Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary, 2002

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EXECUTIVE SUMMARY

In 2002, we initiated a monthly beach seine monitoring program at seven sites in the lower Columbia River and estuary and sampled over 40,000 fish, including 2,608 chinook salmon. We also initiated a trapnet program at three replicate sites within Cathlamet Bay for detailed emergent wetland assessments of salmon-habitat linkages. Nearly 300,000 total fish and 826 chinook were sampled. At all wetland sites, we collected salmon stomachs, scales, and otoliths to evaluate salmonid growth and life history, and we sampled insects from fallout traps and benthic organisms from sediment cores to monitor prey resources.

Physical conditions throughout the lower river and estuary were measured continuously at a network of fixed monitoring stations (CORIE) and within selected marsh habitats with temperature loggers. We also used a conductivity-temperature-depth (CTD) instrument to sample physical conditions during the monthly fish surveys at all beach seine sites in the lower estuary. To assess present and historical salmon habitat opportunity, we are investigating sediment dynamics with in situ instrumentation as well as retrospective analyses and modeling, and we are developing the historical tide series to characterize change in available salmon habitat due to alteration in river hydrology. Additionally, protocols for historic habitat reconstruction and habitat change analysis are being developed in GIS for selected reaches of the estuary.

CONTENTS

INTRODUCTION

Estuaries are considered important to rearing of juvenile salmon and represent an integral component of the continuum of habitats that salmon occupy for significant periods of time. There is, however, a general lack of science-based information concerning attributes of these tidal freshwater and oligohaline transition zones needed to support juvenile salmon, particularly in the lower Columbia River and estuary. Further, recent evidence supports the concern that flow in the Columbia River significantly affects the availability of estuarine habitats, that flow is much reduced compared to historical levels, and that seasonal flow patterns are much different now than a century ago.

The long history of wetland loss in the Columbia River estuary coupled with change in flow patterns suggests that restoration of these habitats may benefit recovery of depressed salmon stocks. The development of effective restoration strategies requires empirical data for habitat-salmon linkages in the lower Columbia River and estuary. This research report documents results from our first full year=s effort to understand these linkages. Accomplishments in 2002 included

1) Continuation of a monthly beach-seine monitoring program at seven sites in the lower Columbia River and estuary since December 2001,

2) Trap-net sampling at three replicate sites for detailed emergent wetland assessments of salmon-habitat linkages near Russian Island,

3) Deployment of a physical monitoring system in the Cathlamet Bay region to complement the existing network of real-time physical monitoring stations in the Columbia River estuary (CORIE),

4) Establishment of the historical tide series needed to fully characterize change in habitat opportunity, and

5) Development of protocols for historic habitat reconstruction and habitat change analysis in a GIS, with application to selected reaches of the estuary.

Details of these research findings are summarized below.

OBJECTIVE 1: Abundance and Life history trends in Shallow Habitats Between Puget Island and the Columbia River Mouth

Site Location and Preliminary Sampling

Seven beach-seine sites have been sampled monthly since December 2001 (Figure 1). Two sites were located in the ocean-influenced zone near the mouth of the Columbia River (Clatsop Spit and West Sand Island), two sites were near the salt-freshwater interface (Pt. Ellice and Pt. Adams Beach), and three sites were in the freshwater zone at the upriver end of Cathlamet Bay (Lower Elochoman Slough, East Tenasillahe Island, and Upper Clifton Channel).

At each site, we processed catch from the beach seines in an identical manner. For non-salmonid species, we measured (nearest 1.0 mm), weighed (nearest 0.1 g), and released a representative subsample (30 individuals) of each species. All other non-salmonids were counted and released. For salmonids, we sacrificed a maximum of ten individuals of each species and size class for genetic, stomach, scale, and otolith samples. In addition, we measured and weighed 20 individuals of each salmonid species and size class prior to release and retained non-lethal tissue and scale samples for genetic and age/growth analyses, respectively.

In 2002, we collected 39 species of fishes, 3 crustaceans, and 1 amphibian (Tables 1-8). Of these, 26 species had a total abundance greater than 10. The following summary is compiled from these more abundant species. Almost 70% (40,113 individuals) of all fish sampled were threespine sticklebacks *Gasterosteus aculeatus* (Table 9). The next five most abundant fish were shiner perch *Cymatogaster aggregata*, surf smelt *Hypomesus pretiosus*, chinook salmon *Oncorhynchus tshawytscha*, starry flounder *Platichthys stellatus*, and prickly sculpin *Cottus asper*, respectively.

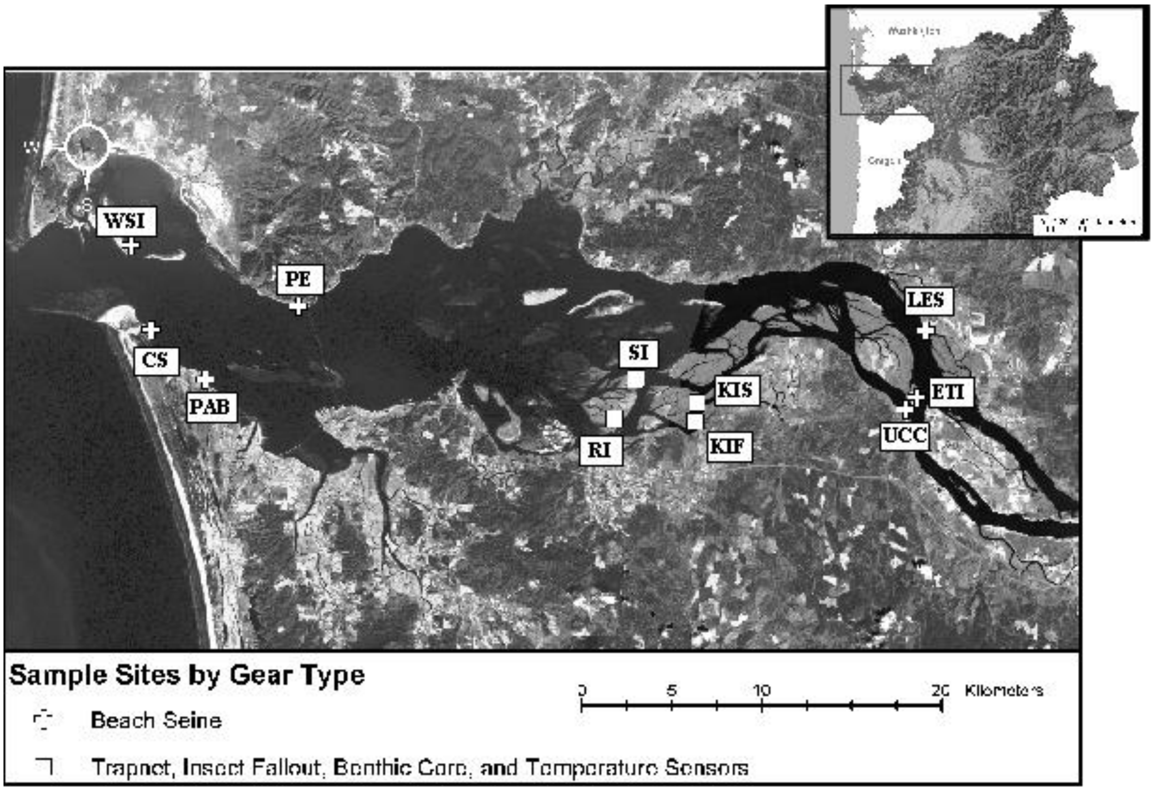


Figure 1. Lower Columbia River and estuary study site, showing beach seine and trapnet locations. Inset shows regional setting. Beach seine sites: WSI, West Sand Island; CS, Clatsop Spit; PE, Pt. Ellice; PAB, Pt. Adams Beach; LES, Lower Elochoman Slough; ETI, East Tenasillahe Island; UCC, Upper Clifton Channel. Trapnet sites; SI, Seal Island; RI, Russian Island; KIS, Karlson Island-shrub; KIF, Karlson Island-forested.

Table 1. Common and scientific names of fish species captured in beach seine and trap net samples in 2002

Common Name	Scientific Name	Common Name	Scientific Name
American shad	*Alosa sapidissima*	Peamouth	*Mylocheilus caurinus*
Banded killifish	*Fundulus diaphanus*	Prickly sculpin	*Cottus asper*
Bay pipefish	*Syngnathus leptorhynchus*	Rainbow trout (steelhead)	*Oncorhynchus mykiss*
Black crappie	*Pomoxis nigromaculatus*	River lamprey	*Lampetra ayresi*
Chinook salmon	*Oncorhynchus tshawytscha*	Saddleback gunnel	*Pholis ornata*
Chum salmon	*Oncorhynchus keta*	Sand roller	*Percopsis transmontana*
Coho salmon	*Oncorhynchus kisutch*	Sand sole	*Psettichthys melanostictus*
Common carp	*Cyprinus carpio*	Snake prickleback	*Lumpenus sagitta*
Cutthroat trout	*Oncorhynchus clarki*	Sockeye salmon	*Oncorhynchus nerka*
Dungeness crab	*Cancer magister*	Speckled dace	*Rhinichthys osculus*
English sole	*Parophrys vetulus*	Speckled sanddab	*Citharichthys stigmaeus*
Eulachon	*Thaleichthys pacificus*	Starry flounder	*Platichthys stellatus*
Largemouth bass	*Micropterus salmoides*	Surf smelt	*Hypomesus pretiosus*
Largescale sucker	*Catostomus macrocheilus*	Threespine stickleback	*Gasterosteus aculeatus*
Longfin smelt	*Spirinchus thaleichthys*	Topsmelt	*Atherinops affinis*
Northern anchovy	*Engraulis mordax*	Walleye surfperch	*Stizostedion vitreum*
Northern pikeminnow	*Ptychocheilus oregonensis*	Whitebait smelt	*Allosmerus elongatus*
Pacific herring	*Clupea harengus pallasi*	Yellow shiner perch	*Cymatogaster aggregata*
Pacific lamprey	*Lampetra tridentata*		
Pacific sand lance	*Ammodytes hexapterus*		
Pacific sanddab	*Citharichthys sordidus*		
Pacific staghorn sculpin	*Leptocottus armatus*		
Pacific tomcod	*Microgadus proximus*		

Table 2. Abundance of species sampled by beach seine at West Sand Island during 2002.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad							3	7	2		1			13
Chinook salmon	1	1	6	2	1	13	20	51	9	1	5	4		114
Chum salmon				1	111	22								134
Dungeness crab	1	1			2	1	5	11	2	4	196	7		230
English sole	7	1			19		4							31
Larval smelt	9		14											23
Northern anchovy											2	1		3
Pacific herring								12			319			331
Pacific sand lance								3	1		8	138		150
Pacific sanddab				1	10									11
Pacific sardine											413			413
Pacific staghorn sculpin	2	4	3	7	1			1		1		3	2	24
Prickly sculpin						1								1
Rainbow trout (steelhead)	1					1								2
Sand sole	8	37	7	4		3		2	3	10	10	4		88
Snake prickleback												1		1
Starry flounder	1	3			6		1			2	9	9		31
Surf smelt				1	4	24	604	825	20	2	580	23		2,083
Threespine stickleback	259		9	4	3	5	14		1	7	2	14		318
Unid. Pleuronectidae	14	5	18											37
Unidentified fish						1								1
Unidentified juv. smelt	1			1										2
Unidentified sanddab	20													20
Yellow shiner perch									1					1
Total	324	52	57	21	157	71	651	912	39	27	1,545	204	2	4,062

Table 3. Abundance of species sampled by beach seine at Clatsop Spit during 2002. ND; Not done.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad											1			1
Bay pipefish										1	1			2
Chinook salmon			1	2	4	30	22	291	38	8	3			399
Coho salmon						4				8				12
Dungeness crab	6		7	6	10	2	2			129	101			263
English sole		1		5	3				2					11
Larval smelt					13									13
Northern anchovy											4			4
Pacific herring						1	1			6	211			219
Pacific Sardine											5			5
Pacific staghorn sculpin			4	1	2					8	2			17
Redtail surfperch											3			3
Saddleback gunnel											1			1
Sand sole	4	4	7		9				12	39	47		9	131
Starry flounder		1	4	2		1			2	2	1		1	14
Surf smelt	1				3	75	339	1	5	60	242			726
Threespine stickleback	30	179	49	6	14	28	63	7	79	17	8		16	496
Unid. Pleuronectidae			14											14
Walleye surf perch											86			86
Whitebait smelt			1							2				3
Yellow shiner perch								2		1				3
Total	41	185	87	22	58	141	427	301	138	281	716	ND	26	2,423

Table 4. Abundance of species sampled by beach seine at Pt. Ellice during 2002.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad			7						1		1	3	17	29
Chinook salmon			17	4	16	35	34	58	14	3	7	3		191
Chum salmon			5	2	419	4								430
Coho salmon						1					1			2
Dungeness crab					3				1		1	12	52	69
English sole			2	117	44	9								172
Eulachon			1											1
Longfin smelt			1										7	8
Pacific herring												2		2
Pacific sanddab				1										1
Pacific staghorn sculpin			9	7	4	25	19	11	20	9	4	1	15	124
Prickly sculpin			2											2
Northern Anchovey												2		2
Saddleback gunnel									2			1		3
Sand sole			1											1
Speckled sanddab					3									3
Starry flounder			7	15	3	25	11	17	60	58	49	144	46	435
Surf smelt						32		5	7	9	36	3	1	93
Threespine stickleback			164	513	84	321	881	870	525	47	1	23		3,429
Tomcod												3	26	29
Top smelt												2		2
Unid. Pleuronectidae			7											7
Unidentified juv. smelt						7								7
Yellow shiner perch						2	61	128	212	58	74	160	96	791
Total	ND	ND	223	659	576	461	1,006	1,089	842	184	174	359	260	5,833

Table 5. Abundance of species sampled by beach seine at Pt Adams Beach during 2002.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad		3						41				12	22	78
Chinook salmon			3	15	3	166	30	54	57	1	6	7	6	348
Chum salmon				1	2	1								4
Coho salmon						19							1	20
Dungeness crab									26		4	1	9	40
English sole			2	24	15		1						1	43
Longfin smelt	1													1
Pacific herring					1			55	17					73
Pacific staghorn sculpin	1		1			11	16	21	38	4			1	93
Purple shore crab									1					1
Rainbow trout (steelhead)							2						1	3
Saddleback gunnel								1	1	1	1			4
Sand sole			6											6
Snake prickleback									5					5
Starry flounder	6		4	3	9	3	39	15	28	18	17	23	25	190
Surf smelt				1	121	99	71	1	5	1		3	3	305
Threespine stickleback	826	1,054	14	37	10	102	308	767	1,023	41	32	120	861	5,195
Tomcod									3				2	5
Unid. Pleuronectidae			11											11
Unidentified fish					1									1
Unidentified juv. smelt		1												1
Yellow shiner perch							18	59	3,521	269	58	11	124	4,060
Total	834	1,058	41	81	162	401	485	1,014	4,725	335	118	177	1,056	10,487

Table 6. Abundance of species sampled by beach seine at Lower Elochoman Slough during 2002.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad		1				1	4		39	32	3			80
Banded killifish								2	1					3
Black crappie													1	1
Chinook salmon			9	38	26	218	113	103	72	15	11	2	1	608
Chum salmon				6		14								20
Coho salmon						90	3							93
Crayfish							5				1			6
Cutthroat trout										2				2
Peamouth		17					4	1	44	12	15	2		95
Prickly sculpin		185	1	1	1	1			1	1				191
Starry flounder		1	5	6	1	2	3	5		2	7	8	6	46
Threespine stickleback	239	193	181	696	808	885	731	1,048	4,552	3,796	47	251	117	13,544
Total	239	397	196	747	836	1211	863	1,159	4,709	3,860	84	263	125	14,689

Table 7. Abundance of species sampled by beach seine at East Tenasillahe Island during 2002.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad						78	1		6		15	1		101
Chinook salmon	1		7	2	180	98	10	47	18	10	3	8	8	392
Chum salmon				1		1								2
Coho salmon						40								40
Cutthroat trout						1								1
Largemouth bass												1		1
Northern pikeminnow							1	2						3
Peamouth		1					2	1	2					6
Prickly sculpin		34		1										35
Rainbow trout						3								3
Starry flounder	3	1	5	12	7	3			2	6	6	10	9	64
Threespine stickleback	1	10	6		756	205	594	532	221	7	37	268	5	2,642
Total	5	46	18	16	943	429	608	582	249	23	61	288	22	3,290

Table 8. Abundance of species sampled by beach seine at Upper Clifton Channel during 2002.

Species (common name)	Dec 01	Jan 02	Feb 02	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02	Total
American shad	1	1			1	6	25		36	70	55	2	4	201
Banded killifish							1	4	1					6
Black crappie											2		1	3
Chinook salmon	2	9	11	40	109	130	106	99	13	8	9	14	6	556
Coho salmon		1				1								2
Common carp									2	2				4
Crayfish												1		1
Cutthroat trout						1								1
Eulachon			3	1										4
Largemouth bass										2		1		3
Largescale sucker		2				6	6	3	19					36
Longfin smelt			1											1
Northern pikeminnow								19	1	3				23
Pacific staghorn sculpin						1								1
Peamouth	1	80			2	18	37	33	62	200	9	3	1	446
Prickly sculpin	96	131					2	25	262	11	6	2	1	536
Rainbow trout (steelhead)						2								2
Sand roller		2								1				3
Starry flounder	1	1	4	14	7	1	4	21	248	9	11	11	15	347
Tadpole													2	2
Threespine stickleback	60	133	235	265	1,922	251	1,531	6579	2,125	698	14	29	647	14,4
Yellow shiner perch									8					8
Total	161	360	254	320	2,041	417	1,712	6783	2,777	1,004	106	63	677	16,6

Table 9. Summary of abundance of 26 of the most common species sampled by beach seine parsed by region.

Species (common name)	Lower estuary		Upper estuary		Freshwater				Percent of
	WSI	CS	PE	PAB	LES	ETI	UCC	Total	Total
American shad	13	1	29	78	80	101	201	503	0.88
Chinook salmon	114	399	191	348	608	392	556	2,608	4.55
Chum salmon	134		430	4	20	2		590	1.03
Coho salmon		12	2	20	93	40	2	169	0.29
Dungeness crab	230	263	69	40				602	1.05
English sole	31	11	172	43				257	0.45
Largescale sucker							36	36	0.06
Larval smelt	23	13						36	0.06
Northern pikeminnow						3	23	26	0.05
Pacific herring	331	219	2	73				625	1.09
Pacific sand lance	150							150	0.26
Pacific sanddab	11		1					12	0.02
Pacific Sardine	413	5						418	0.73
Pacific staghorn sculpin	24	17	124	93			1	259	0.45
Peamouth					95	6	446	547	0.95
Prickly sculpin	1		2		191	35	536	765	1.33
Sand sole	88	131	1	6				226	0.39
Starry flounder	31	14	435	190	46	64	347	1,127	1.96
Surf smelt	2,083	726	93	305				3,207	5.59
Threespine stickleback	318	496	3,429	5,195	13,544	2,642	14,489	40,113	69.93
Tomcod			29	5				34	0.06
Unid. Pleuronectidae	37	14	7	11				69	0.12
Unidentified juv. smelt	2		7	1				10	0.02
Unidentified sanddab	20							20	0.03
Walleye surfperch		86						86	0.15
Yellow shiner perch	1	3	791	4,060			8	4,863	8.48

Fish spatial distributions followed four general patterns (Table 9): lower estuarine species (5); estuarine species (10); freshwater species (4); and euryhaline or anadromous species (6). We assume salinity tolerance to be a major determinant of these spatial patterns. Temporal trends included resident, seasonal, and episodic patterns of abundance.

Chinook salmon were found during all months of the year. We sampled 2,608 chinook, and, based on size frequency histograms, subyearling fish dominated the catch (Figure 2). Trends of abundance varied among river sections. Fish at upriver sites were abundant from March through August, with peak catches in April or May. In the estuarine mixing zone, chinook salmon were most abundant May through August, with peaks in May (PAB) or July (other stations). Mean size of chinook generally increased with time, with the exception of increased mean and variance in some April or May samples due to the presence of yearling fish (Figure 3). However, the size distribution varied between estuarine and freshwater sites. After July, estuarine fish tended to be larger than upriver fish, though no formal comparative analysis has yet been performed.

In contrast to chinook, coho *Oncorhynchus kisutch*, and chum *O. keta* salmon abundances were restricted both spatially and temporally. We sampled 169 coho from every station except WSI, but 79% of these fish were caught in the tidal freshwater region (LES and ETI), and all but a few were sampled in May (Figure 4). Mean size per station in May ranged from 138.8 to 144.2 mm. In contrast, we sampled 590 chum salmon, but 95% were captured at the two Washington stations in the estuarine mixing zone (WSI and PE). Chum salmon were present from February to May (Figure 5), with peak abundance in April (90% of total). Mean size of chum during the April outmigration ranged from 44.5 to 49.7 mm.

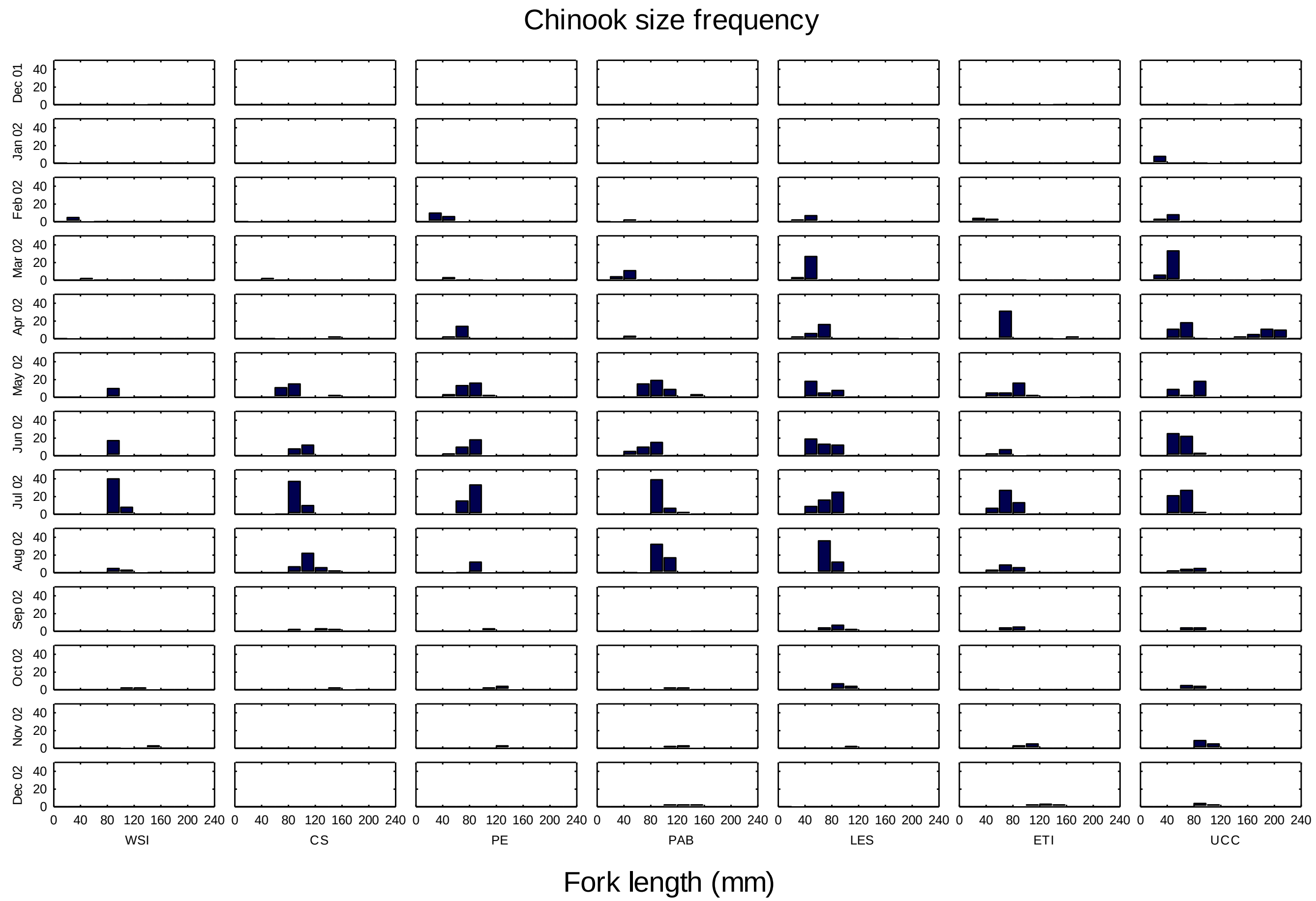


Figure 2. Monthly size frequency histograms reported as catch per unit effort (CPUE) of chinook salmon sampled with beach seines at lower estuarine (CS, USS), upper estuarine (PAB, PE), and freshwater stations (UCC, LES, ETI) during 2002.

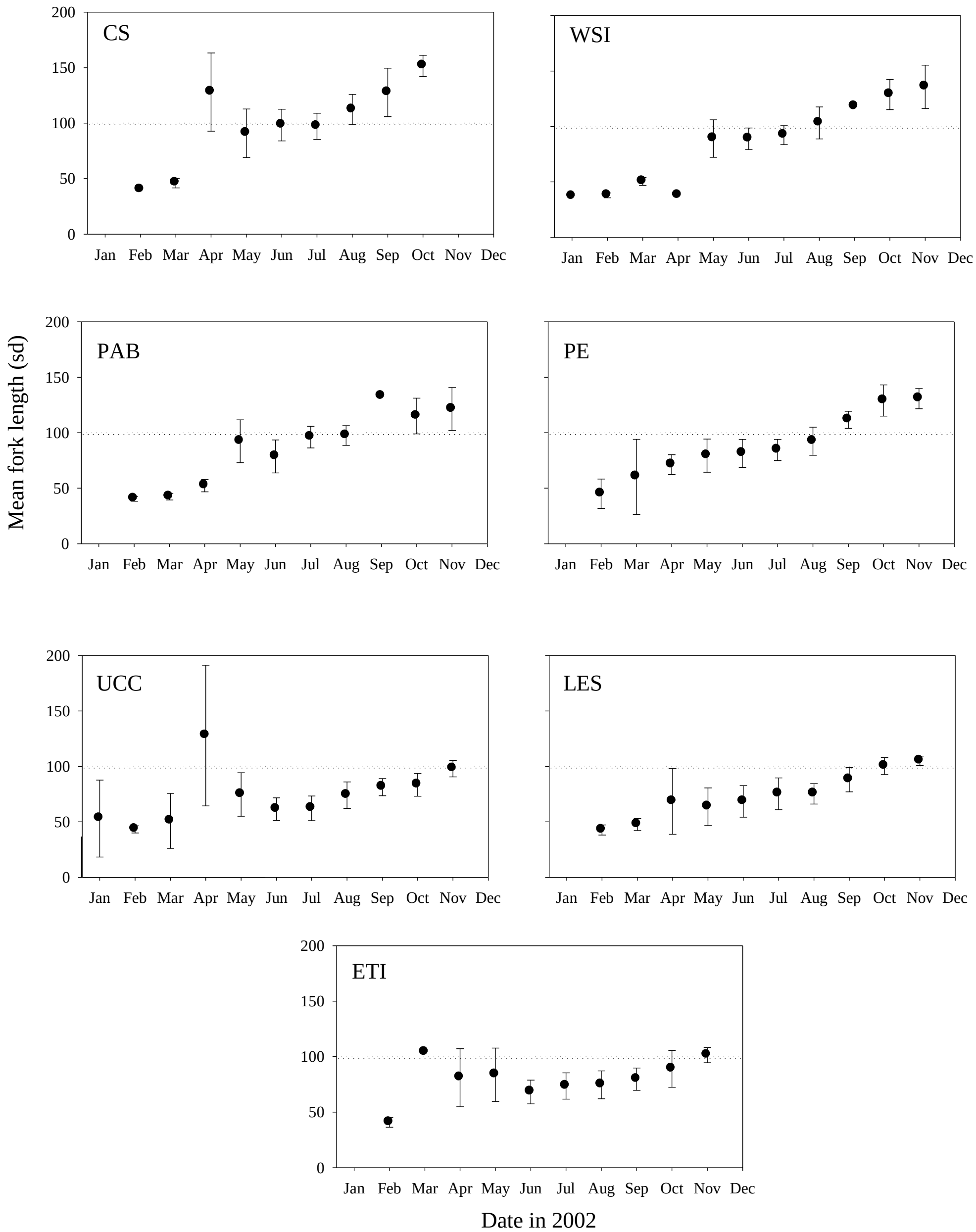


Figure 3. Time series of mean fork length (±SD) of chinook salmon sampled with beach seines at lower estuarine (CS, USS), upper estuarine (PAB, PE), and freshwater stations (UCC, LES, ETI) during 2002. Dashed line at 100 mm is for comparative purposes.

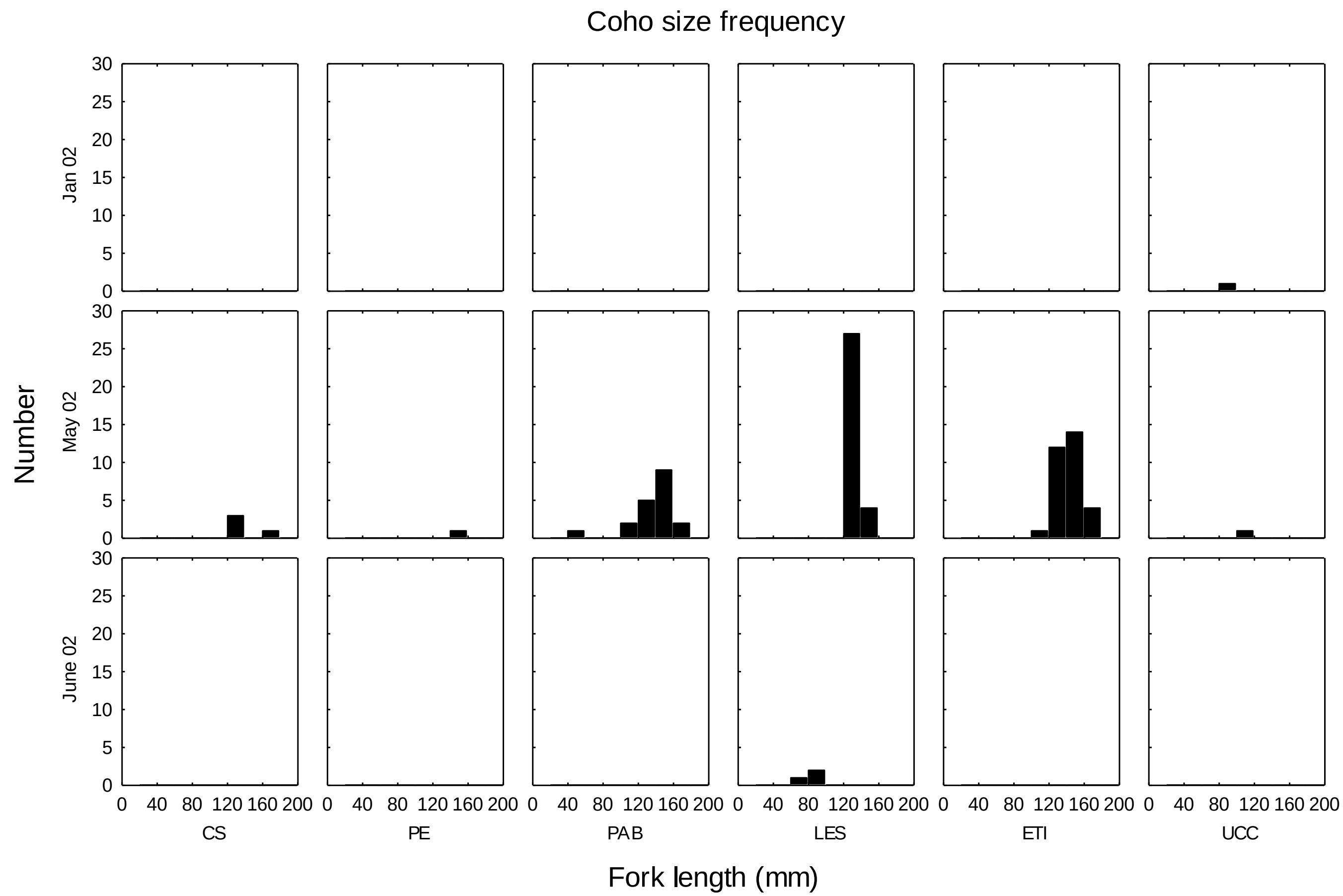


Figure 4. Monthly size frequency histograms of coho salmon sampled with beach seines at lower estuarine (CS), upper estuarine (PAB, PE), and freshwater stations (UCC, LES, ETI) during 2002. Only months when coho salmon were sampled are shown.

Physical Characteristics

During regular beach-seine operations, we profiled the water column with a Sea Bird 19 plus CTD equipped with a Turner Designs SCUFA optical backscatterance sensor and a Wet Labs Wet Star fluorometer.[1] Four casts were made perpendicular to shore in a transect extending from the beach seine site (2-5 m depth) out to the channel 250-300 m from shore. These data are used to evaluate vertical and horizontal gradients of salinity, temperature, chlorophyll a, and turbidity that may influence fish abundance. Data have been collected from November 2002 to the present.

To date, we have found clear distinctions between patterns of physical gradients between sites and times. Data for the estuarine sites during November and December 2002 are presented in Figures 6-7. Within a site, water masses are generally isothermal with both horizontal and vertical temperature gradients generally less than 2ºC. Exceptions occur when local heating warms shallow inshore stations or during intrusions of ocean water in the estuary. Salinity patterns varied widely, depending on seasonal factors and time of the tide we sampled. Very intense vertical gradients of salinity (> 5 psu m^{-1}) were sometimes observed at nearshore sites, while at the surface, maximum horizontal gradients were generally less than 4 psu over a 250-m transect. Salt was not detected at the three upriver sites. Chlorophyll concentration was below 4 mg m^{-3} in the lower estuary during December. Turbidity patterns were quite variable, with strong vertical, horizontal, and between-site gradients apparent.

1 Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

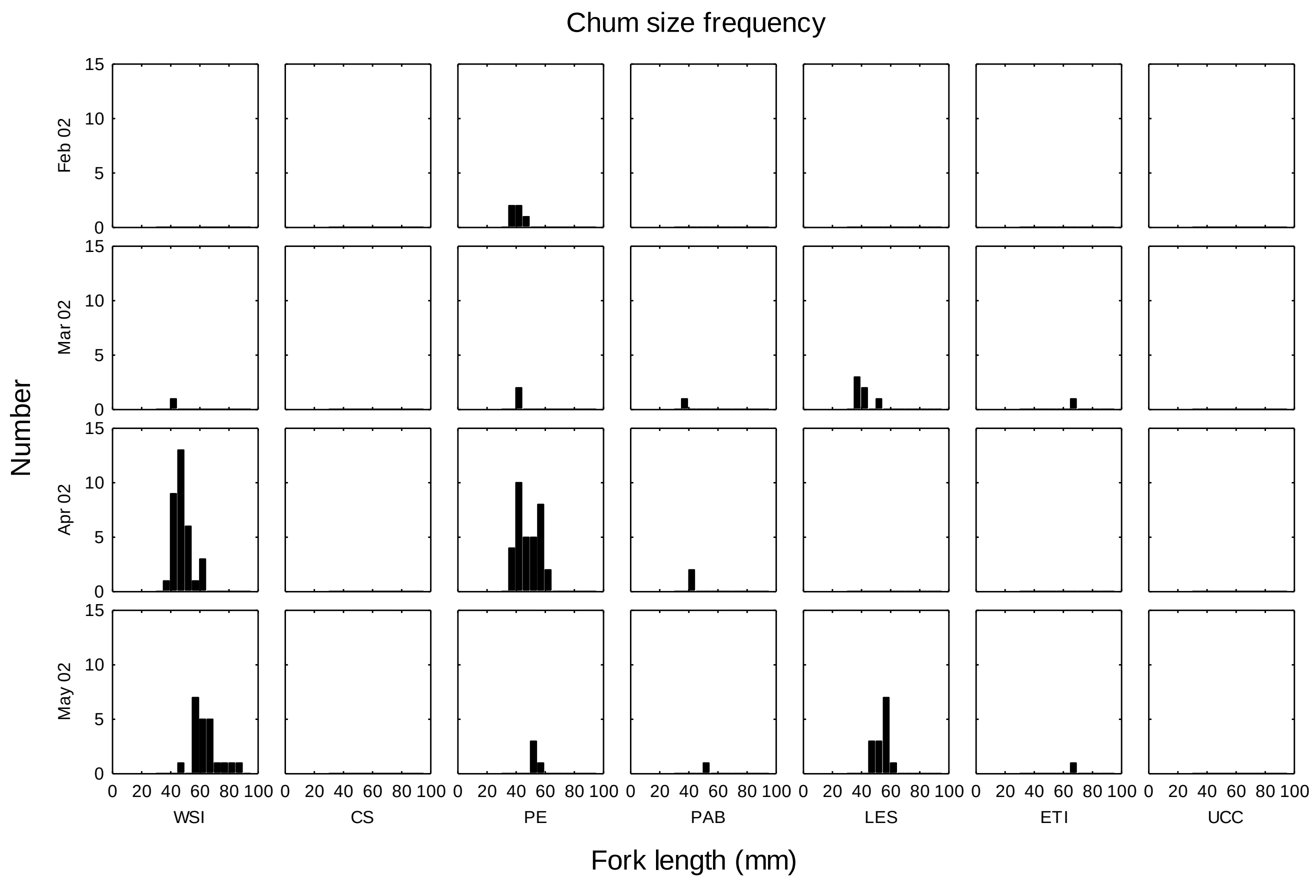


Figure 5. Monthly size frequency histograms of chum salmon sampled with beach seines at lower estuarine (CS, USS), upper estuarine (PAB, PE), and freshwater stations (UCC, LES, ETI) during 2002. Only months when chum salmon were sampled are shown.

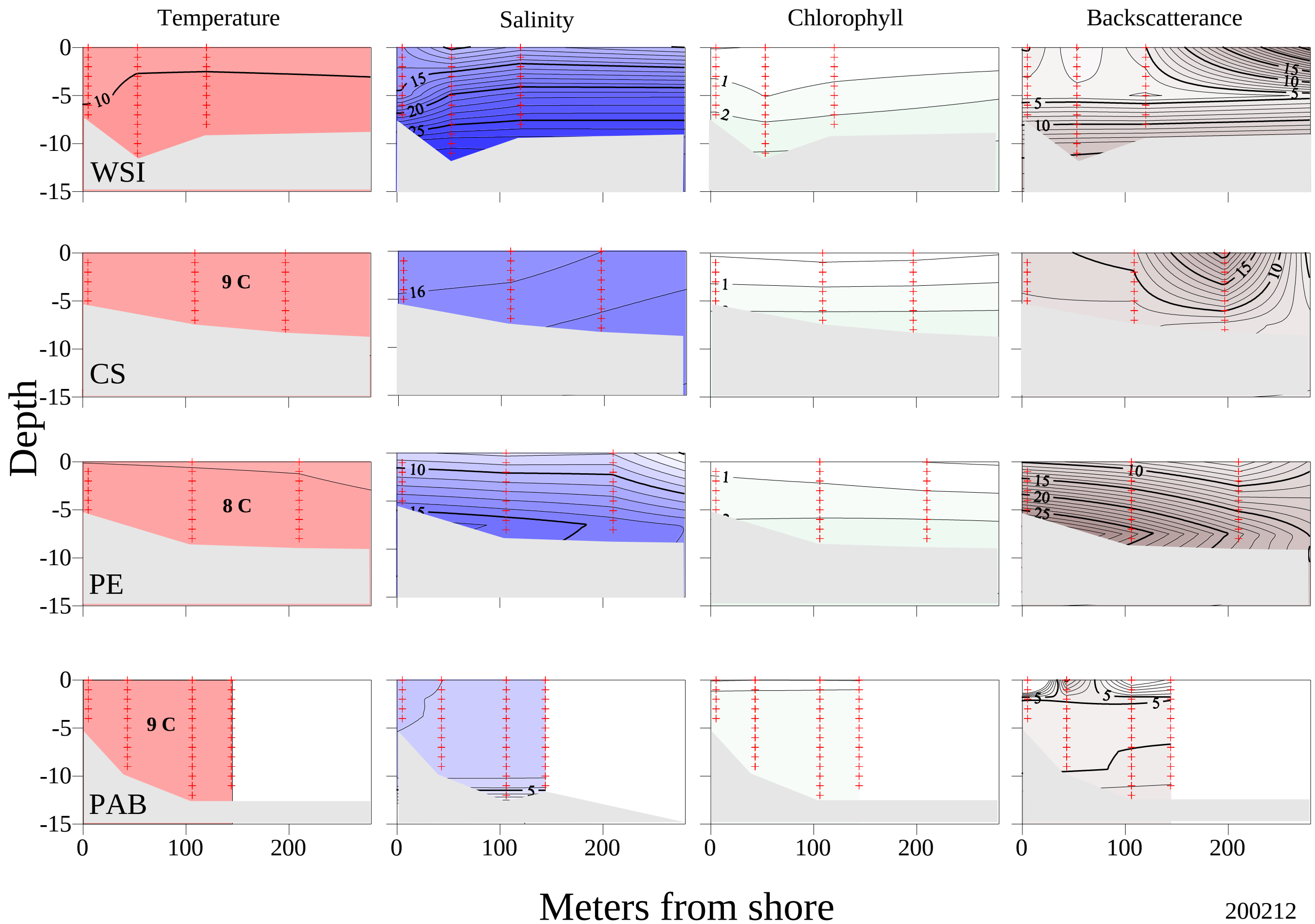


Figure 6. Cross shore transects of temperature, salinity, chlorophyll a, and turbidity at the estuarine stations during December 2002.

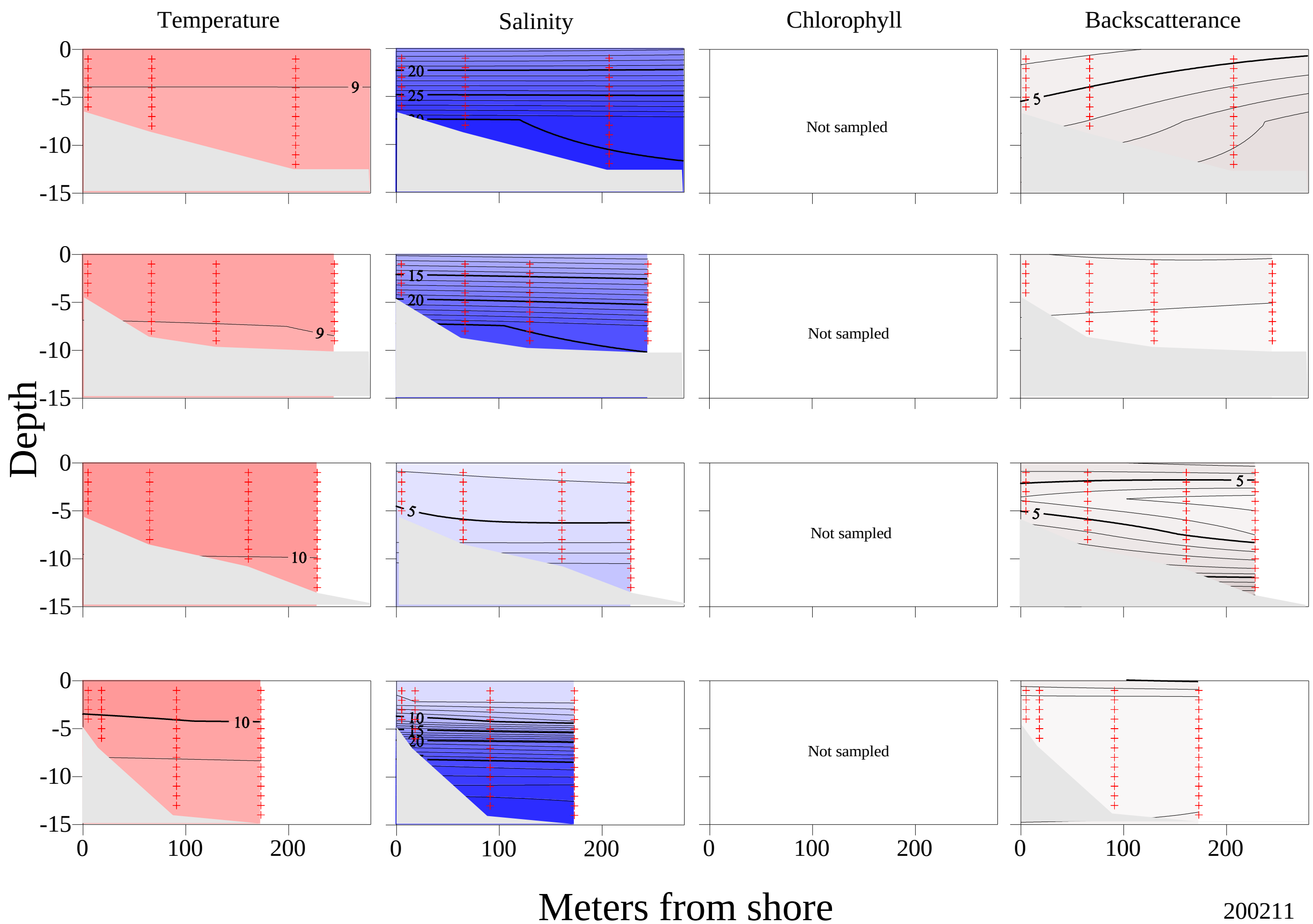


Figure 7. Cross shore transects of temperature, salinity, and turbidity at the estuarine stations during November 2002.

Otolith and Scale Samples

We saved 548 chinook, 54 chum, and 47 coho salmon for detailed analysis of otoliths and scales. An additional 386, 13, and 9 fin clip and scale samples were collected from released chinook, chum, and coho salmon, respectively. These samples are planned to be analyzed in future years.

Time Series of Juvenile Salmon Abundance

We developed and tested a prototype light trap for use in time series monitoring of juvenile fishes. Testing in fish raceways revealed that salmonids entered and were retained in both lighted and unlighted traps, probably reflecting a response to crowding. During June, we deployed traps for several weeks in the Hammond and East Mooring Basins.

The light traps were sampled daily, and they effectively sampled fish of several common species. However, we captured few salmonids; they did not appear to respond as did other fishes. While potentially promising, we concluded that laboratory testing of salmonid response to variations of light intensity and frequency is needed before we deploy light traps in the field.

Trophic Relationships

We saved 548 chinook, 54 chum, and 47 coho salmon for stomach content analysis. These samples are planned to be analyzed in future years.

OBJECTIVE 2: Salmonid use and Performance in Emergent and Forested Wetlands

Sampling Sites in Cathlamet Bay

We used trapnets to sample juvenile salmonids and other fish species in three areas of Cathlamet Bay, Oregon (Fig. 1). Two of the sampling areas are intertidal emergent marshes, one on Russian Island (RI) and the other on Seal Island (SI). The third sample area is Karlson Island, where two types of tidal channels are represented, forested and shrub. The forested site (KIF) has large woody debris and mature conifers along the banks, whereas the shrub site (KIS) has lesser amounts of small woody debris and is lined with deciduous bushes and shrubs.

The trapnets consist of two wing nets (0.75-in mesh) connected to a tunnel that leads to a live box (0.25-in mesh). The tunnel and live box are placed in the channel thalweg, and the two wing nets are set to opposite channel banks. The wing nets direct outmigrating fish into the live box. The trapnet is set at high tide, and when the tide recedes all fishes that entered the marsh channel during the flood period are captured. Fish samples were treated as described above for beach seines. We sampled fish monthly from March through August at all three areas and continued sampling during October/November at Russian Island to verify whether juvenile salmonids vacate marsh habitats by fall.

In 2002, among all three sample areas combined, we captured 20 fish species totaling 299,880 individuals (Tables 10-12). At all sites, threespine stickleback was by far the dominant species throughout the year. Sticklebacks accounted for 99.5% of the Russian and Seal Island total catch, and 94% of the shrub-channel and 98% of the forested-channel catch at Karlson Island. Other commonly represented species in the 2002 catches were banded killifish *Fundulus diaphanus*, peamouth *Myocheilus caurinus*, prickly sculpin, and chinook salmon.

Our results indicate that juvenile salmon rear in shallow marsh habitats of the Columbia River during spring and summer months. Salmonid species composition in the marshes varied monthly; chum and coho salmon appeared in all areas during the spring (March-May), and chinook salmon were common throughout the sampling season.

Table10. Abundance of species sampled by trapnet at Russian Island during 2002. N, North site; S, South site.

Species (common name)	March		April		May		June		July		August		October		November		Total
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	
American shad			1	3		7						2					13
Banded killifish	3		1	1	2	14							38	145	19	39	262
Chinook salmon	2	4	17	22	11	83	7	29	26	62	1	12		1			277
Chum salmon			7	37		1											45
Common carp												2					2
Peamouth			3		1	3	1	2		1		2	6	87	1	13	120
Starry flounder				1													1
Threespine stickleback	4,373	3,290	9,382	14,165	5,874	17,674	19,516	35,335	8,432	14,793	2,830	13,526	1,064	7,063	5,075	10,122	172,514
Unidentified lampry								1									1
Yellow shiner perch														184			184
Total	4,378	3,294	9,411	14,229	5,888	17,782	19,524	35,367	8,458	14,856	2,831	13,544	1,108	7,480	5,095	10,174	173,419

Table 11. Abundance of species sampled by trapnet at Seal Island during 2002. N, North site; S, South site.

Species (common name)	March		April		May		June		July		August		Total
	N	S	N	S	N	S	N	S	N	S	N	S	
Banded killifish			63	6	45	2	16	1	1		2		136
Chinook salmon			28	20	90	86	36	16	31	8	3	1	319
Chum salmon			9	5		1							15
Coho salmon				2		1							3
Cutthroat trout											1		1
Common carp											2		2
Peamouth			2	1	1	2	1	1	1				9
Threespine stickleback			20,908	14,819	17,845	8,673	16,864	8,577	11,150	7,330	783	951	107,900
Prickly sculpin			1										1
Total	ND	ND	21,011	14,853	17,981	8,765	16,917	8,595	11,183	7,338	791	952	108,386

Table 12. Abundance of species sampled by trapnet at Russian Island during 2002. F, Forested site; Sh, Shrub site.

Species	March		April #1		April #2		May #1		May #2		June		July		August		
(common name)	F	Sh	F	Sh	F	Sh	F	Sh	F	Sh	F	Sh	F	Sh	F	Sh	Total
American shad				1											7	82	90
Banded killifish											2	1	1	1		1	6
unidentified salmon						12											12
Chinook salmon	7				6	23	25	84		19	18	20	2	6	1	2	230
Chum salmon	1			2	2	9	1										15
Coho salmon				3	3	2						2					10
Cutthroat trout						1											1
Steelhead						3											3
Common carp																1	1
Peamouth	2			1	1	1	1	1	1	2	2		6	43	21	51	133
Starry flounder											1	8					9
Threespine stickleback	3922			957			569					1235	183		722	1199	
Prickly sculpin				15		8		20		30	2	28	2	21	9	88	223
Unidentified sculpin	6			4	4	26	3	5	3		1	7				4	63
Largescale sucker				1	1	1		2						5		1	11
Black crappie																2	2
Sunfish						2											2
Largemouth bass																1	1
Total		ND															18075

Although the catch totals in Tables 10-12 accurately depict species composition and relative abundances at each site, between-channel comparisons of fish abundance are not yet possible since the channel areas and volumes sampled above each trapnet are not identical. During 2003-04, we will use aerial imagery, remote sensing, and other available resources to estimate channel areas and volumes and to standardize fish counts at each trap site.

Preliminary length-frequency analyses for chinook salmon show that marsh habitats are utilized primarily by subyearling migrants (Fig. 8). The time series of mean lengths reveal no obvious growth trends for chinook salmon during the rearing season within any of the sampling areas. However, the mean fork lengths of chinook were generally smaller in the Karlson Island shrub and forested sites than in the emergent marshes, particularly during March-May. Forthcoming scale and otolith analyses will provide additional details about the life histories and growth of juvenile salmon inside and outside of shallow marsh habitats.

Availability and Utilization of Invertebrate Prey Resources

During 2002, we examined the habitat-specific utilization of prey resources by juvenile salmon by monitoring the abundance and species composition of prey from three distinct wetland types in Cathlamet Bay. Fallout traps and benthic cores were used to sample potentially available insect and benthic invertebrate prey. The trapnet samples described above were used to obtain samples for diet composition analysis and fullness.

Insect fallout traps measure the quantity and diversity of wetland insects falling on the surface of waters and are an indication of potentially available prey for juvenile salmon. The traps consist of a plastic box (51.7 cm × 35.8 cm × 14 cm) filled approximately halfway with soapy water. The box rests on a stand of PVC pipe that is inserted into the substrate, and is then surrounded with three bamboo poles and a PVC pipe to prevent the trap from floating away. The trap is allowed to float vertically with the tides. Five insect fallout traps were placed along each study channel within 100 meters of the mouth of the channel. All the traps were set on the same day and collected after 48 hours. Insects were identified to the lowest taxonomic level feasible under a dissection microscope.

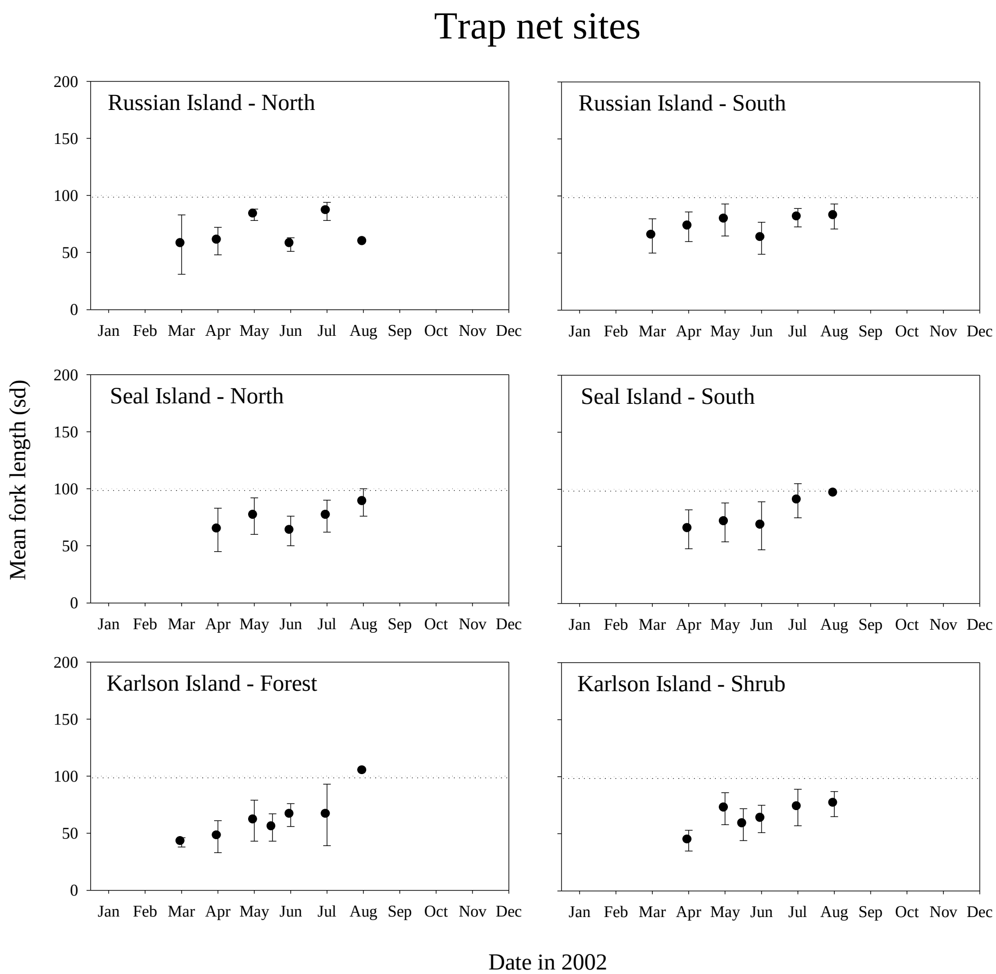


Figure 8. Time series of mean fork length (±SD) of chinook salmon sampled with trapnets at 6 freshwater stations during 2002. Dashed line at 100 mm is for comparative purposes.

At each of the fallout trap sites, a PVC benthic core (20 cm^3 volume) was used to sample macroinvertebrate fauna. Samples were collected along the tidal channel gradient at low tide. Organisms were identified under a dissection microscope to the lowest taxonomic level feasible. Thirty fallout traps and 30 benthic cores were collected each month from March to August 2002. There were also an additional 10 benthic cores taken at the Russian Island sites during fish sampling in October. The number of cores collected in 2002 totaled 190, and the number of insect samples collected totaled 180. A total of 306 chinook salmon were saved for analysis of stomach contents.

Preliminary analysis of juvenile salmon diet samples from April 2002 indicate that emergent insects (primarily Diptera, Chironomidae, Psychodidae) and benthic amphipods *Corophium* spp. dominated the diet of juvenile chinook (Figs. 9-10). Although this diet composition was somewhat representative of all sites, variations among habitats and sites are apparent. Fish larvae were prominent food items at Seal Island-South channel, *Corophium* spp. was commonly consumed at Russian Island-South and Karlson Island Shrub-Scrub channels, and the richest diversity in prey taxa was found at the Karlson Island-Forested site.

To date we have analyzed benthic core data from April and May. The composition of potential invertebrate prey sampled with the benthic core varied both spatially and temporally. In April, other than the numerically prominent oligochaetes and nematodes, chironomid and ceratopogonid insect larvae dominated at most sites, with polychaete annelids *Manayunkia* spp. and ostracods occurring secondarily (Figs. 11-12).

Densities were comparable at Russian Island-South, both Seal Island sites, and Karlson Island-Forested, but were considerably lower at Russian Island-North and Karlson Island-Shrub. At all sites in May, potentially available macroinvertebrate prey (excluding oligochaetes and nematodes) were considerably more abundant than the previous month except at Russian Island-South channel (Fig. 13). In addition to chironomid and ceratopogonid larvae and ostracods, amphipods, gastropods, and bivalves were more abundant in May than in April. Analysis of insect composition in the fallout traps is planned for future years.

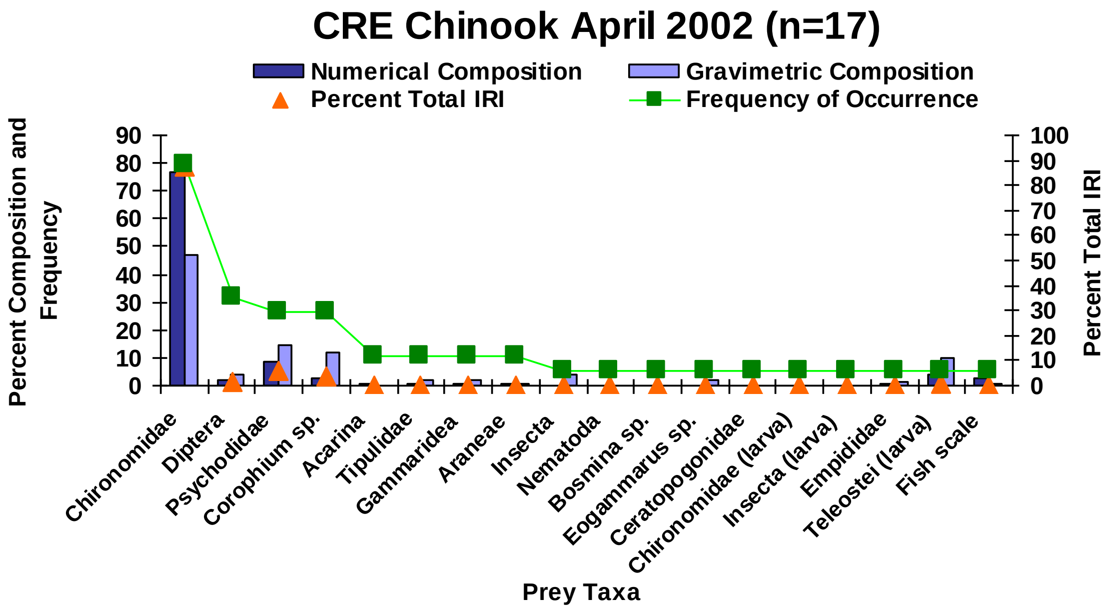


Figure 9. Juvenile chinook diet (taxa) composition from all wetland sampling locations, Columbia River, 2002.

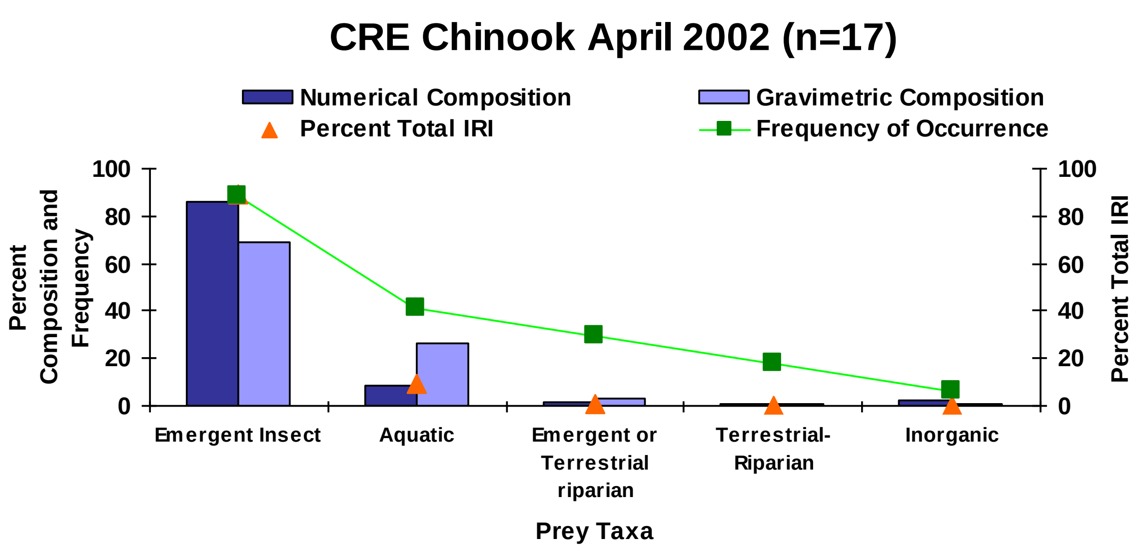


Figure 10. Juvenile chinook diet (source) composition from all wetland sampling locations, Columbia River, 2002.

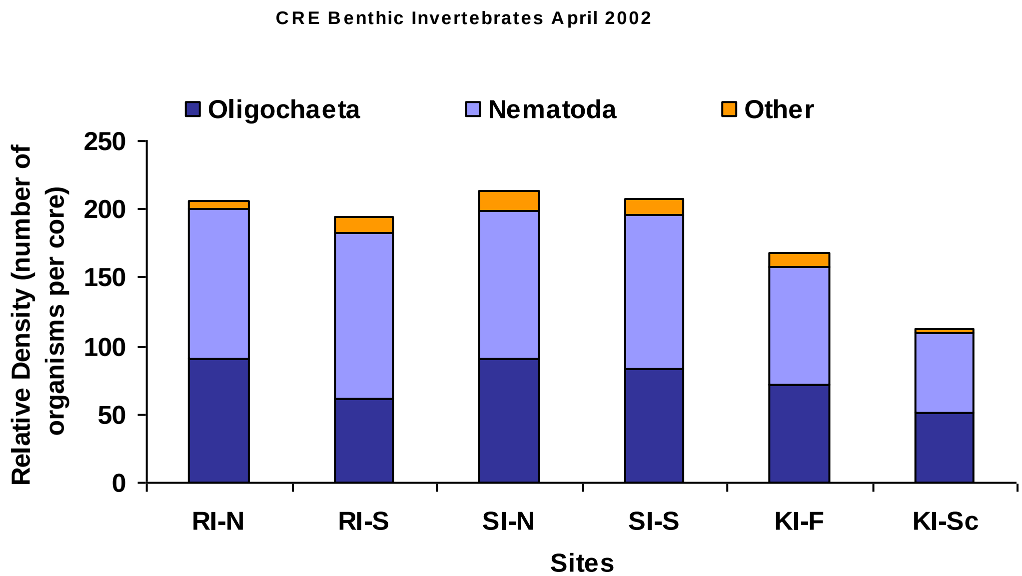


Figure 11. Relative density of benthic macroinvertebrates from all wetland sampling locations, Columbia River, April 2002.

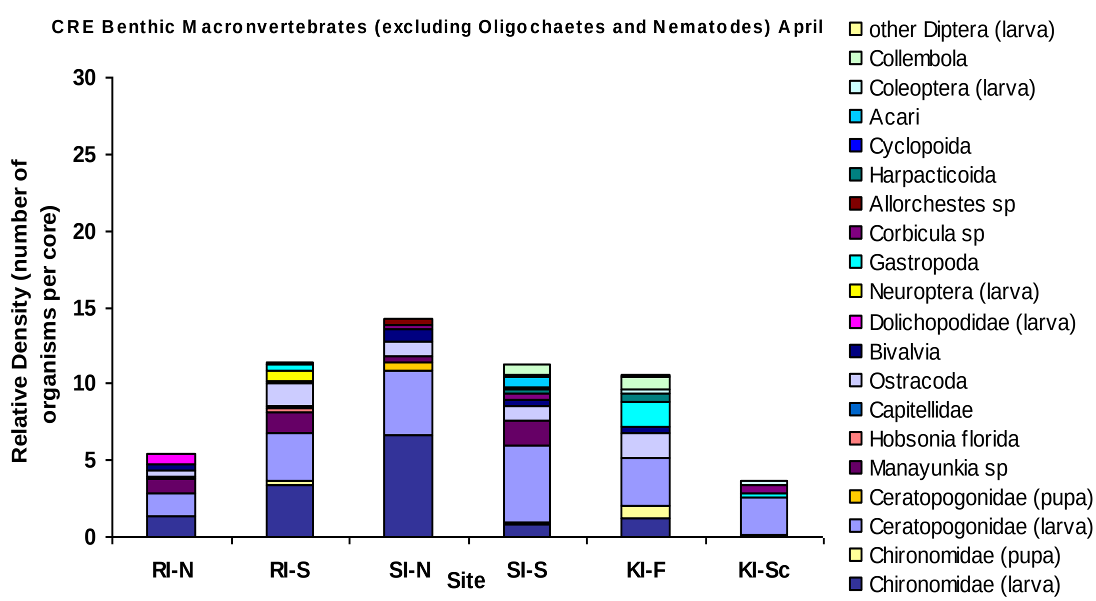


Figure 12. Relative density of benthic macroinvertebrates (excluding oligochaetes and nematodes) from all wetland sampling locations, Columbia River, April 2002.

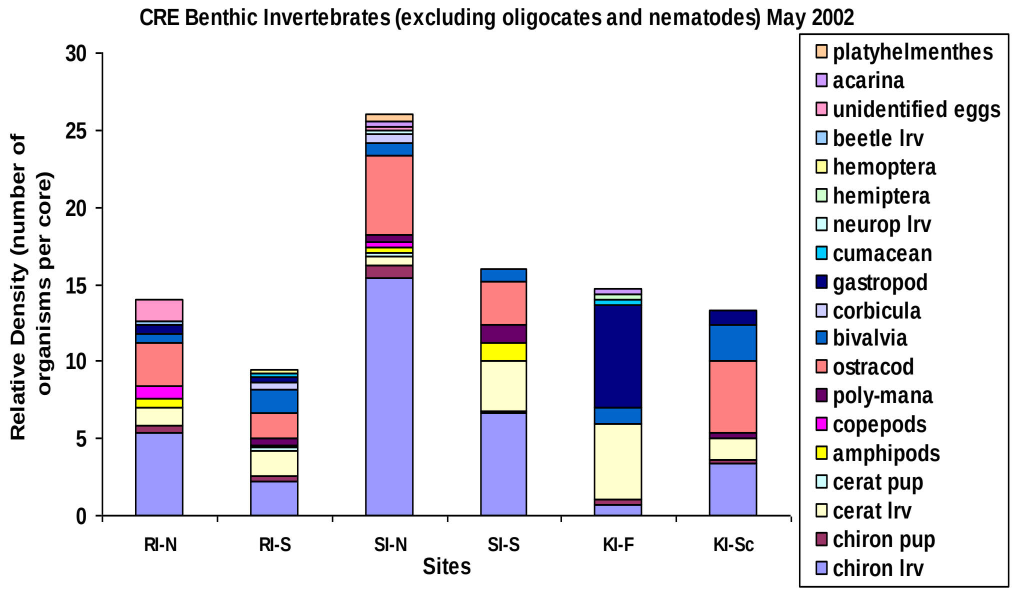


Figure 13. Relative density of benthic macroinvertebrates (excluding oligochaetes and nematodes) from all wetland sampling locations, Columbia River estuary, May 2002.

Physical Factors

We are monitoring the physical attributes throughout the Cathlamet Bay region and within selected marsh habitats, including temperature, salinity, tide level, and other features. The characterization and interpretation of physical factors includes:

1) monitoring the physical attributes via the CORIE network,
2) monitoring the physical attributes of channels located within selected marsh habitats,
3) estimation of physically-based habitat opportunity indicators, and
4) interpretation of observed change (2003 and beyond).

The results to date are discussed below.

Physical Attributes of the Estuary

Instrument moorings were deployed in the Cathlamet Bay region to complement the existing network of real-time physical monitoring stations in the Columbia River estuary (Fig. 14). The Cathlamet instrument network is outlined in Table 12. Additionally, an atmospheric station is being developed for Marsh Island.

Sensors include a wind speed and direction probe, and an air temperature and relative humidity probe housed in a radiation shield. Data are collected at 0.5 Hz, and then locally processed to describe at 10-minute intervals wind speed and direction, peak gust, air temperature, and relative humidity. Solar radiation is measured with a Yankee Environmental Systems Total Solar Pyranometer for wavelengths between 0.3 μm and 3 μm, and an Eppley Laboratories Precision Infrared Pyranometer, from 3.5 μm to 50 μm. For both sensor models, we are using two instruments, one facing upward and the other downward. The instruments were deployed in test mode from week 49 in 2002 to week 5 in 2003, and will be redeployed (target date: July 2003) with a long-term perspective.

The CORIE web site reports most of the data from instrument moorings on a real-time basis which can be accessed at http://www.ccalmr.ogi.edu/CORIE/network. Observed salinity (via conductivity), temperature, and pressure data are publicly available. For each station, users can visualize and download quality-controlled data. For example, data from the Mottb sensor can be viewed at http://www.ccalmr.ogi.edu/CORIE/data/publicarch/mottb. Other products include statistical compilation of physical datasets (climatology), for example: http://www.ccalmr.ogi.edu/CORIE/data/publicarch/mottb/clim.html. Users can access one-year ensemble views of the physical datasets from the Cathlamet Bay sensor network at http://www.ccalmr.ogi.edu/CORIE/data/publicarch/ensemble/. The CORIE web site also contains a description of the adopted quality control procedures which have become CORIE standards at http://www.ccalmr.ogi.edu/CORIE/data/publicarch/ methods_quality.html.

The meteorological station required refinement. Wind and air instruments worked satisfactorily, however the solar radiation instrumentation had problems with faulty calibration battery units. This problem has since been corrected.

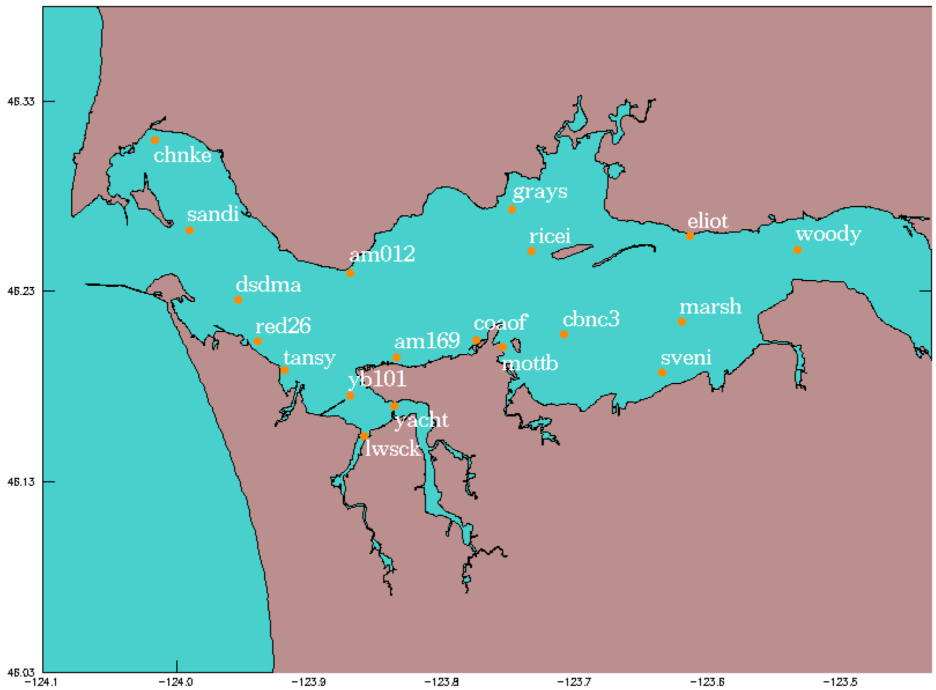


Figure 14. Mooring stations comprising the CORIE Network.

Table 13. CORIE stations supported by this project.

Station	Instrumentation	Telemetry	Starting Date
MOTTB	Conductivity, Temperature Pressure (CTD)	Radio	2000
CBNC3	CT	Radio	2000
SVEN1	CTD	Radio	2001
MARSH	CTD	Radio	2001
ELIOT	CTD	Radio	2001
TNSLH	TD	Radio	2003

Physical Attributes within Selected Marsh Habitats

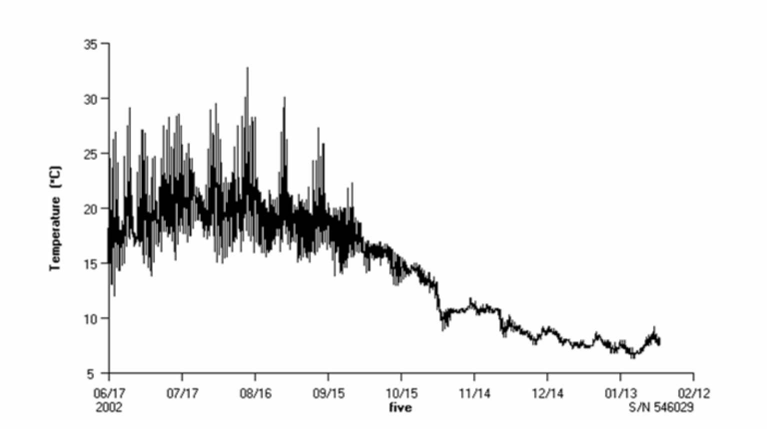
Temperature sensors were deployed at the Russian Island and Karlson Island-Forested site in May and at the Seal Island and Karlson Island-Shrub sites in June. The sensors are recording water temperatures at 10-minute intervals.

The two emergent marsh sites displayed the greatest temperature variation, likely due to their exposure to the sun during the lowest summer tides (Fig. 15). Water temperatures did not vary as dramatically at either of the Karlson Island sites. This probably reflects shading by dense overhead vegetation and ponding of water at low tide which ensures that the temperature sensors are always submerged. At all sites, water temperatures began declining in mid-September and continued a cooling trend through December.

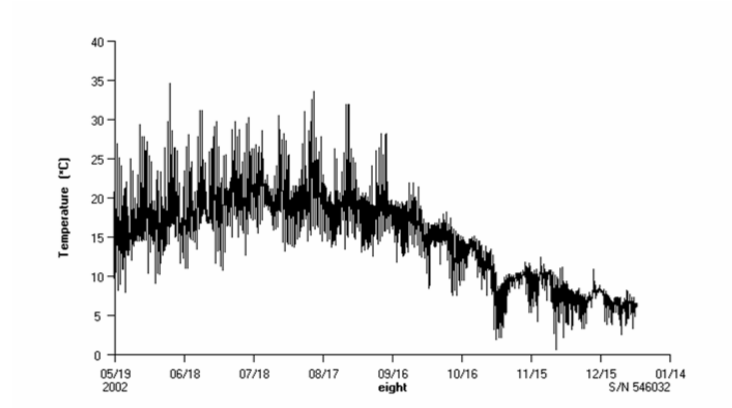
Physically-Based Habitat Opportunity Indicators

Indicators of habitat opportunity for juvenile salmon based on water depth, velocity, and salinity have been developed as a way to evaluate the possible influence on salmon populations of spatial and temporal variability in the physical environment.

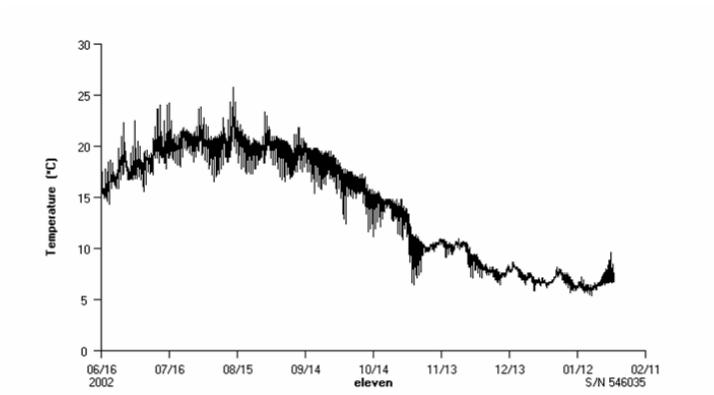
To date, we have computed 2002 habitat opportunity metrics for the CORIE observation stations listed in Section 2.3a (based on salinity and velocity criteria; all stations are deep enough to make the depth criteria trivially zero at the station). We have also started producing maps with daily forecasts of habitat opportunity (depth, salinity and velocity criteria). An example is shown in Figure 16. We are developing the quality control procedures and display scripts necessary to support web-based access to that information. Results will be discussed in the next future principal investigator meetings, with routine web publication expected shortly thereafter.



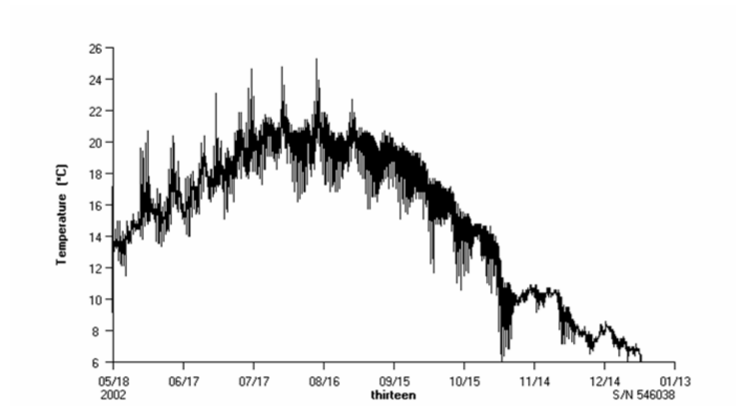
Seal Island



Karlson Island--forested



Russian Island



Karlson Island--shrub

Figure 15. Time series of temperature at selected trapnet sites in Cathlamet Bay.

Vegetation Community Structure at Wetland Sites

Vegetation community structure was characterized using the LCREP-generated classifications from remote sensing satellite (LANDSAT 7 ETM and panchromatic) and other data sources (CASI hyperspectral). These classifications and the delineation of discrete vegetation communities as habitat Apolygons@ will be verified and systematically sampled by conventional analyses for vegetation composition and relative abundance using percent cover and other (e.g., shoot density, above-and below-ground biomass) measurements at each site.

In coordination with LCREP, we selected priority sample sites. Vegetation community samples were collected throughout the estuary and coincidental with Landsat 7 (ETM and panchromatic) and CASI (hyperspectral) data sources. We completed systematic measurements of vegetation samples to characterize community structure and composition at sample sites, and we provided vegetation results to LCREP for image classification and verification.

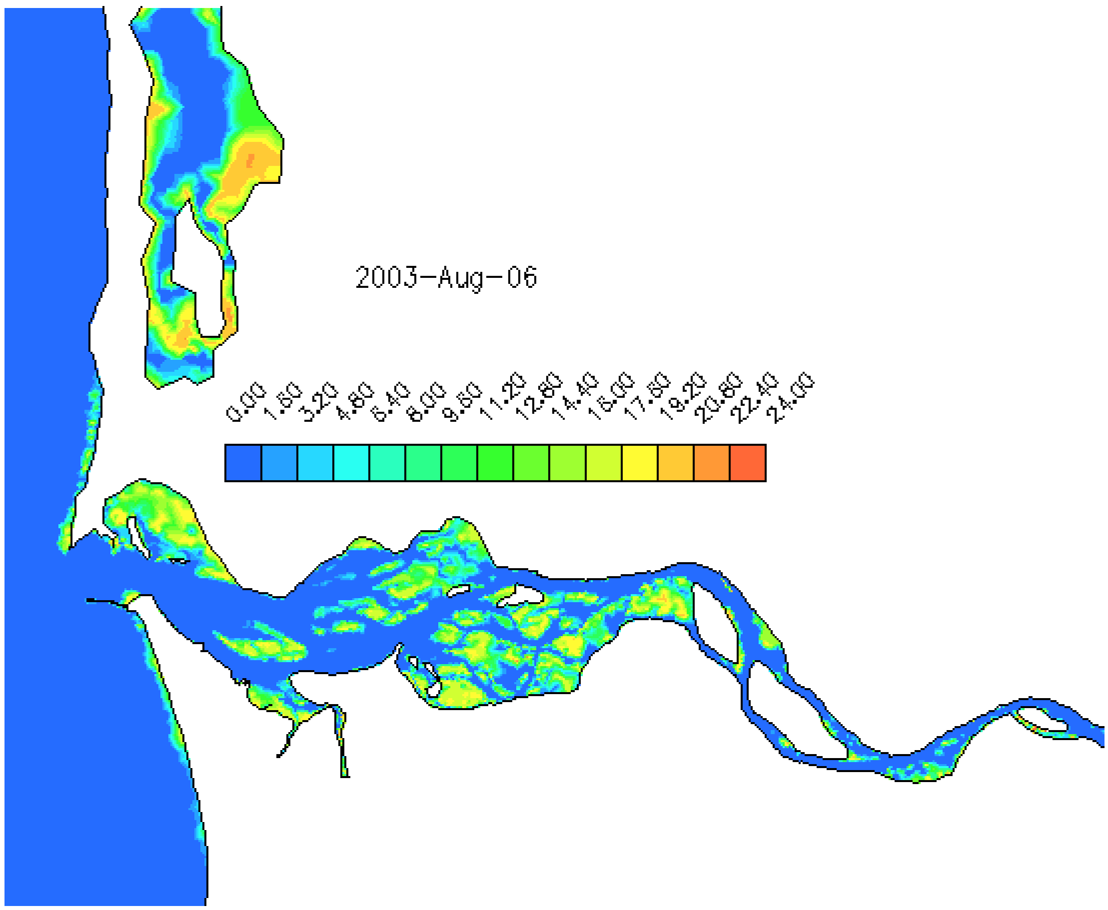


Figure 16. Habitat utilization potential (hours) for juvenile salmonids based on depth criteria during 6 August 2003.

OBJECTIVE 3: Historical Change in Flow and Sediment Input to the Estuary and Change in Habitat Availability

Climate and Human Effects on River Flow and Sediment Input

The goals of this task are to use recent geological history and available data to determine: (1) historical changes in the salinity and tidal regimes, (2) changes in water and sediment input to the system related to climate, human alteration, and major geological events, and (3) the variations between sub-basins of climate and anthropogenic effects (Jay 2003). The results to date are discussed below.

Interaction of Tides, River Flow, and Shallow-Water Habitat

We used historical data to analyze changes in the tidal regime caused by changes in flow magnitude and seasonality; and we also evaluated the effects of the daily and weekly power peaking cycles. Over the last two years, we improved the method for analysis of river tides devised by Jay and Flinchem (1997) and Flinchem and Jay (2000). We then analyzed the 1980-2001 Columbia River tidal height data set (about 50 station-years) to establish the response of tidal properties to river flow, from the estuary to Bonneville Dam. Using a depth criterion, we calculated the shallow water habitat area (SWHA) available every day for the 1974-1998 period in the reach between Skamokawa, Washington and Beaver, Oregon.

Four SWHA scenarios were considered: a) virgin flow--no dikes, b) virgin flow-with dikes, c) observed flow-no dikes, and d) observed flow-with dikes (Fig. 17). The figure clearly shows the substantial reduction of shallow water habitat due to modification of the system hydrology.

This work is now in published format (Kukulka 2002; Kukulka and Jay, 2003a,b). In the coming year, we will further examine the impacts of power peaking.

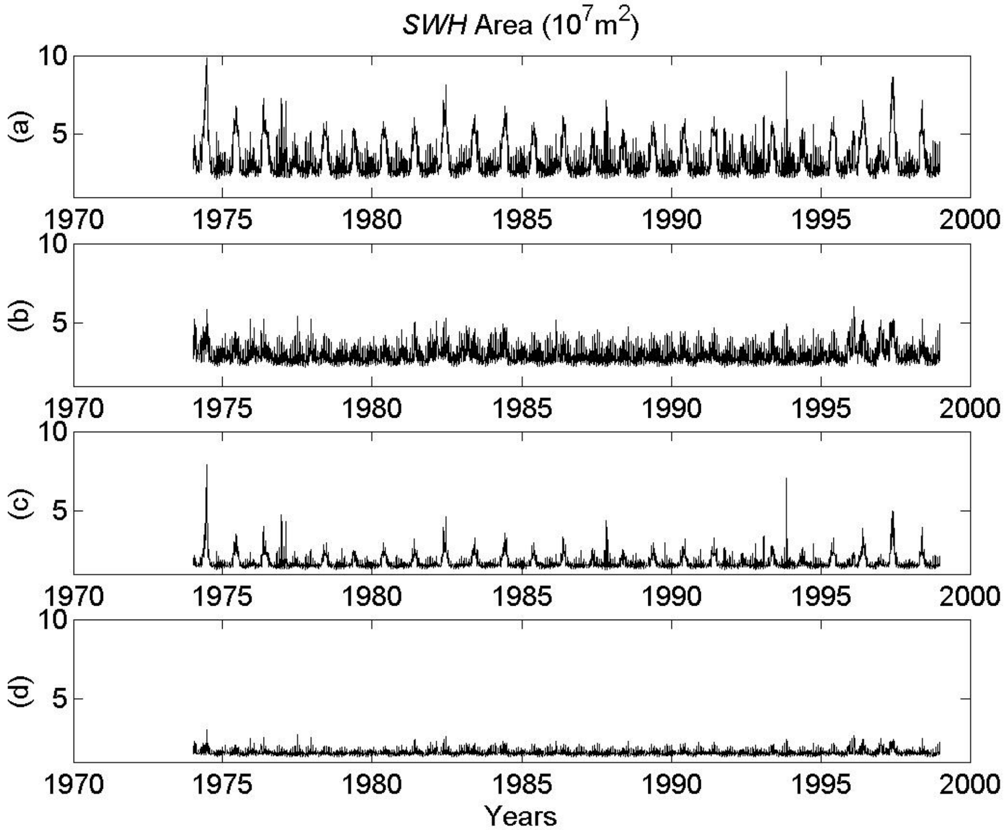


Figure 17. Daily Shallow-Water habitat (SWH) Area from 1974 to 1998 for virgin (a) and observed (b) river flows without dikes, and for virgin (c) and observed (d) flows with dikes, from Kukulka (2003b).

Salinity Intrusion and Shallow-Water Habitat

We used historical salinity, flow, and bathymetric data to understand changes in salinity patterns related to changes in river flow and bathymetry. Part of the historical data set was assembled and organized for analysis, and hypotheses were generated concerning the relationship between salinity intrusion, tides, and river flow. Data will be analyzed in the next fiscal year to test the hypotheses. The analysis method will be similar to that employed in Kukulka and Jay (2003a,b) for river tides. Thus, the mean and tidal salinity variations will be uncoupled and analyzed separately, in terms of external forcing by river flow, tides, and atmospheric factors.

Historical Changes in Sediment Input to the Estuary

We seek to understand changes in: a) seasonality and amount of river flow, b) the supply of fine and coarse material to the estuary, and c) the quantity and quality of material supplied from selected sub-basins. This task also includes collaboration with the U.S. Geological Survey (USGS) in historical analyses.

We have analyzed the causes of flow changes (Jay and Naik, 2002) and estimated virgin flows at The Dalles (Naik and Jay, 2002a,b). We have also implemented a routing algorithm to estimate a daily flow at Beaver since 1912. We have extended knowledge of spring freshet timing and volume back before the beginning of the daily record at The Dalles using historic records and newspaper accounts. Changes in volume and timing of total sediment load at Vancouver, Washington have been partitioned between climate change, flow regulation, and flow diversion (Fig. 18). We have recovered and digitized some of the historic (1960s) USGS sediment transport records for the Columbia River Basin.

Characteristics of Sediment Inputs to the Columbia River and Estuary

We are using state-of-the-art optical methods to determine seasonal patterns in size distribution and concentration of sediment transported into the estuary. We are also collaborating with USGS on historical analyses, sampling methods, instrument calibration, and monitoring at Beaver.

Suspended Sediment Concentration and Size at Beaver

We are using optical methods to monitor Columbia River sediment properties using a laser in-situ scattering transmissometer (a LISST-FLOC manufactured by Sequoia Scientific). The LISST-FLOC uses scattering of laser light to divide particles between 10 and 1,500 μm in diameter into 32 size classes. Our LISST-FLOC is unique (the first of a new class of LISST) in that it measures not just sand and fines up to 500 microns, but also larger particles, especially aggregates. Following its deployment at Beaver over the entire year and with suitable calibration studies and USGS monitoring, the instrument will allow us to determine seasonal quantity and quality of suspended particulate matter (SPM) entering the estuary.

To date, we performed an exploratory field survey in June 2002, at the end of the spring freshet. We investigated the cross-sectional distributions of flow, the bed and water column (suspended) sediment, and the tidal variations in water column properties. A deployment site for the LISST-FLOC was found for initial studies scheduled in 2003. We have further sought to characterize aggregates in the river using scanning electron microscopy (Fig. 19). This approach allows us to discern the structure of aggregates and determine the elemental composition of individual particles in the aggregates. We are also examining aggregate size-density relationships and reasons for the observed patterns. An abstract regarding this work has been submitted to the INTERCOH conference on cohesive sediment transport (Chisholm et al. 2003).

In coordination with ongoing National Science Foundation research, we are investigating the factors responsible for the retention vs. export of fine sediment and aggregates in the Columbia River estuary. In this work, the Fraser River estuary (which in many respects resembles an unregulated Columbia River) has been used to understand

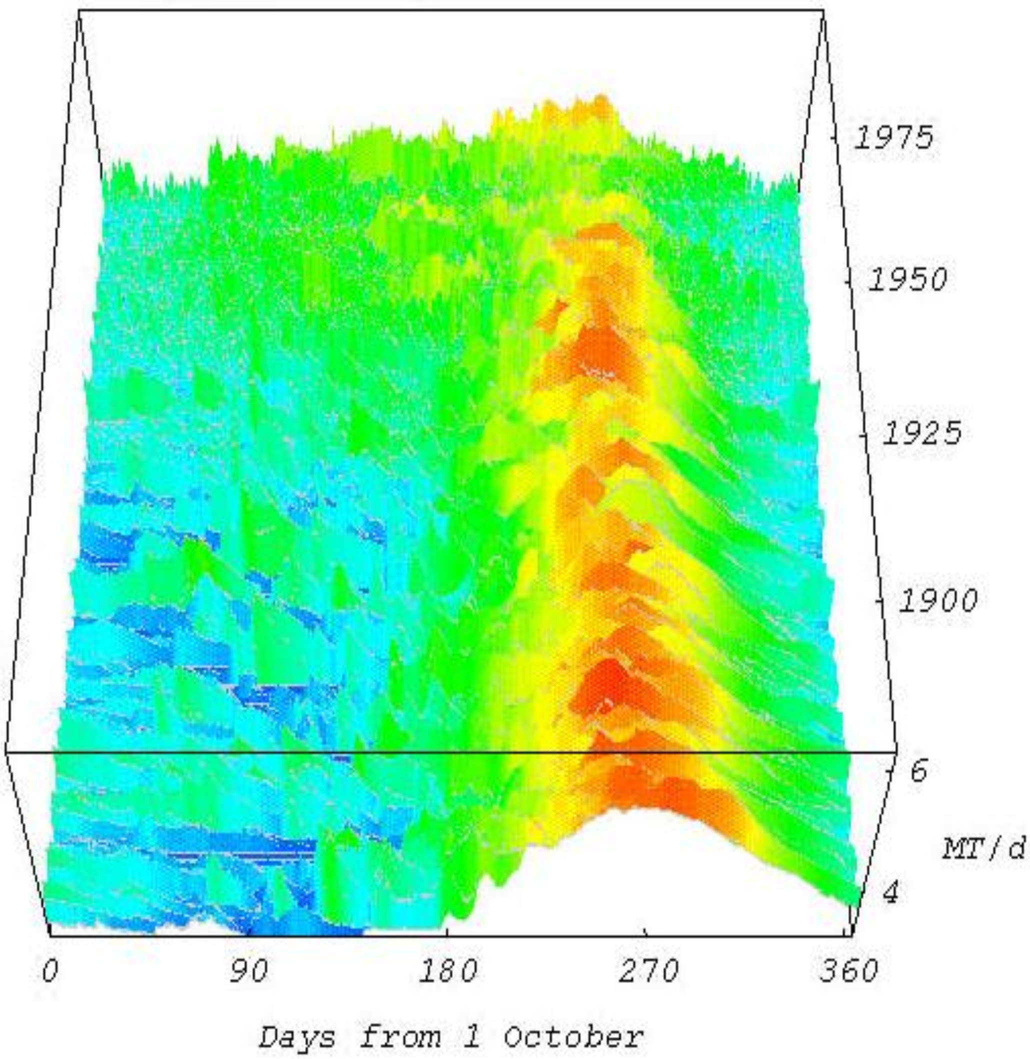


Figure 18. Log10 of Columbia River total sediment load at Vancouver (metric tons d-1). Spring freshet sediment transport has greatly decreased, primarily due to flow regulation, secondarily due to irrigation withdrawal and climate change. Winter sediment transport has increased due to pre-release of flow.

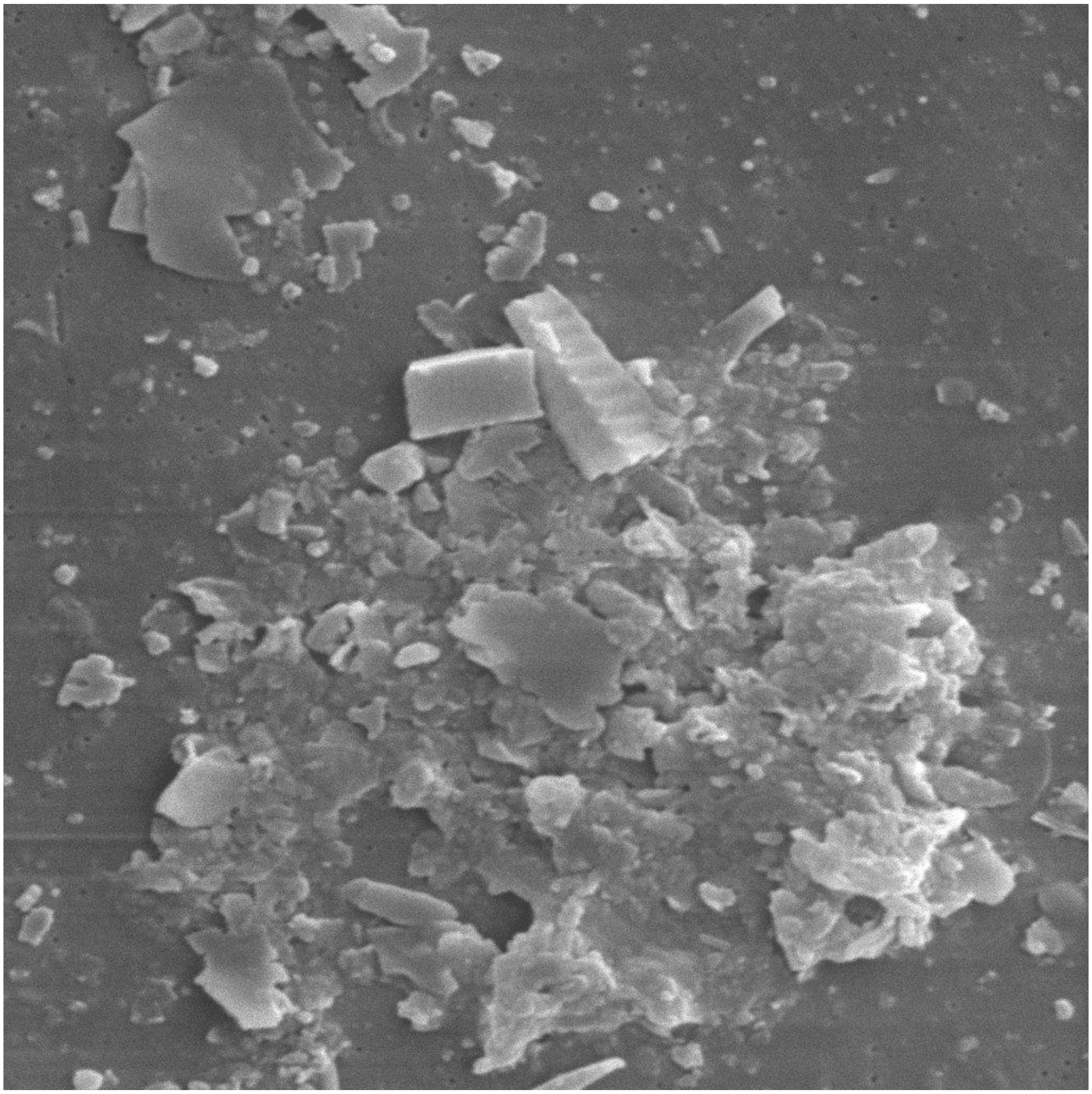


Figure 19. Scanning electron micrograph of flocculated material collected at Beaver. The floc is approximately 30 microns across. It appears to contain both organic and inorganic material.

the historic behavior of the Columbia River. It has been found that sediment retention varies inversely with the ratio of river flow to tidal velocity, and that aggregation plays an important role in trapping sediment, especially in systems with low river flow (Jay et al. 2003a,b).

Judging from conditions in the Fraser, the historic Columbia, with much higher spring flows than at present, was unable to retain significant amounts of SPM in an estuarine turbidity maximum during the larger spring freshets. Sediment trapping was historically weak, because all salt was removed from the estuary, SPM residence time was short, and aggregation was not rapid enough relative to export. Instead, SPM was likely retained in peripheral bays and marshes, which were much more extensive than at present (Orton et al. 2002; Jay et al. 2002).

Coordination with the U.S. Geological Survey

There are three primary aspects to this coordination. The first is to coordinate our work with the flow gauging and water quality sampling routinely carried out by USGS (Portland District). Second, we will be working with USGS scientists at the Grand Canyon Monitoring and Research Center (GCMRC) and Menlo Park, California to calibrate the new LISST-FLOC in 2003. Finally, we work with USGS-Menlo Park scientists regarding historical changes in sediment transport, and GCMRC scientists regarding system comparison.

Calibration of the LISST-FLOC in coordination with the USGS Grand Canyon Monitoring and Research Center (GCMRC) is scheduled for the next annual reporting period. We coordinate with USGS Portland District regarding our respective monitoring efforts at Beaver. We now routinely receive acoustic and optical backscatter data from USGS monitoring at Beaver. We are collaborating with scientists at USGS-Menlo Park in analyzing historic sediment transport for the Columbia River Basin.

Habitat Change Analyses

We assembled and georeferenced a complete collection of historical topographic maps (t-sheets) dated 1868 to 1901 that depict hydrologic, floodplain, and upland features of the Columbia River estuary (Fig. 20). The maps show the extent of wetland and terrestrial habitats preceding subsequent development of the Columbia River floodplain. We reconstructed the historic wetland and floodplain habitats for eight t-sheets encompassing four priority areas (Fig. 21). The final map products and analysis results demonstrated changes in the array and spatial distribution of salmonid habitats and will assist restoration activities for salmonid estuarine habitats.

Literature Review of Methods and Analysis

We completed an exhaustive literature review examining numerous georeferencing and digitizing methods carried out by similar historical habitat reconstruction projects throughout the United States. In addition, we examined the classification schemes for historical habitats, types of spatial analyses performed, and methods used to quantify error and uncertainty.

The habitat reconstruction project obtained 27 pre-1900s t-sheets in scanned Tagged Image Format (TIF) comprising the entire Columbia River estuary from the mouth to Rooster Rock. The digital t-sheets lacked geographic placement in the real world that made them useless in a GIS or for spatial analyses. Thus we searched for the best and most defensible georeferencing method available by conducting an exhaustive review of historical (pre-1900) habitat reconstruction projects conducted throughout the United States.

Similar habitat reconstruction projects using historical t-sheets occurred in Texas, Alabama, San Francisco, Coastal Oregon and Washington, and Florida. Of the metadata available for Texas, Alabama, and San Francisco, only the Alabama project acknowledged the techniques used to georeference the t-sheets. The Alabama project adopted the recommended methods of NOAA Coastal Services Center (1999a), which is also referred to as the mathematical method in Daniels and Huxford (2001). Daniels and Huxford compared the spatial accuracy of four different georeferencing methods for historical t-sheets along the Oregon and Washington coast. The most accurate results were obtained from the mathematical method, which involved applying a shift to the latitude-longitude graticules annotated on the t-sheets to bring the graticules up to modern

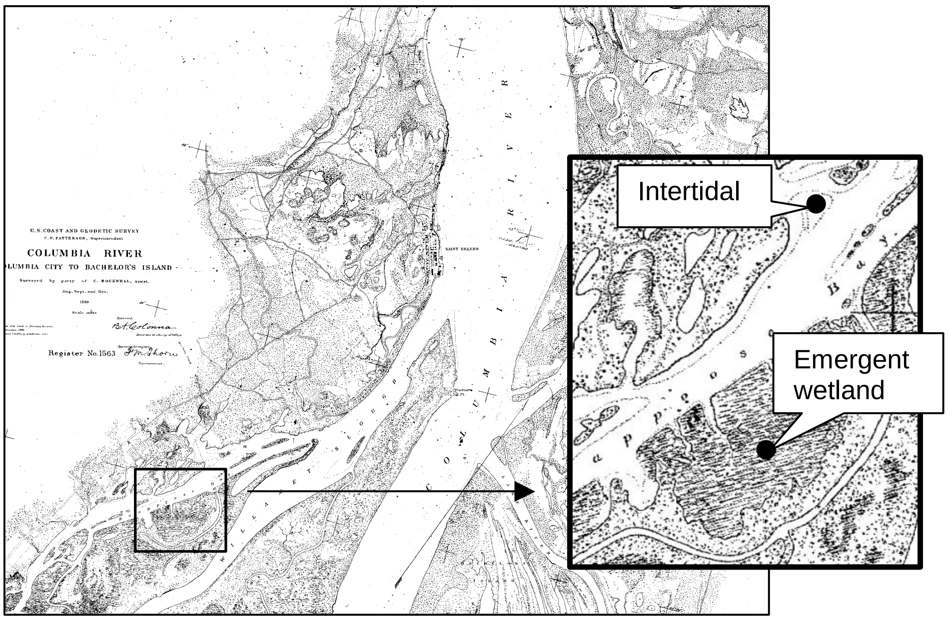


Figure 20. T-sheet, T1563, with a zoom window and two habitat types identified.

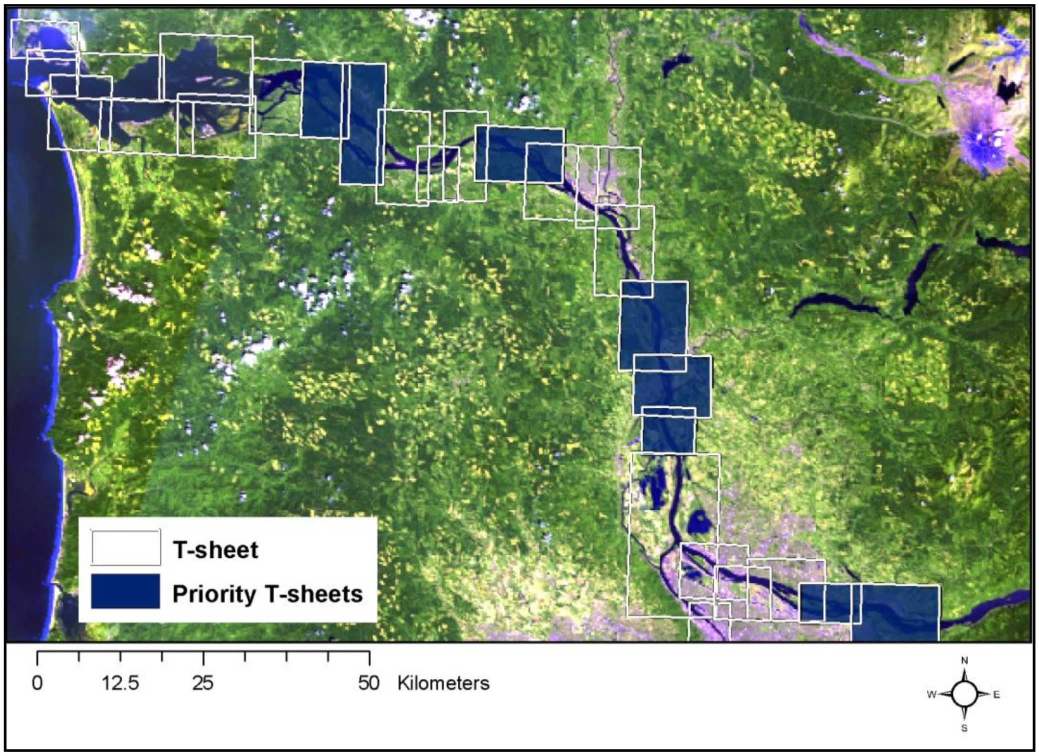


Figure 21. T-sheets and priority areas in the Columbia River estuary. Imagery courtesy of LCREP and EDC, Inc.

coordinates. Daniels and Huxford also provided a method to measure the accuracy of the georeferencing. In addition, Fann (2001) used the mathematical methodology to georeference historical t-sheets for a habitat reconstruction project in Florida and obtained acceptable results. Based on the results of the projects reviewed, our project adopted the mathematical method as the best georeferencing method providing the most spatially accurate results.

The georeferenced t-sheets produced spatially-correct raster images that display the data as 2-bit, black and white, information (Fig. 20). To conduct spatial analyses, polygon coverages summarizing the areas of similar habitat types must be created (Fig. 22). NOAA Coastal Service Center (1999b) provided the base digitizing methodology that we adopted for all 27 t-sheets.

Digitizing the t-sheets produced a map of polygon features based on a habitat classification scheme that interprets map symbology. Interpretation and classification of map features varied according to the objectives of the projects. Shalowitz (1964) provided the most comprehensive guide to the interpretation of cartographic symbology used by the early surveyors constructing the historical t-sheets.

Similar t-sheet habitat reconstruction projects that occurred in Texas and Alabama enabled Shalowitz (1964) to classify shoreline features; however, the projects did not classify continuous habitats such as wetlands or shallow-water areas. Thomas (1983) and Grossinger (2001) developed simple wetland and floodplain habitat schemes that ranged from 9 to 10 classes for the historical t-sheets. Kistritz et al. (1996) devised a different approach by delineating only those habitats used by salmonids in the Lower Fraser River using historical maps similar to the U.S. Coast and Geodetic t-sheets.

Several habitat reconstruction projects in the Pacific Northwest incorporated ancillary historical data along with the t-sheets to derive more complex vegetation classes. In all cases the projects based their habitat classes on the Cowardin (1979) classification scheme, a hierarchical system delineating salinity regimes, landscape placement, and connectivity. Allen (1991) applied a modified Cowardin classification scheme to habitats in the Columbia River estuary delineated from aerial photographs. Collins et al. (2003) incorporated Shalowitz (1964) in interpreting the t-sheets and augmented the habitat classes with a modified Cowardin (1979) scheme based on vegetation data from the General Land Office field notes for the Puget lowlands. We concluded that we would adopt the Cowardin (1979) classification scheme with additional classes pertaining to habitats used by salmonids.

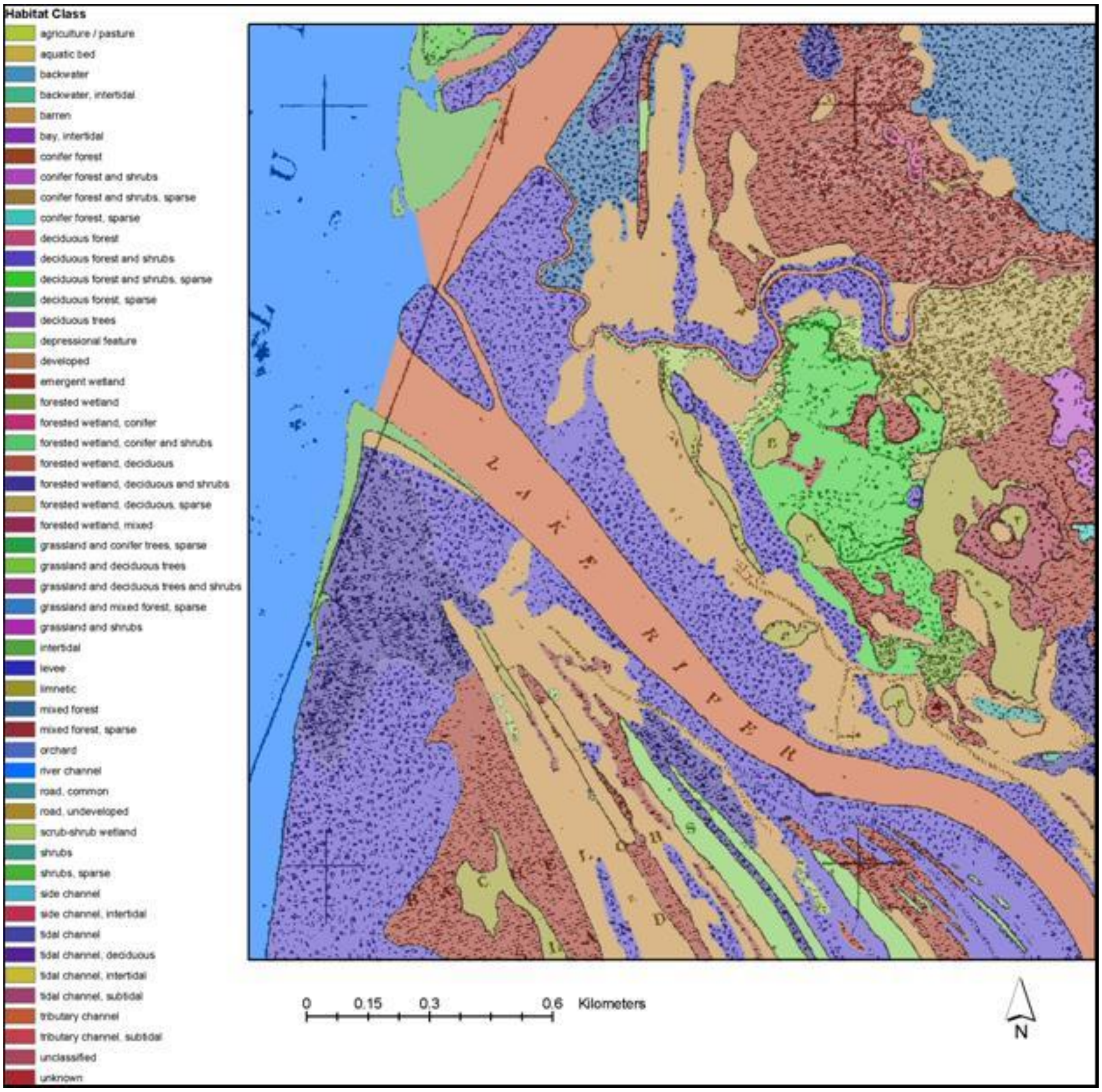


Figure 22. Modified habitat classes applied to historical t-sheets of the Columbia River estuary.

Historical t-sheets georeferenced, digitized, and classified in a GIS provide a means to conduct spatial analyses using various GIS software and software for comparative analyses and spatial summaries. Typical historical habitat analyses compare the total acres of estuarine habitats lost or gained through a time period or assess shoreline changes (North and Teversham 1984, Thomas 1983, Allen 1991, Kistritz et al. 1996, Grossinger 2001, Collins et al. 2003). Our project will conduct a summary of habitat change and shoreline change analyses in addition to landscape-level spatial analyses.

Inaccuracies in historical map reconstruction arise from inherent, precision, and interpreted error sources and will propagate through the analysis. Inherent error originates during the historical map-making process (i.e., surveying and cartographic annotation), precision errors occur during the GIS processing, and interpretative errors occur in the delineation and interpretation of map symbols. ESRI=s ArcDoc outlines the cumulative effect of inherent and precision errors during the conversion of paper maps to digital polygon format (Table 14).

NOAA Coastal Services Center (2000) outlined standard quality assurance and quality control procedures during the digitizing process of the t-sheets. Uncertainty and error assessment of interpretation and classification of habitats appeared in only one of the habitat reconstruction projects reviewed. Grossinger (2001) devised a quantitative and qualitative method of assigning certainty to the reconstructed map feature. Historical maps features received a high, medium, or low level of certainty based on their presence, size, and location in multiple historical data sources. Our project will identify and quantify error and uncertainties similar to Grossinger (2001).

All of the projects reviewed were attempting to identify regions of restoration potential, testimony to the importance of accuracy, precision, and tracking of error and certainty of the habitat reconstruction processes.

Table 14. RMS error associated with GIS georeferencing and mean error accuracy assessment.

			Total Georeferencing RMS error		Mean Error Accuracy Assessment	
t-sheet	X Error	Y Error	Inches	Meters	Long (m)	Lat (m)
T1250	0.0013	0.0014	0.0019	0.00695	2.53	2.05
T1331	0.0013	0.0013	0.0018	0.00658	1.37	4.15
T1431A	0.0005	0.0008	0.0009	0.00329	2.41	4.1
T1495	0.0005	0.001	0.0011	0.00402	3.06	3.31
T1542	0.0009	0.0006	0.0011	0.00402	0.25	2.22
T1563	0.0009	0.0017	0.0023	0.00841	No benchmarks	
T2522	0.0016	0.0001	0.0016	0.00585	3.15	0.97
T2577	0.0015	0.0012	0.0019	0.00695	6.97	3.63
Average			0.00158	0.00576	2.82	2.92

Establish a Common Defensible Protocol for Habitat Reconstruction

The purpose of this project is to generate a high-resolution and spatially accurate historical estuarine habitat coverage in a GIS. Three previous mapping efforts in the Columbia River estuary by Thomas (1983), Allen (1991), and Graves et al. (1995) lacked the desired resolution, geographic accuracy for spatial analyses, and consistent classification of habitats. Implementation of the best available methods now available will avert a similar drawback for our products in the future. Therefore, we developed and applied a consistent methodology to georeferencing, digitizing, and classifying habitats for all 27 t-sheets.

The RMS error and accuracy assessment values of the georeferencing processes attested to the precision of the historical map surveyors, the benefit of obtaining corrected geodetic data from the National Geodetic Survey office for georeferencing, rigor of the mathematical methodology, and the reward of a consistent and meticulous methodology (Table 15). The total RMS error for each t-sheet was less than 0.04 in, which is the standard level of acceptance for georeferencing maps (ESRI ArcDoc). The horizontal accuracy of the map features, represented by the mean error accuracy assessment in Table 2 were predominately less than the maximum 5 m set by the National Map Accuracy Standards for maps produced at a 1:10,000 scale (U.S. Bureau of the Budget 1947). Thus the georeferencing methods adopted by our project produced readily acceptable results.

Our digitizing methodology promoted precision and accuracy in creating GIS polygon and line coverages of the historical habitats from t-sheets. We employed the methods of NOAA Coastal Services Center (1999b, 2000), and incorporated tolerance levels and processing options as outlined in ESRI ArcDoc for creating polygon coverages with the greatest accuracy possible.

After digitizing the t-sheets, we created a habitat classification hierarchy primarily based on Cowardin (1979) but also inclusive of classes outlined in Shalowitz (1964) and habitats directly important to salmonids. We finalized the modified Cowardin classification scheme in cooperation with Earth Design Consultants, Inc. (EDC, Inc.), to ensure compatibility with contemporary habitat schemes for the entire estuary for future spatial analyses and comparison between datasets.

The combined results of the georeferencing, digitizing, and classification efforts will be a consistent, high resolution, spatially accurate seamless GIS coverage of historical estuarine habitats. Our primary effort is currently focused on four priority areas. Pending future funding, the methods may be applied to the entire estuary for a complete habitat reconstruction of the estuary.

Coordinate with Regional and Local Organizations

A concurrent project conducted by EDC, Inc., and the Lower Columbia River Estuary Project (LCREP) mapped the contemporary habitats of the Columbia River estuary from remote sensing imagery at 30 m and 1.5 m resolution. We consulted with EDC, Inc., LCREP, and Columbia River Estuary Study Taskforce (CREST) to identify the four priority areas and produce a common habitat classification scheme between our historical and their contemporary mapping projects to facilitate habitat change analyses in the 4 priority areas.

We are participating in the final review of the contemporary remote sensing imagery to ensure the compatibility of the habitat classifications between projects. EDC, Inc. and our project will work jointly on the spatial analyses for the historical and contemporary comparison.

Application of Protocols

Georeferencing:

All 27 t-sheets are georeferenced.

Digitizing:

Two of the eight t-sheets in the priority areas are completed and verified.

Classification:

Two of the eight t-sheets in the priority areas are completed and verified.

Spatial Analyses

The coupling of the historical and contemporary mapping products creates a snapshot of these habitats and permits spatial analyses and comparisons with a temporal component. In addition, we will examine spatial distribution of estuarine habitats, connectivity of habitats to the river and terrestrial upland areas, and additional landscape-level comparisons of historical and contemporary habitats. Habitat analyses will be conducted using FragStats (http://www.umass.edu/landeco/research/fragstats/fragstats.html), a freeware tool to measure landscape-level metrics, and spatial analytical tools embedded within ESRI ArcGIS software.

Dissemination

The georeferenced t-sheets, digitized coverages, error and certainty tables, and spatial analyses results will be freely available upon completion of the project. We distributed one georeferenced t-sheet to Sea Resources for digitizing and classification of habitats under our supervision. Additionally, we provided all georeferenced t-sheets to USGS in Portland for analyses of sediment contributed to the system from volcanism. Both organizations agreed to not distribute the products without prior consent.

Historical maps provide a simplistic reproduction of past conditions and patterns across the landscape. Combined with contemporary habitat data, the historical maps and analyses will be useful for restoration site selection and identification of landscape-level salmonid habitat needs. Through the coordination of the various agencies and organizations involved, a complementary set of historical and contemporary GIS habitat coverages will be available to resource managers in the Columbia River estuary for

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