1.6	bottom
		Cormorant	520	11.7	8.6 - 16.8	26.3	19.9 - 32.1	0.1	1.6	bottom
		Cormorant A	36	11.3	10.9 - 15.6	27.8	27.7 - 28.3	0.0	1.0	bottom
		Eagle Reef	10	11.3	8.5 - 13.5	26.0	25.5 - 26.5	0.2	3.1	1.5 - bottom
		Hogum Bar A	257	12.6	8.9 - 15.5	26.4	21.8 - 32.3	0.2	2.3	0.9 - bottom
		Hogum Bar B	495	13.5	10 - 16.9	26.3	9.1 - 32.2	0.2	2.4	0.8 - bottom
		Hogum Bay	343	13.0	8.9 - 17.2	26.1	12.5 - 32.3	0.2	3.2	0.9 - bottom
		Ketron East	406	12.3	8.7 - 16.1	27.1	24.2 - 32.2	0.1	1.9	1.1 - bottom
		Ketron West	1	10.9	10.9 - 10.9	28.1	28.1 - 28.1	0.3	2.8	bottom
		Oro Bay	470	12.5	8.4 - 16.8	27.2	22.9 - 32.3	0.0	2.0	0.8 - bottom
		Sequalitchew	658	12.2	8.7 - 16.2	25.3	15.1 - 32.0	0.1	2.1	0.8 - bottom
		Solo	400	12.3	8.7 - 16.5	24.6	7.2 - 32.0	0.1	2.1	0.8 - bottom
		Thompson Cove	494	12.9	8.5 - 16.2	23.7	8.2 - 32.4	0.1	1.8	1.2 - bottom
		Whale Bone	206	12.5	8.9 - 17.7	26.5	25.6 - 32.2	0.1	1.5	1.1 - bottom

Table 6. Beach seine average catch per set by species and geographic area for 2010-2015 combined.

Species Common Name	Species Latin Name	Nisqually Delta	Nearshore: Cormorant	Nearshore: Nisqually Reach	Nearshore: N. Anderson & McNeil	All areas Combined
Chum Salmon	*Oncorhynchus keta*	3.05	17.88	19.93	32.33	13.37
Hatchery Chinook	*Oncorhynchus tschawytscha*	15.81	23.71	5.46	0.74	12.23
Shiner Perch	*Cymatogaster aggregata*	9.05	1.56	19.85	16.35	11.37
Pink Salmon	*Oncorhynchus gorbuscha*	0.20	23.37	2.65	36.31	10.20
Sculpin	*Cottidae spp.*	10.71	3.17	15.13	6.31	9.74
Pacific Herring	*Clupea harengus pallasi*	0.26	13.54	0.23	0.01	1.95
Starry Flounder	*Platichthys stellatus*	2.26	0.57	1.14	0.31	1.48
Pacific Sand Lance	*Ammodytes personatus*	1.95	3.00	0.01	0.27	1.43
Unmarked Chinook	*Oncorhynchus tschawytscha*	2.49	0.55	0.09	0.07	1.36
Saddleback Gunnel	*Pholis ornata*	0.09	2.67	0.41	3.50	1.10
Coho Salmon, hatchery	*Oncorhynchus kisutch*	0.32	1.15	1.91	0.61	0.78
Surf Smelt	*Hypomesus pretiosus*	0.98	0.12	0.60	0.02	0.63
Coho salmon, unmarked	*Oncorhynchus kisutch*	0.65	0.76	0.27	0.17	0.51
Three Spine Stickleback	*Gasterosteus aculeatus*	0.26	0.17	0.91	0.21	0.36
Cutthroat Trout	*Oncorhynchus clarki clarki*	0.45	0.26	0.19	0.08	0.31
English Sole	*Parophrys vetulus*	0.08	0.45	0.22	0.72	0.27
Pacific Snake Prickleback	*Lumpenus sagitta*	0.01	0.08	0.88	0.16	0.20
Mountain Whitefish	*Prosopium williamsoni*	0.32	0.00	0.00	0.00	0.16
Bay Pipefish	*Syngnathus leptorhynchus*	0.00	0.25	0.03	0.21	0.08
Tube-snout	*Aulorhynchus flavidus*	0.00	0.29	0.01	0.14	0.07
Speckled Sanddab	*Citharichthys stigmaeus*	0.01	0.08	0.04	0.19	0.06
Speckled Dace	*Rhinichthys osculus*	0.11	0.00	0.00	0.00	0.06

Other species caught at less than 0.05 per set (all areas combined) included: American Shad (*Alosa Sapidissima*), C-O Sole (*Pleuronichthys coenosus*), Crescent Gunnel (*Pholis laeta*), Largescale Sucker (*Catostomus macrocheilus*), Pacific Snake Prickleback (*Lumpenus sagitta*), Pacific Spiny Lumpsucker (*Eumicrotremus orbis*), Penpoint Gunnel (*Apodichthys flavidus*), Pile Perch (*Rhacochilus vacca*), Red Gunnel (*Pholis schultzi*), Sand Sole (*Psettichthys melanostictus*), Sockeye (*Oncorhynchus nerka*), Steelhead/Rainbow Trout (*Oncorhynchus mykiss*), Striped Seaperch (*Embiotoco lateralis*), Unknown Greenling, Unknown Lamprey, Unknown Poacher, Unknown Rockfish, Unknown Snailfish, Whitespotted Greenling (*Hexagrammos stelleri*), and Yellow Perch (*Perca Flavescens*).

Table 7. Lampara average catch per set by species and geographic area for 2010-2015 combined.

Species Common Name	Species Latin Name	Nisqually Delta	Nearshore: Cormorant	Nearshore: Nisqually Reach	Nearshore: N. Anderson & McNeil	All areas Combined
Hatchery Chinook	*Oncorhynchus tschawytscha*	11.53	32.00	9.04	1.90	14.52
Chum	*Oncorhynchus keta*	4.79	20.38	12.38	6.62	10.45
Pink	*Oncorhynchus gorbuscha*	0.31	10.97	1.60	41.24	8.00
Pacific Sand Lance	*Ammodytes personatus*	9.51	1.31	0.39	0.02	4.27
Shiner Perch	*Cymatogaster aggregata*	4.33	0.90	1.59	1.05	2.48
Hatchery Coho	*Oncorhynchus kisutch*	0.25	4.20	0.43	0.36	1.22
Chum/Pink undetermined (even years only)		0.89	2.52	0.50	0.00	1.07
Surf Smelt	*Hypomesus pretiosus*	0.87	1.27	0.49	0.00	0.77
Unmarked Chinook	*Oncorhynchus tschawytscha*	0.65	0.72	0.51	0.09	0.56
Pacific Herring	*Clupea harengus pallasi*	0.26	0.98	0.66	0.00	0.49
Unmarked Coho	*Oncorhynchus kisutch*	0.23	0.69	0.44	0.11	0.37
Tube-snout	*Aulorhynchus flavidus*	0.14	0.31	0.40	0.00	0.23
Saddleback Gunnel	*Pholis ornata*	0.18	0.09	0.41	0.11	0.21
3 Spined Stickleback	*Gasterosteus aculeatus*	0.05	0.48	0.06	0.09	0.16
Starry Flounder	*Platichthys stellatus*	0.24	0.04	0.06	0.02	0.12
Sculpin	*Cottidae spp.*	0.13	0.05	0.16	0.04	0.11
Pile Perch	*Rhacochilus vacca*	0.01	0.04	0.06	0.00	0.03
Bay Pipefish	*Syngnathus leptorhynchus*	0.02	0.05	0.01	0.01	0.02
Pacific Snake Prickleback	*Lumpenus sagitta*	0.02	0.01	0.03	0.06	0.02

Other species caught at 0.01 per set or less (all areas combined) included: Cutthroat Trout (*Oncorhynchus clarkii*), C-O Sole (*Pleuronichthys coenosus*), Crescent Gunnel (*Pholis laeta*), English Sole (*Parophrys vetulus*), Kelp Greenling (*Hexagrammos decagrammus*), Northern Anchovy (*Engraulis mordax*), Northern Clingfish (*Gobiesox maeandricus)*, Penpoint Gunnel (*Apodichthys flavidus*), Plainfin Midshipman (*Porichthys notatus)*, Speckled Sanddab (*Citharichthys stigmaeus*), Striped Seaperch (*Embiotoco lateralis*), Unknown Gunnel, Unknown Perch, and Unknown Snailfish (Liparidae).

Table 8. Number (and percentage) by release basin of coded wire tagged juvenile hatchery Chinook salmon caught in beach seine and lampara sampling from 2010-2015. Basin of release was identified using the Regional Mark Information System database. Average 2010-2015 total CWT marked release and average 2010-2015 proportion of the total release that had CWT marking are also shown.

	Hatchery Release Basin						
Geographic Area Caught	Nisqually	Chambers	East Kitsap Peninsula North of Narrows	East Kitsap Peninsula South of Narrows	Puyallup	Duwamish	Snohomish
Nisqually Delta (delta flats and estuarine emergent marsh zones only)	333 (75.3%)	3 (0.7%)	4 (0.9%)	3 (0.7%)	48 (10.9%)	24 (5.4%)	27 (6.1%)
Nearshore- Cormorant	118 (69%)	8 (4.7%)	3 (1.8%)	4 (2.3%)	13 (7.6%)	23 (13.5%)	2 (1.2%)
Nearshore- Nisqually Reach	87 (70.2%)	1 (0.8%)	3 (2.4%)	3 (2.4%)	14 (11.3%)	10 (8.1%)	6 (4.8%)
Nearshore- North Anderson and McNeil	12 (50%)	0 (0%)	3 (12.5%)	7 (29.2%)	1 (4.2%)	1 (4.2%)	0 (0%)
All Areas Combined	550 (72.3%)	12 (1.6%)	13 (1.7%)	17 (2.2%)	76 (10%)	58 (7.6%)	35 (4.6%)
Release Information:							
Average # CWT released per year	448,727	78,706	484,475	427,086	513,675	502,581	640,143
Average % of total release marked with CWT	17.7%	98.6%	59.3%	97.9%	95.6%	77.0%	37.7%

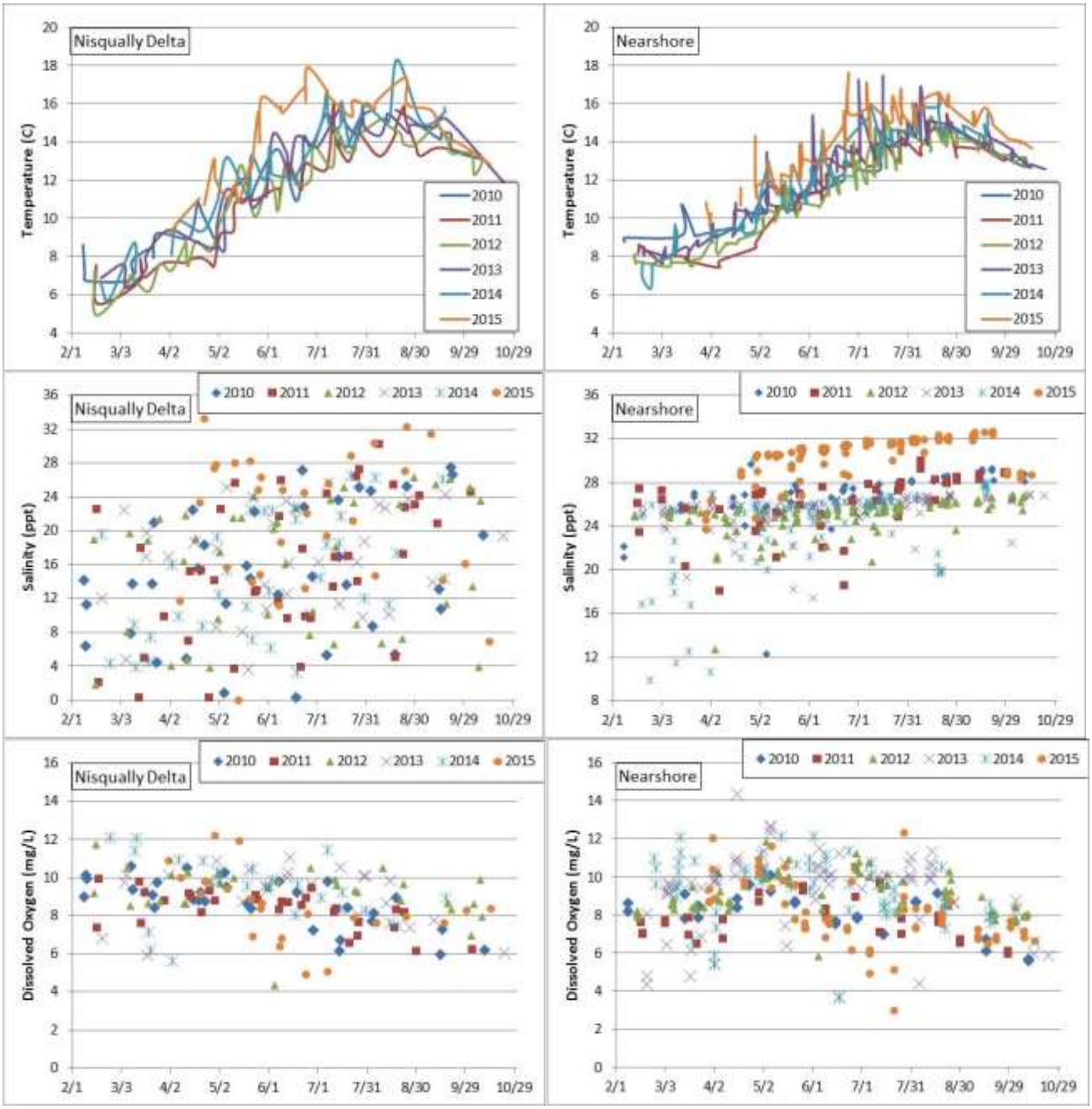

Figure 6. Water temperature, salinity, and dissolved oxygen in the Nisqually Delta and nearshore areas by season and year. Measurements were taken at the surface of the water column and values were averaged across multiple sites on a given sampling date. Temperature and salinity values were measured at beach seine and lampara sites; dissolved oxygen at beach seine sites only. The three nearshore geographic areas were combined because measurements in the different areas were quite similar.

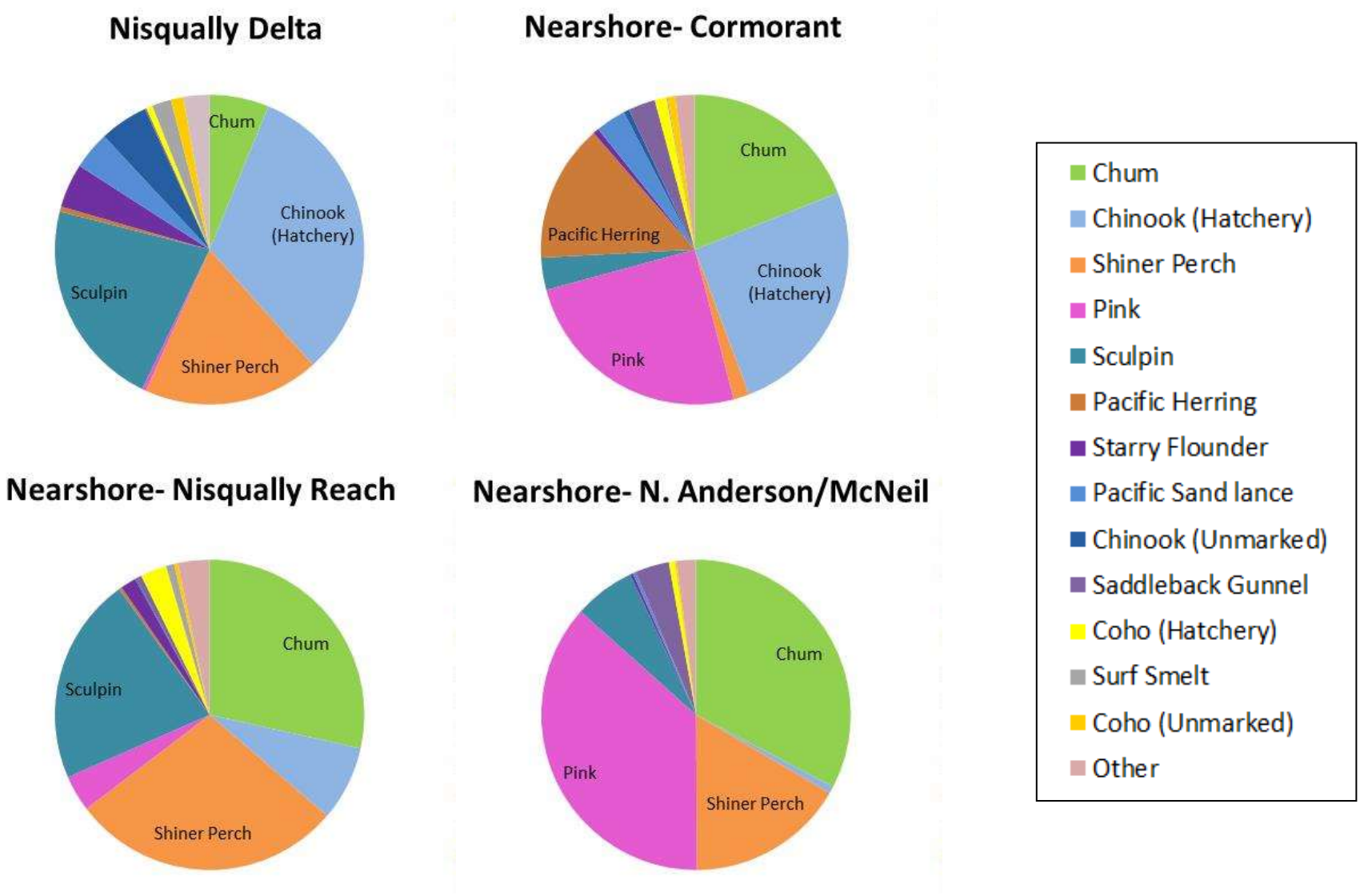

Figure 7. Beach seine catch composition by geographic area for 2010-2015.

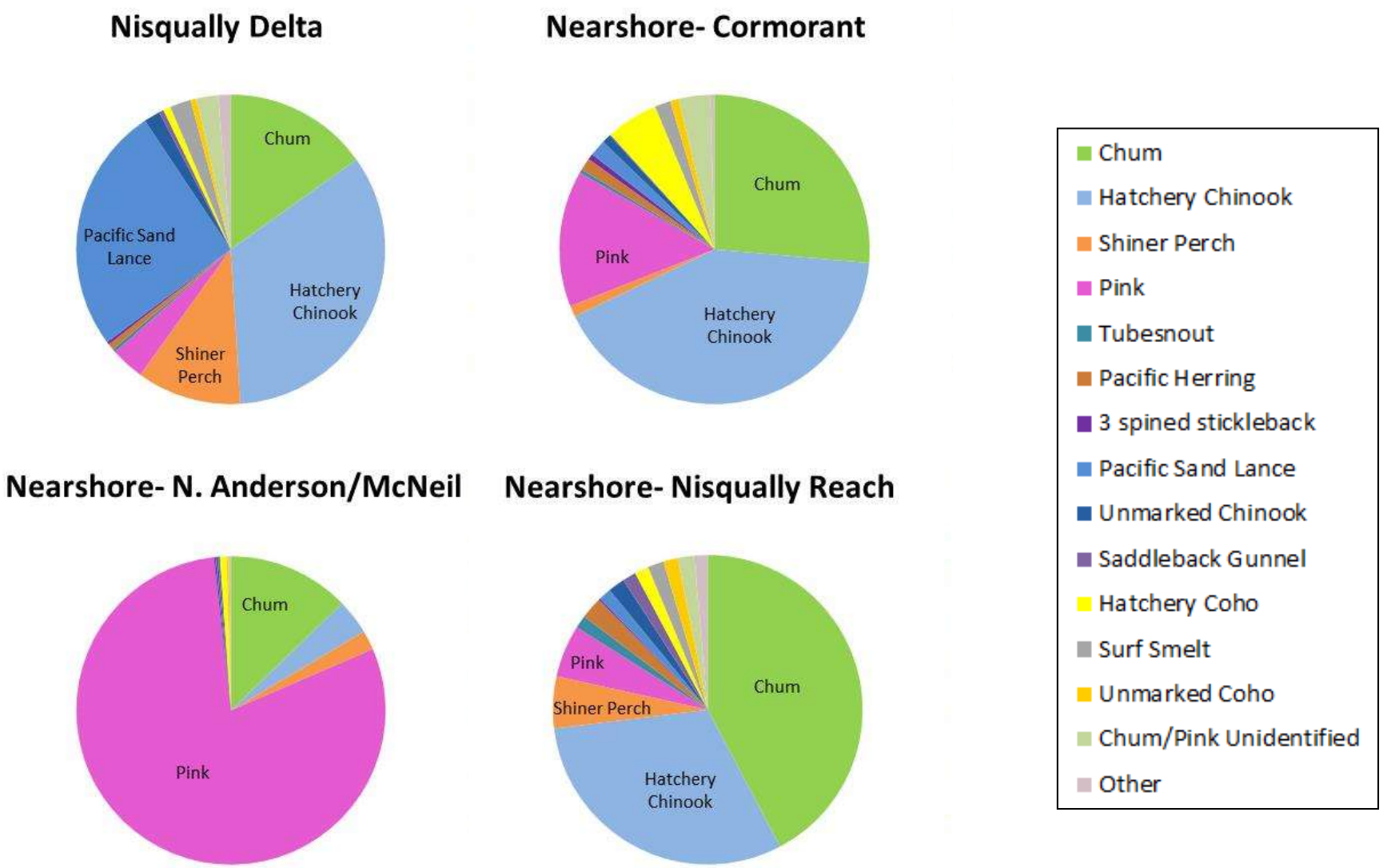

Figure 8. Lampara catch composition by geographic area for 2010-2015.

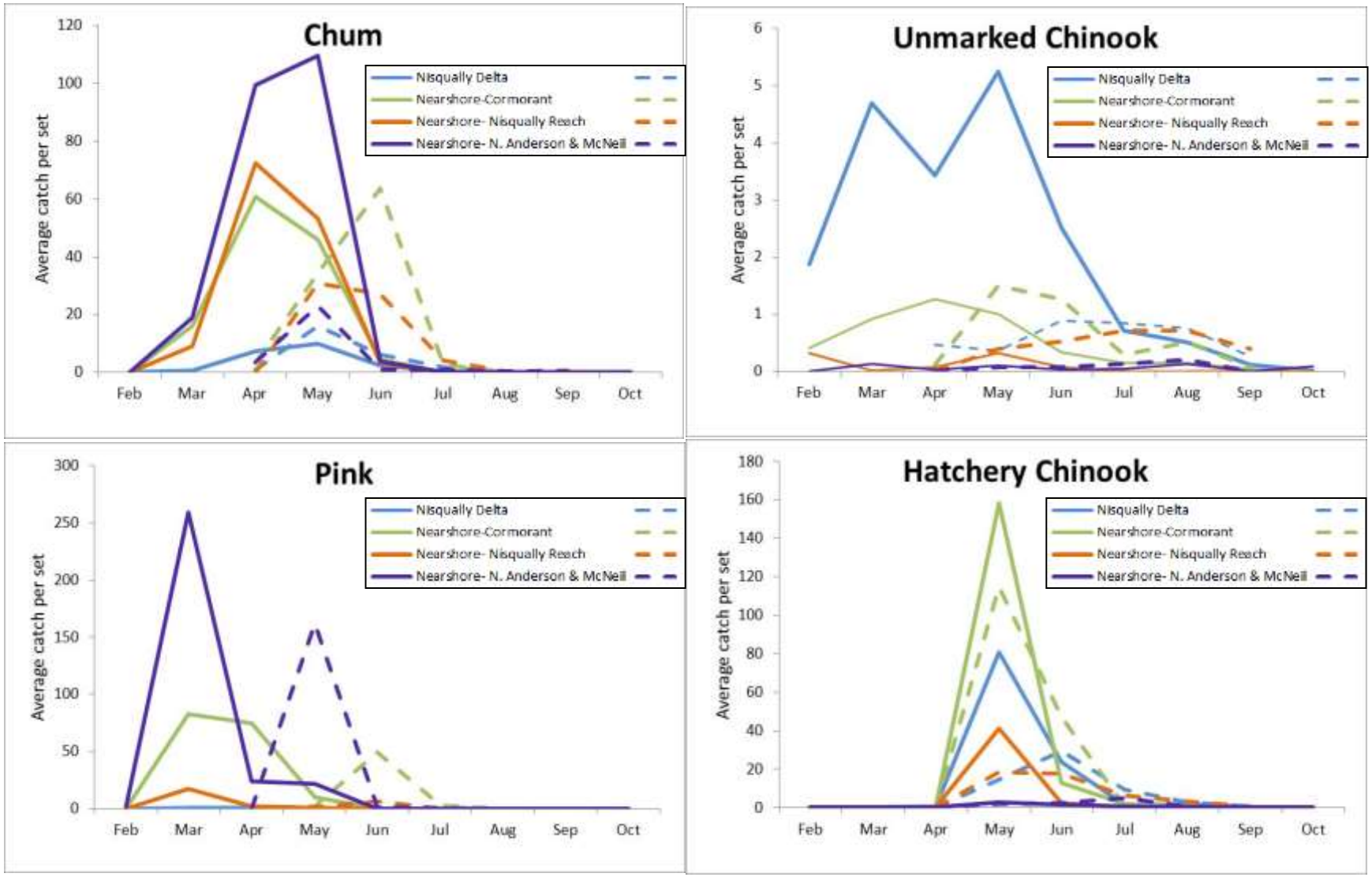

Figure 9. Average monthly beach seine (solid line) and lampara (dotted line) catch per set in four geographic areas from 2010-2015. For non-salmonids, only the species with >1 average catch per set for all sites combined are shown. Note that beach seine and lampara catch per set are not directly comparable due to different net sizes and lampara sampling occurred from April – September only.

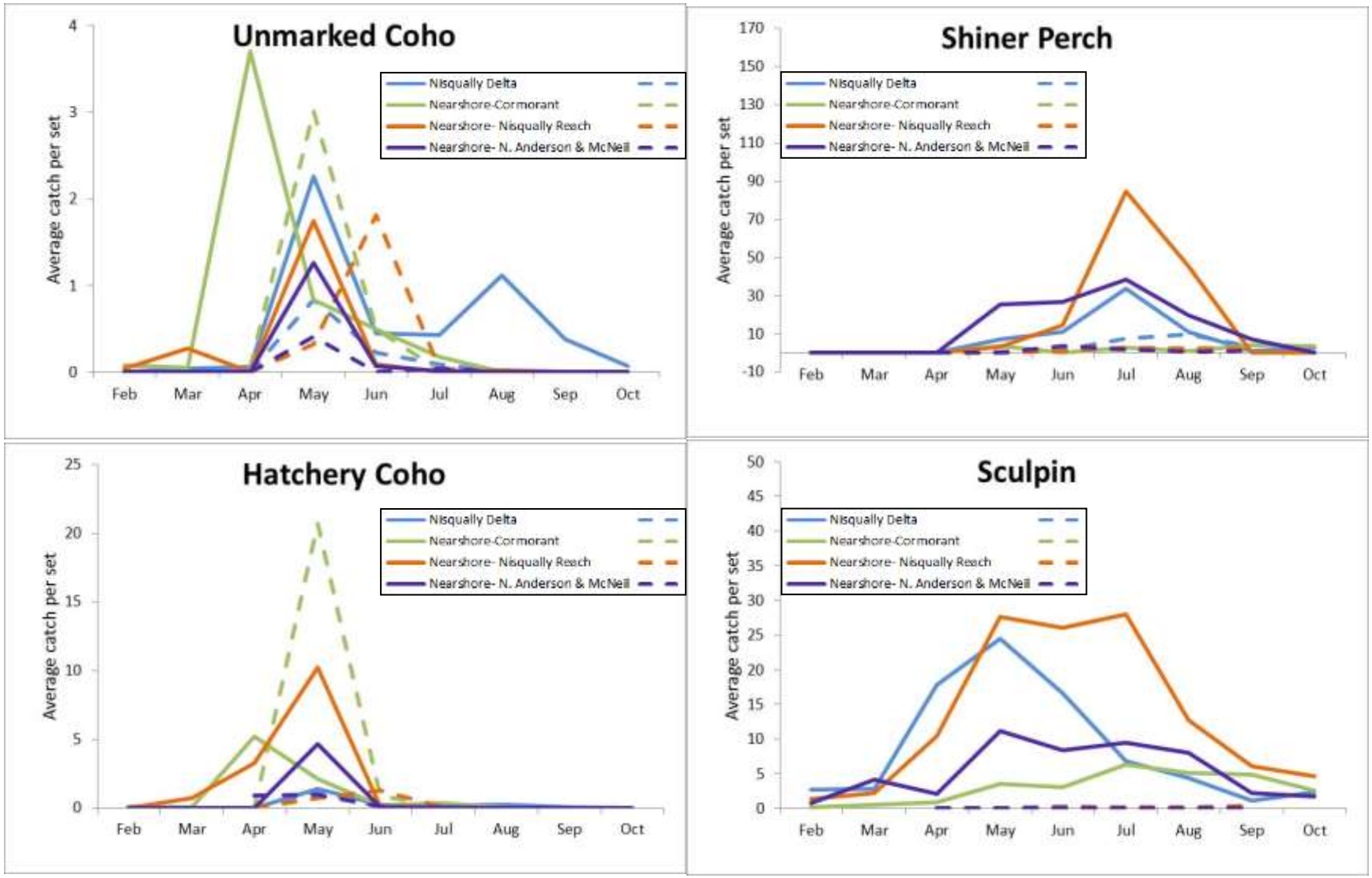

Figure 9, continued. Average monthly beach seine (solid line) and lampara (dotted line) catch per set in four geographic areas from 2010-2015. For non-salmonids, only the species with >1 average catch per set for all sites combined are shown. Note that beach seine and lampara catch per set are not directly comparable due to different net sizes and lampara sampling occurred from April – September only.

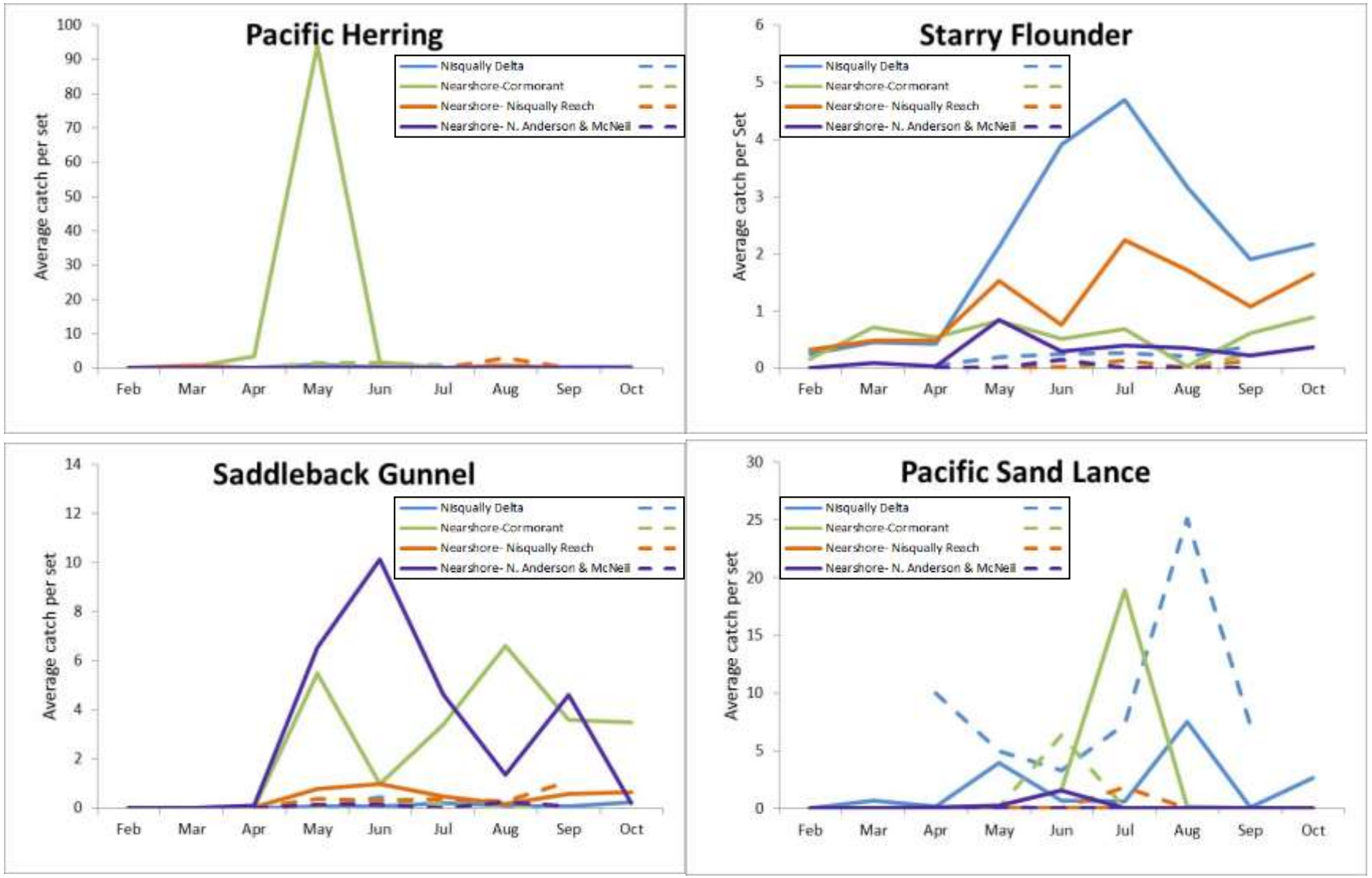

Figure 9, continued. Average monthly beach seine (solid line) and lampara (dotted line) catch per set in four geographic areas from 2010-2015. For non-salmonids, only the species with >1 average catch per set for all sites combined are shown. Note that beach seine and lampara catch per set are not directly comparable due to different net sizes and lampara sampling occurred from April – September only.

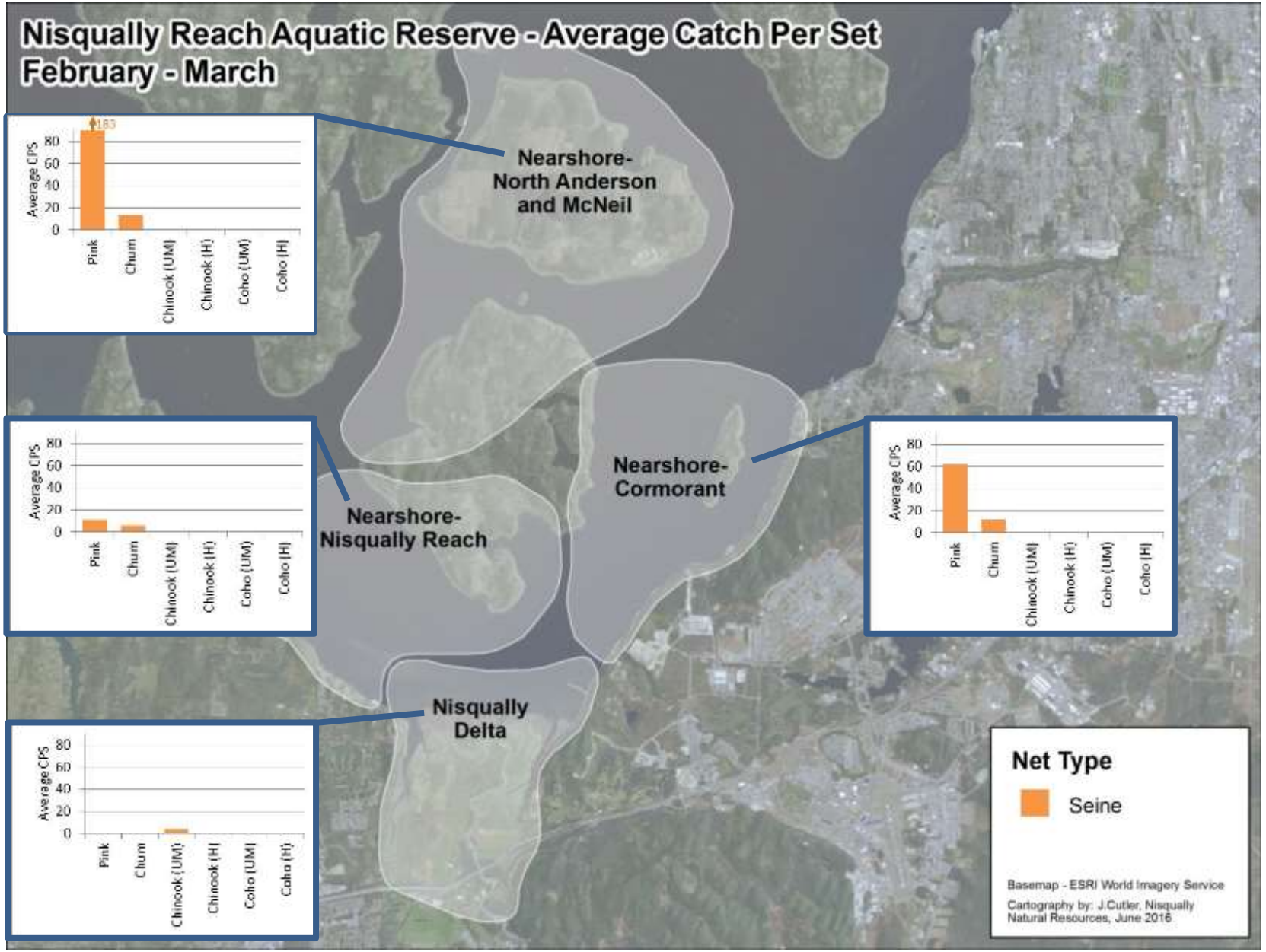

Figure 10. Salmon catch per set (CPS) by geographic area from February-March, based on average beach seine catch per set 2010-15. There was no lampara sampling during these months. Mark status is shown as unmarked (UM) or hatchery (H).

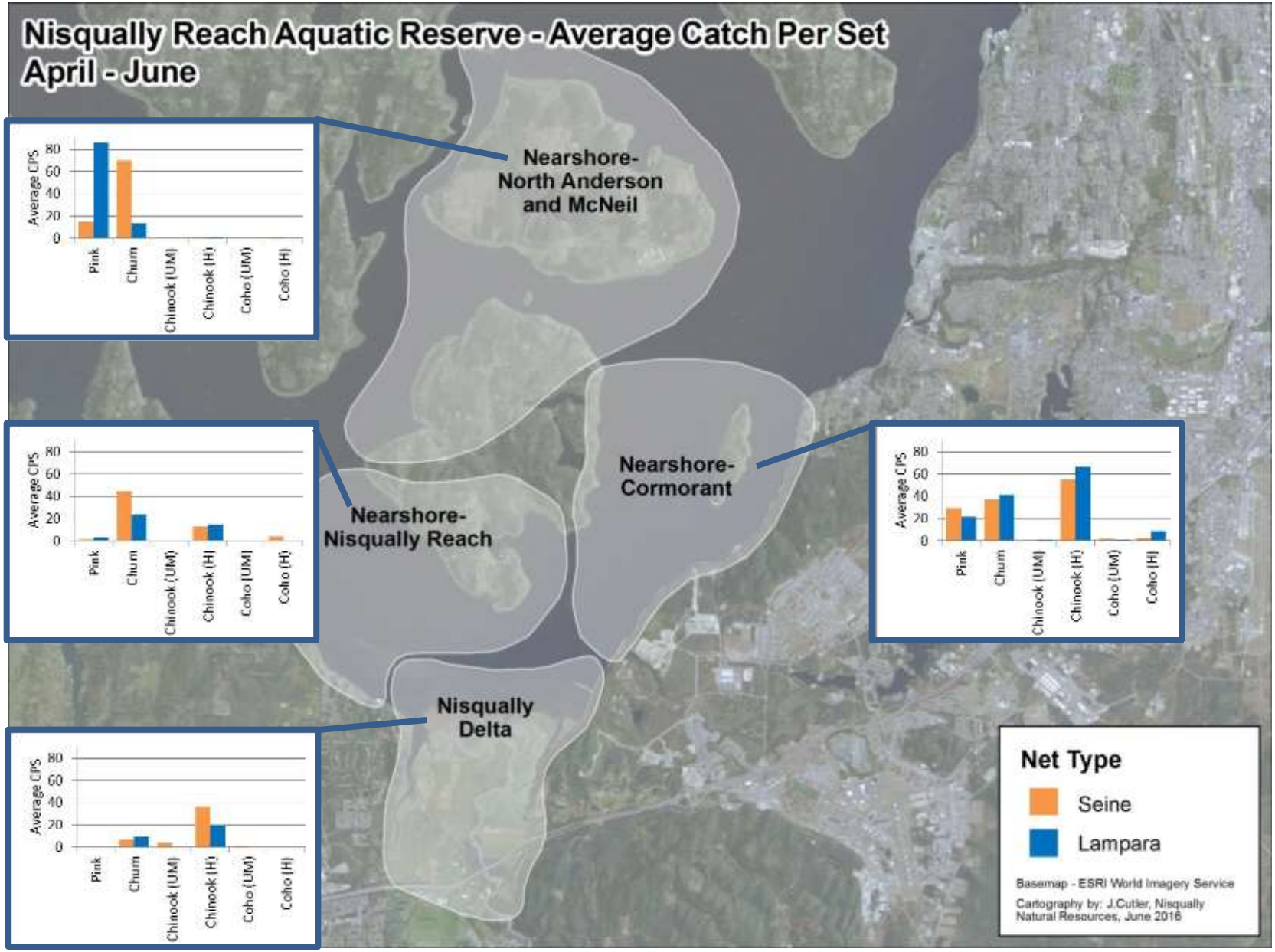

Figure11. Salmon catch per set (CPS) by geographic area and method in April-June, based on average catch per set 2010-15. Mark status is shown as unmarked (UM) or hatchery (H).

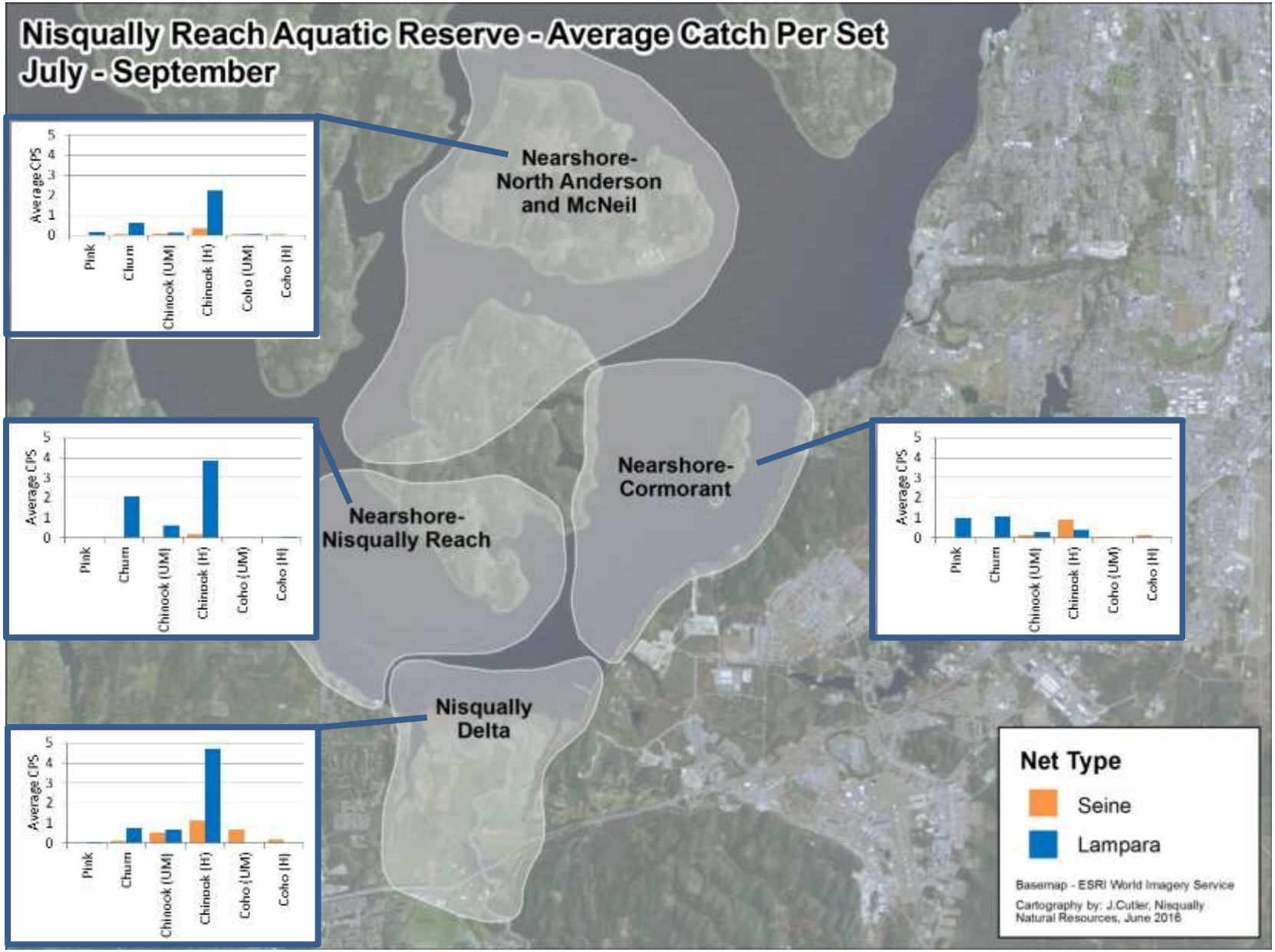

Figure12. Salmon catch per set (CPS) by geographic area and method in July-September, based on average catch per set 2010-15. Mark status is shown as unmarked (UM) or hatchery (H). Note the y-axis scale is different than in previous two figures to show smaller catches in later months.

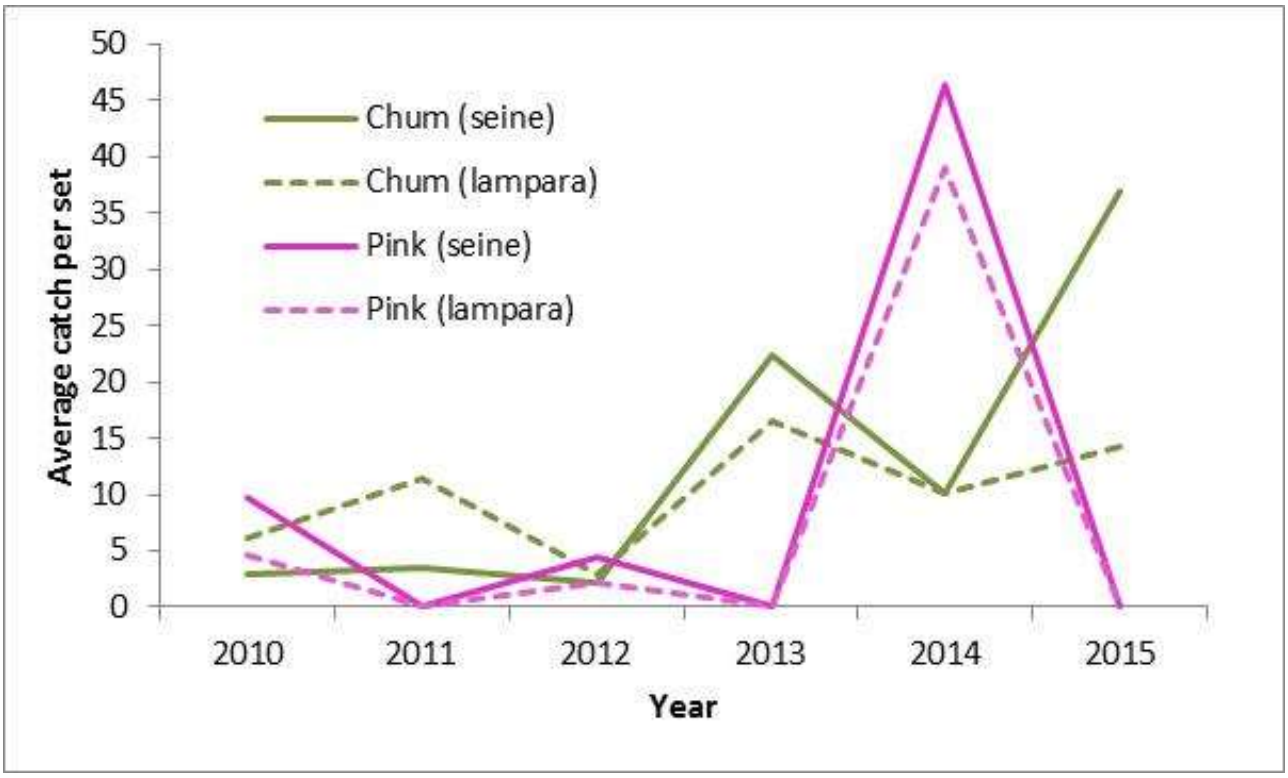

Figure 13. Average annual catch per set for chum and pink salmon beach seine (solid lines) and lampara net (dotted lines). Note that beach seine and lampara catch per set are not directly comparable due to different net sizes.

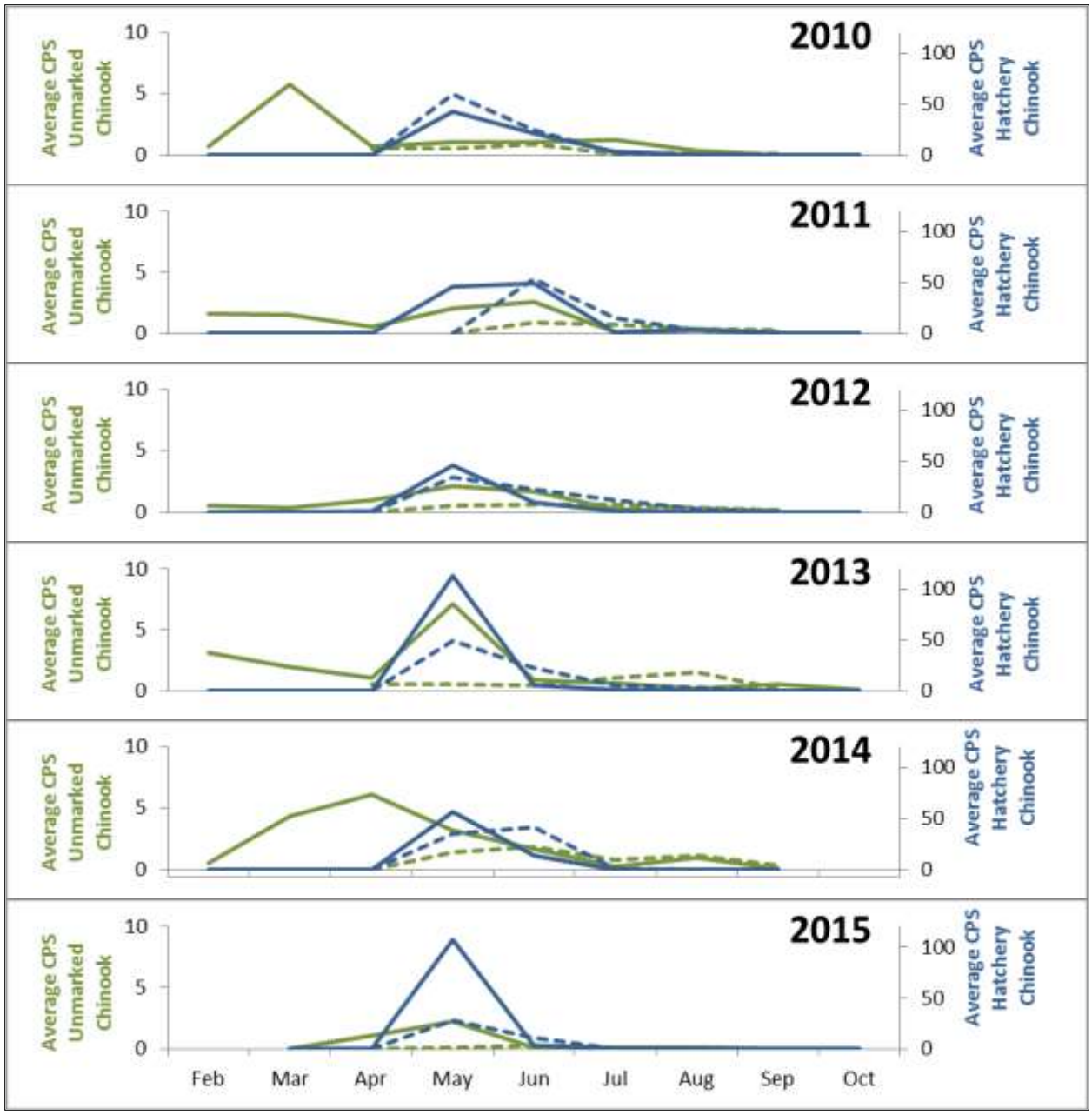

Figure 14. Average monthly catch per set (CPS) for unmarked Chinook (green, left axis) and hatchery Chinook (blue, right axis) from 2010-2015. Beach seine sets (solid lines) and lampara sets (dashed lines) are both shown but are not directly comparable due to differences in net size. Lampara sampling did not occur in February, March, or October.

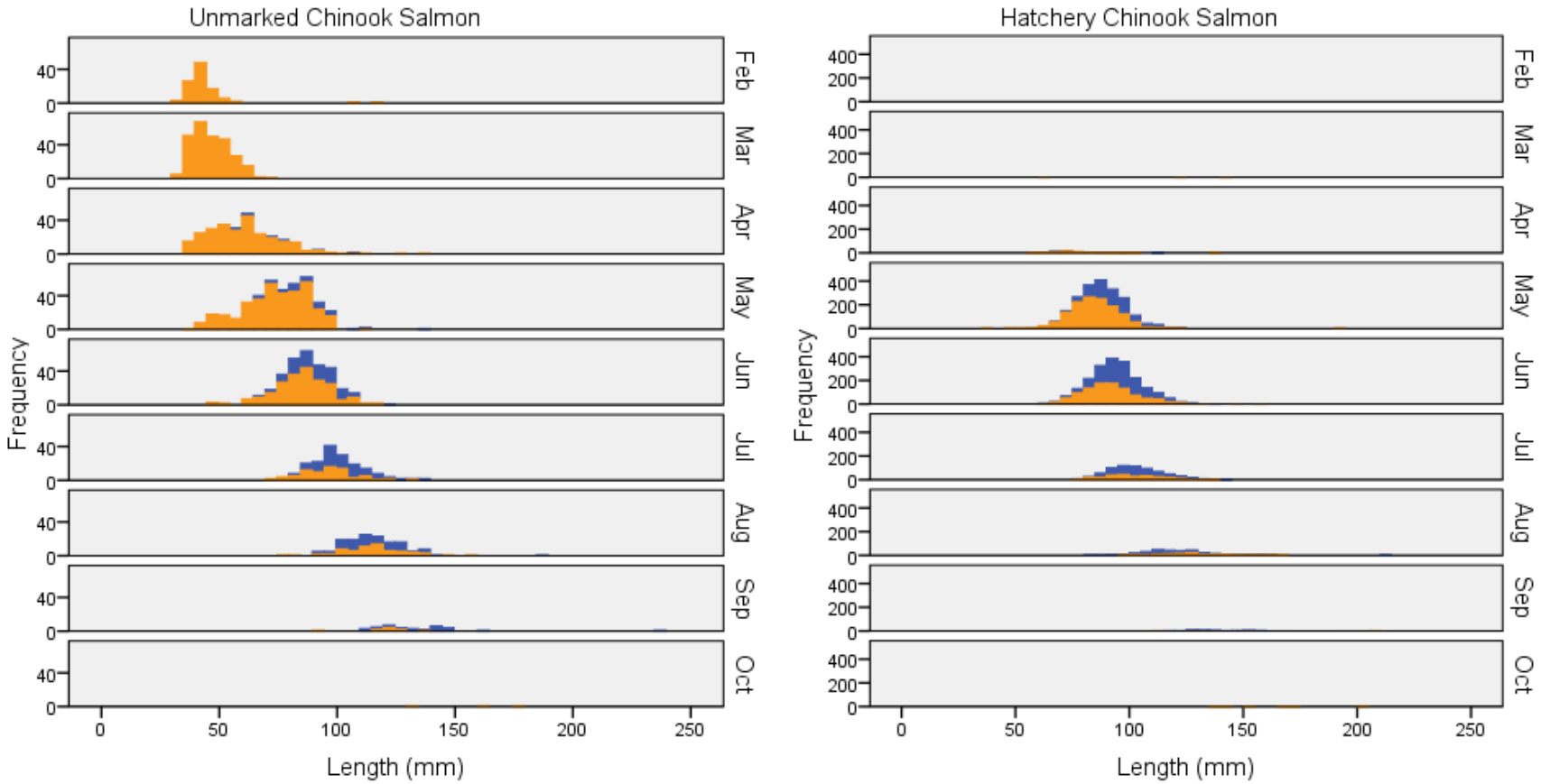

Figure 15. Length-frequency histograms for unmarked and hatchery Chinook salmon caught by beach seine (orange) and lampara net (blue) by month. Lampara sampling only occurred April – September. Geographic areas were combined because lengths were similar among them. February was the only month with no hatchery Chinook caught.

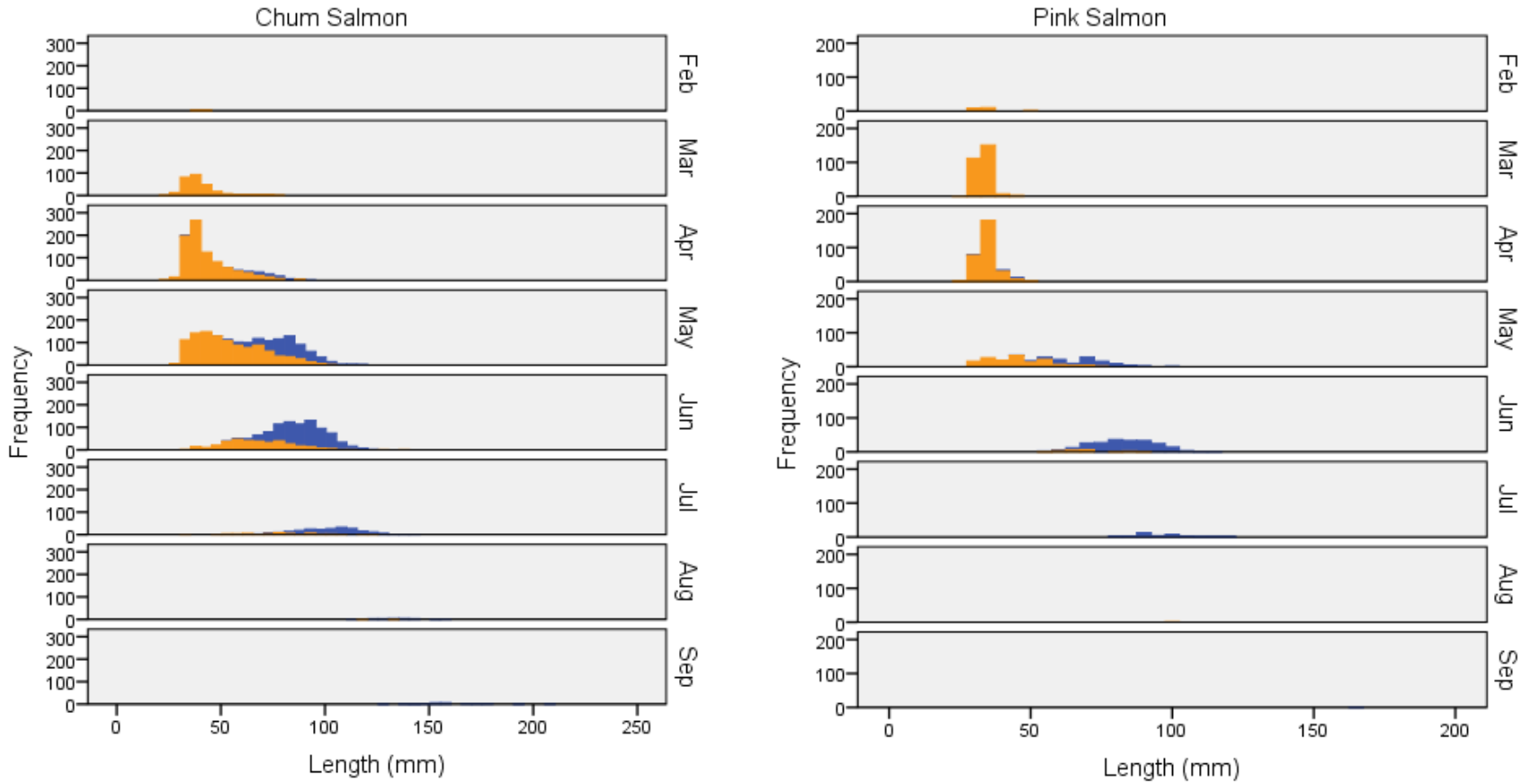

Figure 16. Length-frequency histograms for chum and pink salmon caught by beach seine (orange) and lampara net (blue) by month. Lampara sampling only occurred April – September. Geographic areas were combined because lengths were similar among them.

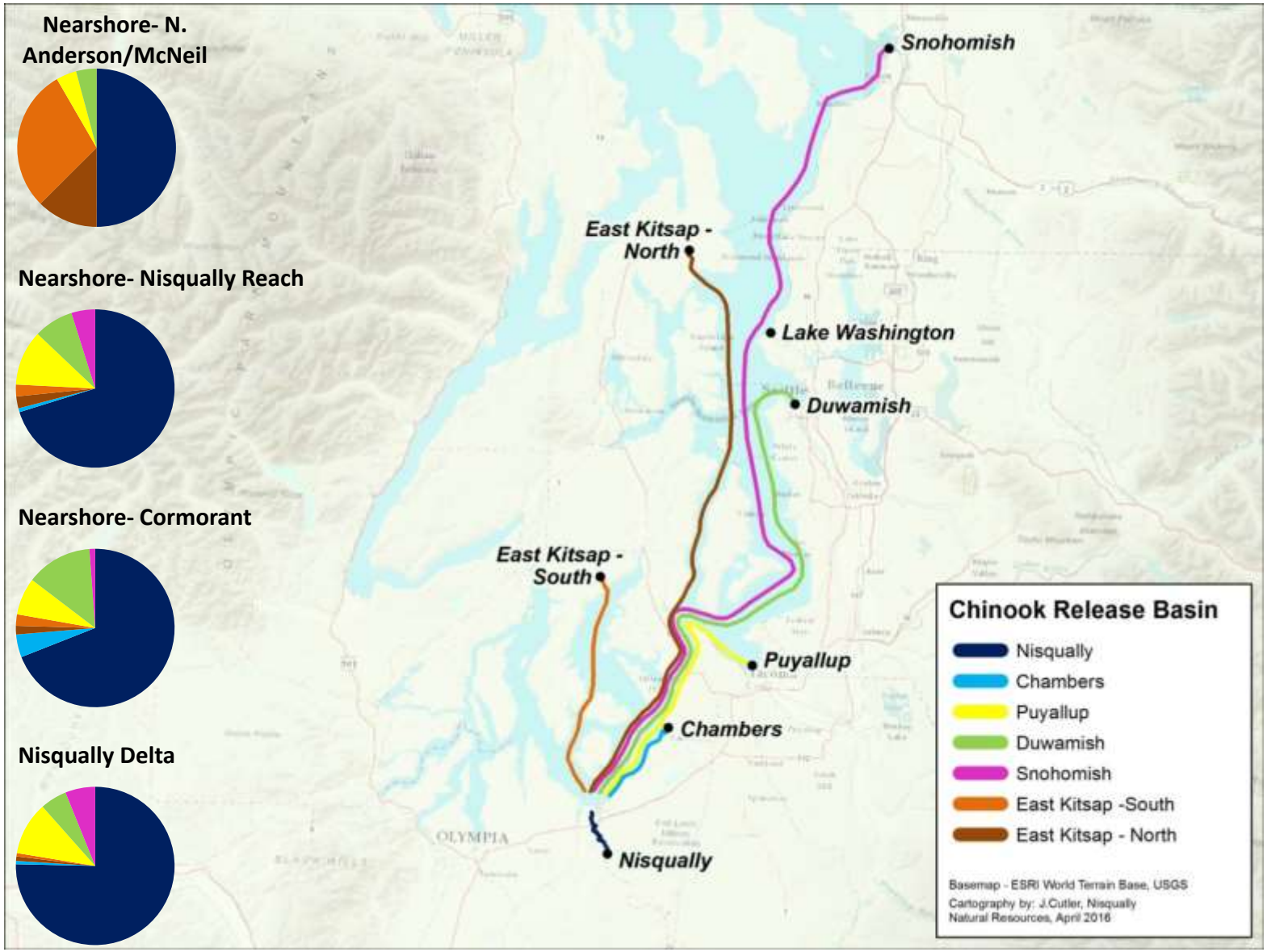

Fig. 17. Release basins of juvenile, hatchery Chinook salmon caught in the Nisqually Delta and nearby nearshore areas. Pie charts show the proportions of CWT fish caught from different release basins within each geographic sampling area. Data were based on coded-wire tagged fish captured with beach seine or lampara net from 2010-2015.

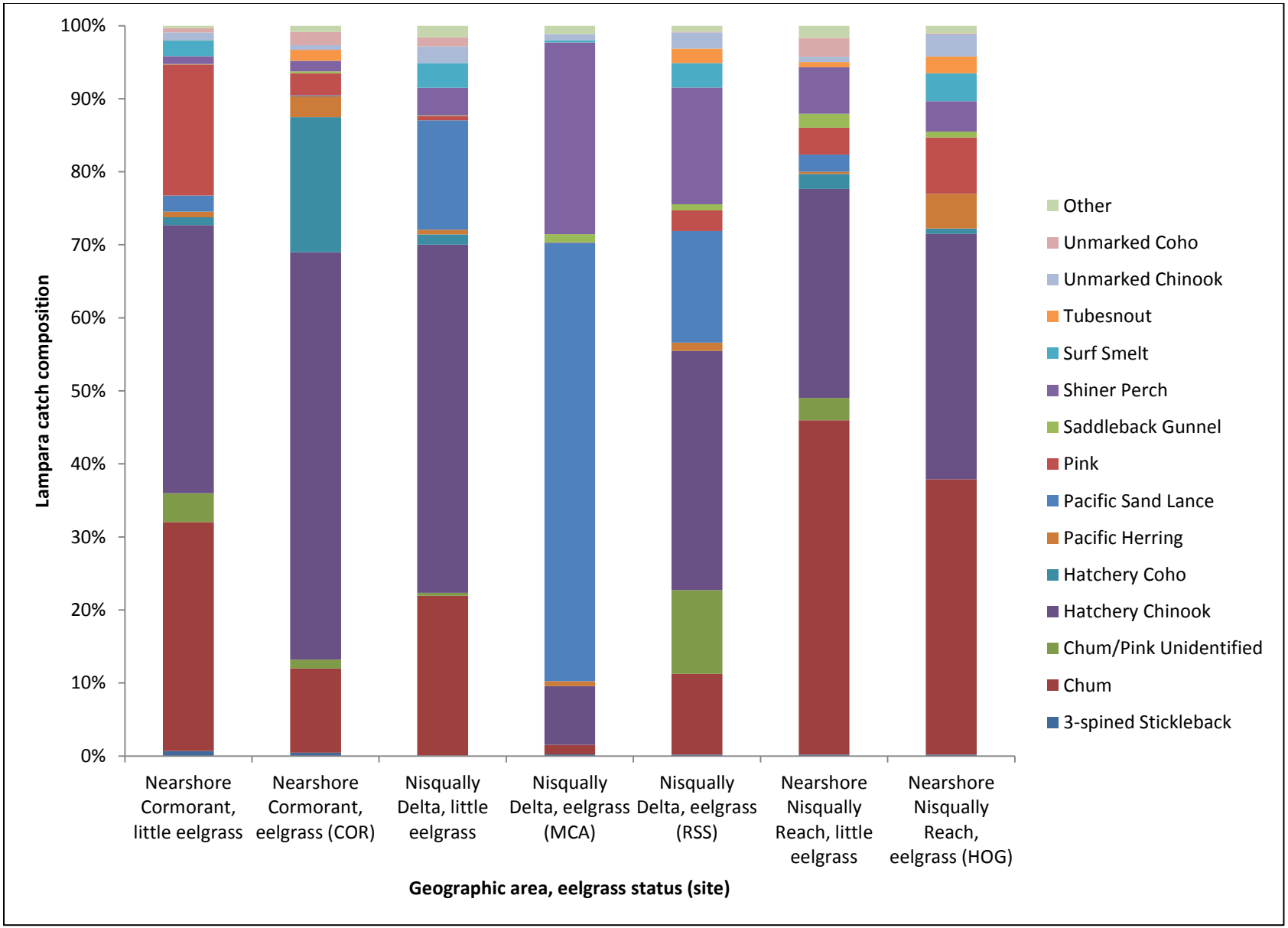

Figure 18. Lampara catch composition by geographic area and eelgrass status, mean of 2010-2015. Catch was averaged over sites for which there was little eelgrass present.

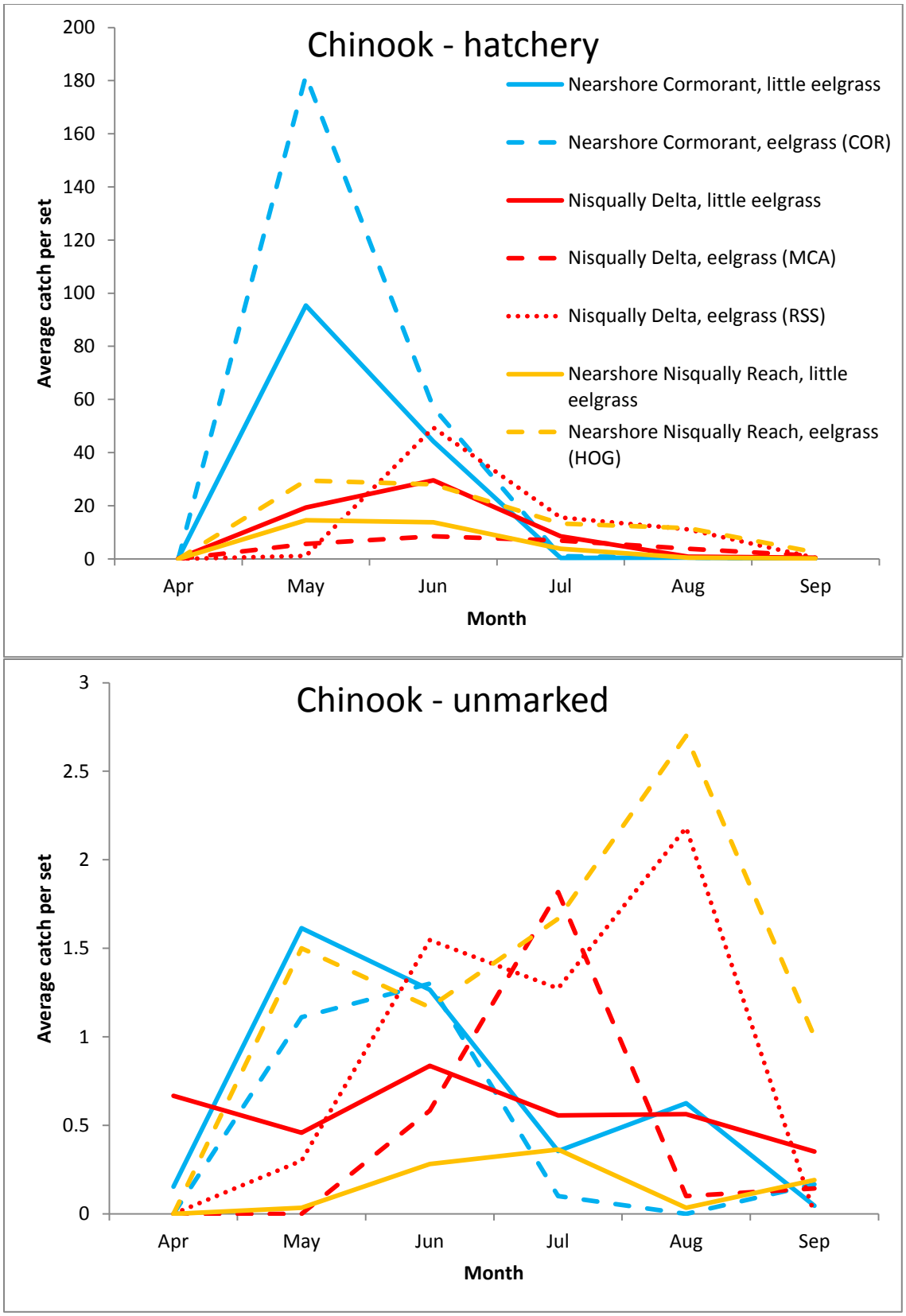

Figure 19. Average monthly lampara catch per set for hatchery and unmarked Chinook salmon by geographic area and eelgrass status, 2010-2015. Catch was averaged over sites with little eelgrass present.

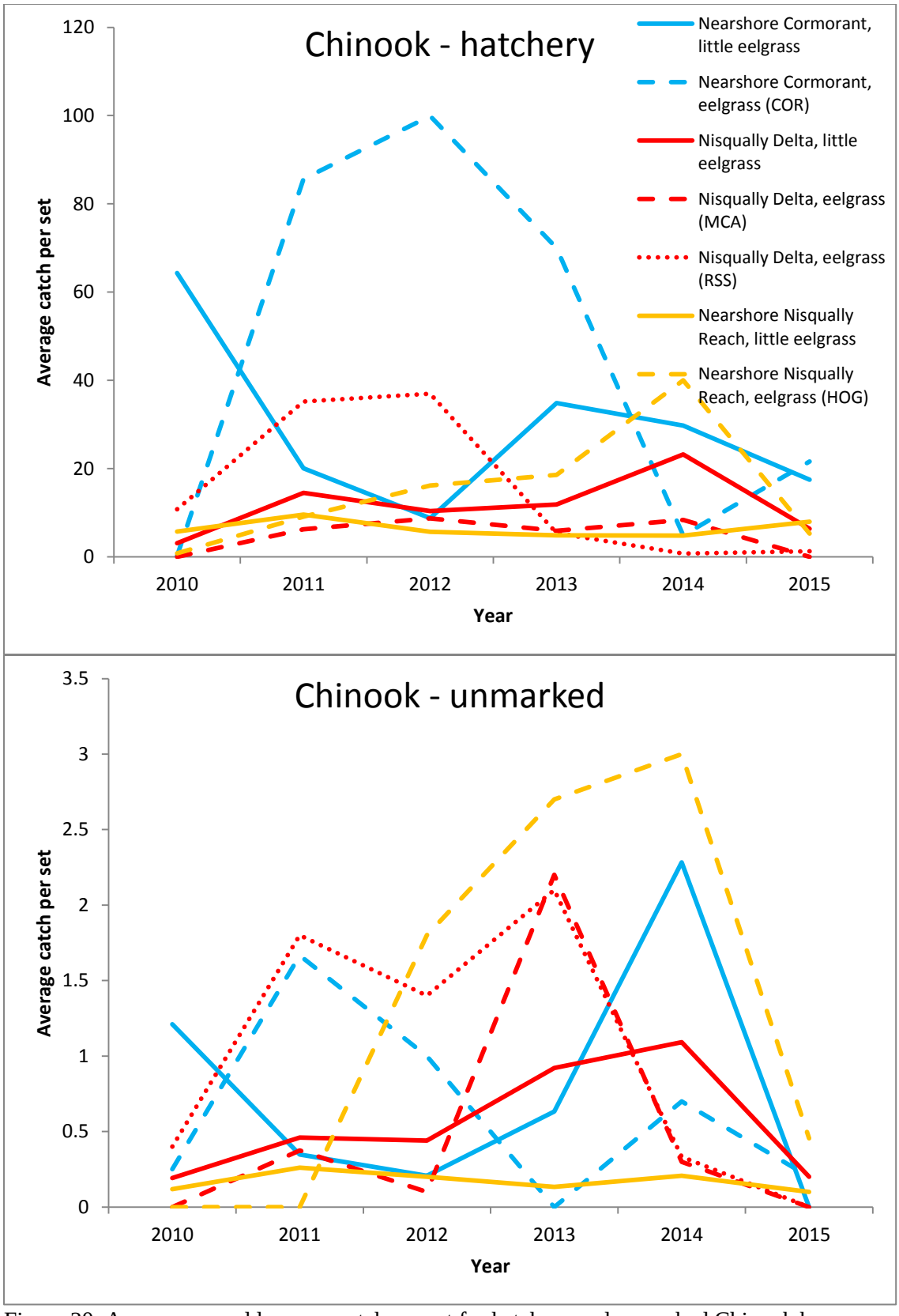

Figure 20. Average annual lampara catch per set for hatchery and unmarked Chinook by geographic area and eelgrass status. Catch was averaged over sites at which there was little eelgrass.

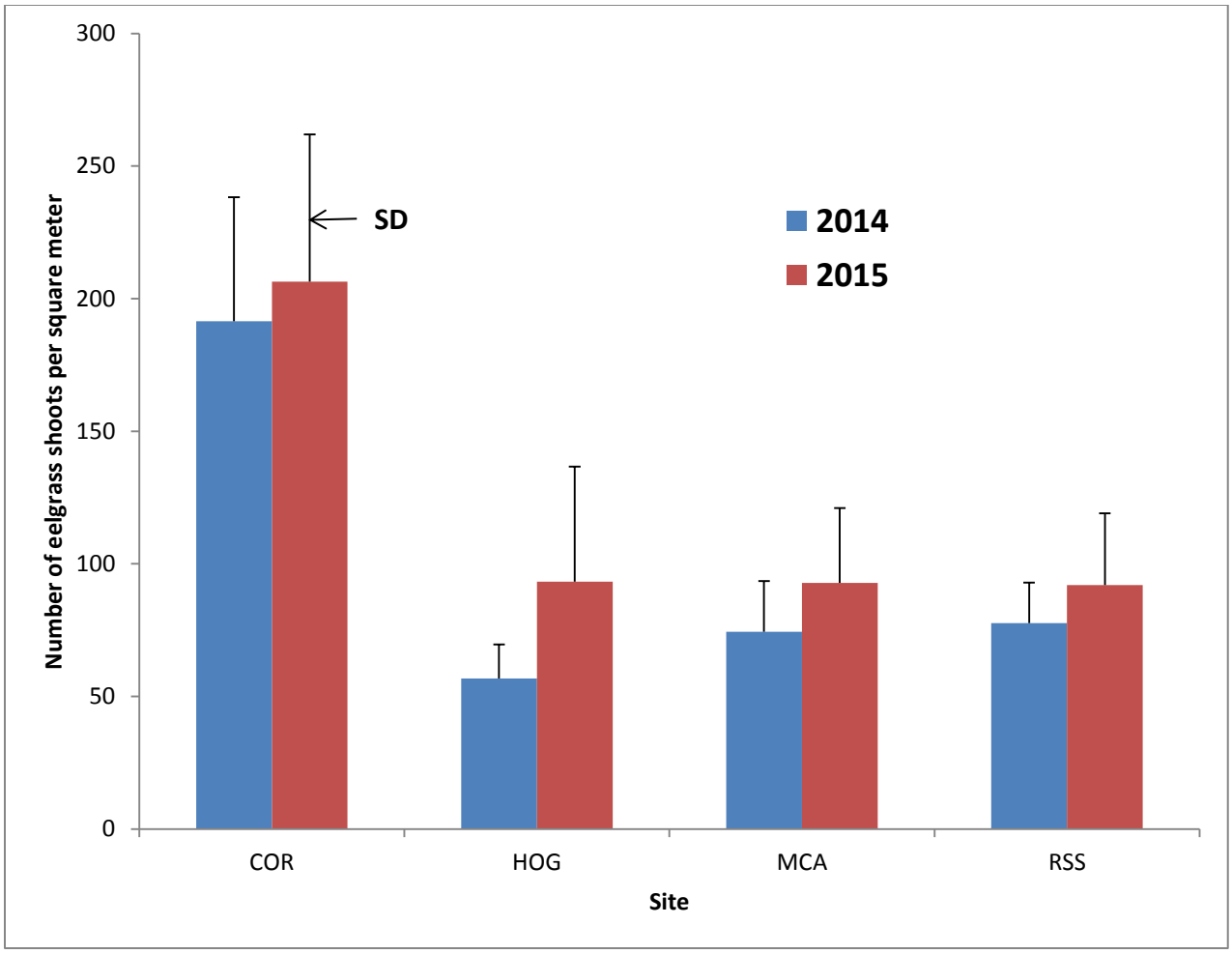

Figure 21. Mean and standard deviation (SD) of eelgrass shoot density at four eelgrass sites on 12-13 June 2014 and 16-17 June 2015.

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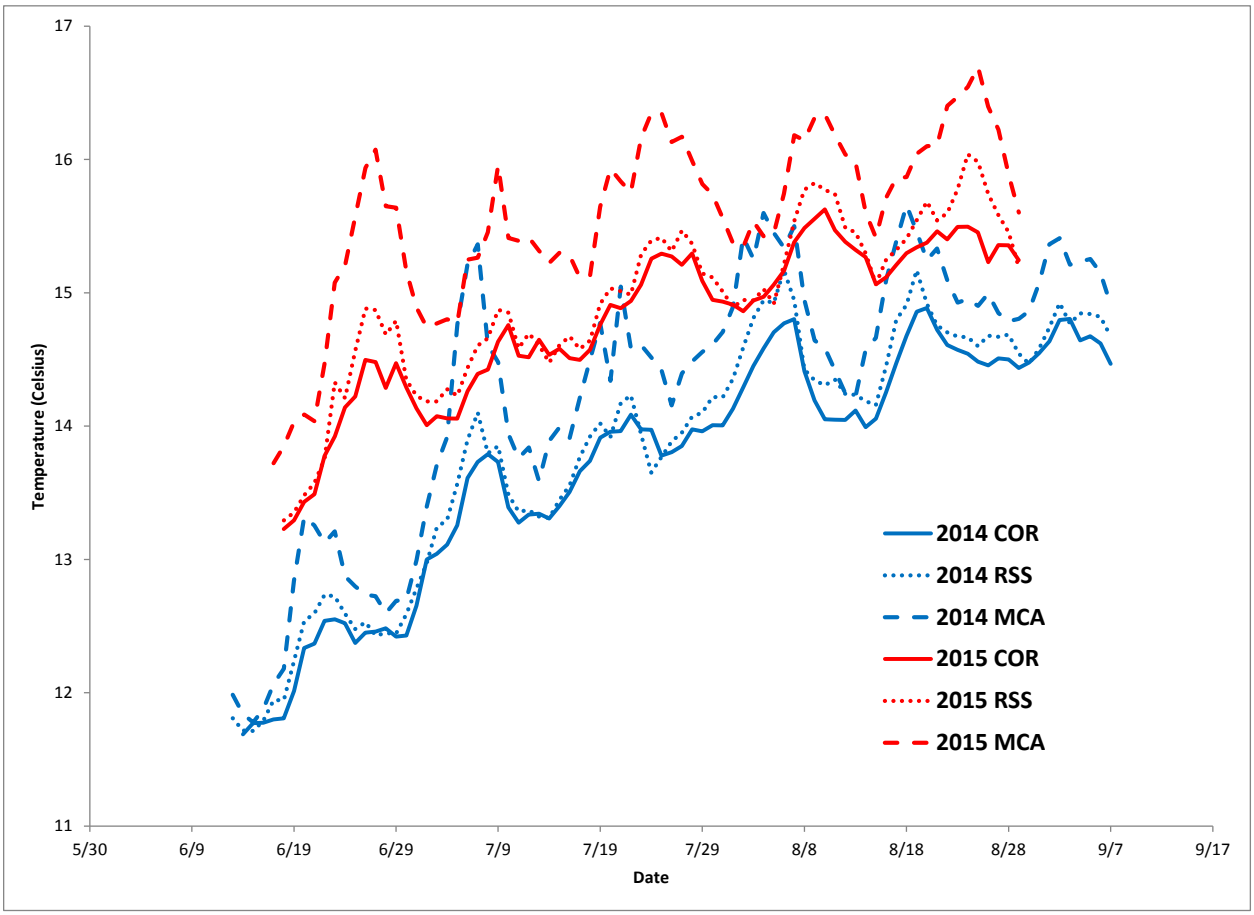

Figure 22. Daily mean temperatures at three eelgrass sites in summer 2014 and 2015.

Conclusions

Sampling of the Nisqually Reach Aquatic Reserve area of South Puget Sound showed the importance of this area for pink, chum and Chinook salmon migration and rearing. Salmon timing patterns were similar to those previously described for the area (Ellings and Hodgson 2007, Fresh et al. 1979, Duffy 2003). As has been observed in other estuaries (Aitkin 1998, Fresh 2006) Chinook and chum salmon were the most abundant salmon in the delta, with a more prolonged period of rearing there than other species. South Puget Sound nearshore areas had abundant catches of pink, chum, and Chinook salmon, while coho salmon were caught in much smaller numbers and cutthroat and steelhead trout were rarely caught. These larger trout tend to migrate quickly out of South Puget Sound (Moore et al. 2015), prefer deeper water, and may be more able to avoid the sampling gear we used for catching smaller fish.

There were geographical differences in the distribution of the catch. Most notably, the North Anderson/McNeil area had more abundant catches of pink salmon than the Nisqually Reach and Cormorant nearshore areas. The North Anderson/McNeil nearshore area also had fewer Chinook salmon (both hatchery and unmarked) in the catch than the other nearshore areas.

Salmon timing was similar among the delta and nearshore sites. Compared to the beach seine sampling, the lampara sampling tended to catch later fish and larger fish (especially for pink and chum salmon), consistent with a pattern of these fish moving away from the shallow shoreline habitats and into the deeper areas as they grow. Our unmarked Chinook catch represented at least the delta fry migrant and, to a lesser extent, fry migrant life history types as described by Fresh (2006). These types both have short freshwater residence times and move down to the estuary at a small size, with the fry migrants passing through the delta quickly while the delta fry migrants reside there longer. The growth and residence of these delta fry migrants has been examined with otolith microstructure analysis which has found Chinook salmon residence times from 10-35 days in the delta (Lind-Null et al. 2009). In addition to fry, the outmigrant trap operated by the Washington Department of Fish and Wildlife in the Nisqually River also catches Fresh's (2006) parr and yearling migrant type life history types, both of which reside in fresh water longer and enter the estuary larger. Based on a comparison of timing and size of the catches in the delta and at the outmigrant trap it appears that the parr and yearling migrant types, if present at all, were very uncommon in our catch.

Hatchery Chinook salmon presence was mostly confined to the May-June period, with smaller numbers caught mostly in the lampara sampling in July-August, while unmarked Chinook salmon were caught in much smaller numbers but over a more protracted period from February-September. Coded-wire tag analysis indicated heavy use of the area by Chinook salmon released from Nisqually River hatcheries (75% of tags read) with substantial presence of hatchery Chinook salmon released from other basins, mainly from the north, such as the Puyallup River (11%), the Duwamish River (5%) and the Snohomish River (6%). These hatchery Chinook salmon from the north were less common in the North Anderson/McNeil area of the nearshore than in the other areas sampled.

Eelgrass meadows may be especially important to Chinook salmon late in the outmigration period (July-August). This was indicated by higher catches of hatchery and unmarked Chinook salmon in eelgrass meadows compared to other delta or nearshore sites during those months. The trend of high late-season catches was particularly true for the Hogum Bar (HOG) and Red Salmon Slough (RSS) sites. Both of these meadows are extensive and are located on the outer edge of the Nisqually Delta (Hogum

Bar can be considered a northwest extension of the delta even though we included it in the Nearshore-Nisqually Reach geographic area). In contrast, the McAllister Creek (MCA) meadow is farther inshore along the creek channel, and the Cormorant Passage (COR) meadow is relatively thin and borders a steeply sloping (compared to the delta flats) cobble beach. As yet uncharacterized attributes of eelgrass meadows on the outer edge of large river deltas may be particularly well suited for juvenile Chinook salmon late in outmigration.

High water temperatures and salinities were noted in our 2015 sampling. This was also noted in nearby Puget Sound at a monitoring buoy in Carr Inlet (PSEMP 2016). Low abundance of hatchery and unmarked Chinook salmon at lampara sampling sites with eelgrass in 2015 may have been related in some way to the high summer temperatures. Lower abundances of hatchery and unmarked Chinook salmon at MCA than at RSS (and HOG) may have been related to comparatively warmer temperatures at the MCA site. Bottom temperatures measured during lampara sampling averaged (across all sampling dates in all years) 0.2^0 C warmer at HOG than at RSS but 3.3^0C warmer at MCA than at HOG.

Although basic fish timing and distribution patterns have been established through this investigation, periodically monitoring these same attributes would be valuable to track trends over time, to monitor fish population responses to habitat restoration, and to monitor changes in the use of the delta and nearshore habitat. For Chinook salmon, this will be critical information as the population adapts in response to changes in habitat recovery and stock management. Information that tracks individual fish habitat use over time and food requirements, such as otolith analysis that is being used to study the delta residence time and growth of Chinook salmon (Lind-Null and Larsen 2010) and stomach content analysis will also be a valuable complement to other fish monitoring data and will lead to a better understanding of life history of the fishes in the habitats of the Nisqually Reach Aquatic Reserve and South Puget Sound.

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