Southern Resident Killer Whale diet as determined from prey remains and fecal samples

Brad Hanson

Northwest Fisheries Science Center

Killer whales were historically viewed as “generalists” in their foraging behavior

By 1981 (Hoyt) there were over 50 published reports of stomach contents or predation events of killer whales worldwide which included:

30 Fish species
23 Whale species
14 Seal species
9 Bird species
2 Squid species
1 Turtle species
Sea Otters

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Determining the diving behavior of "southern resident" killer whales in the trans-boundary waters of British Columbia and Washington to assess foraging ecology

A suction-cup attached Time-Depth Recorder on a southern resident killer whale

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Wildlife Computers Mk6/8 TDR

Sensors

- Depth
- Velocity
- Temperature
- Light

In a syntactic foam body with a VHF transmitter

Suction cup attached TDRs deployed opportunistically by crossbow on killer whales in Haro and Georgia Straits
Photo by S. Hooker

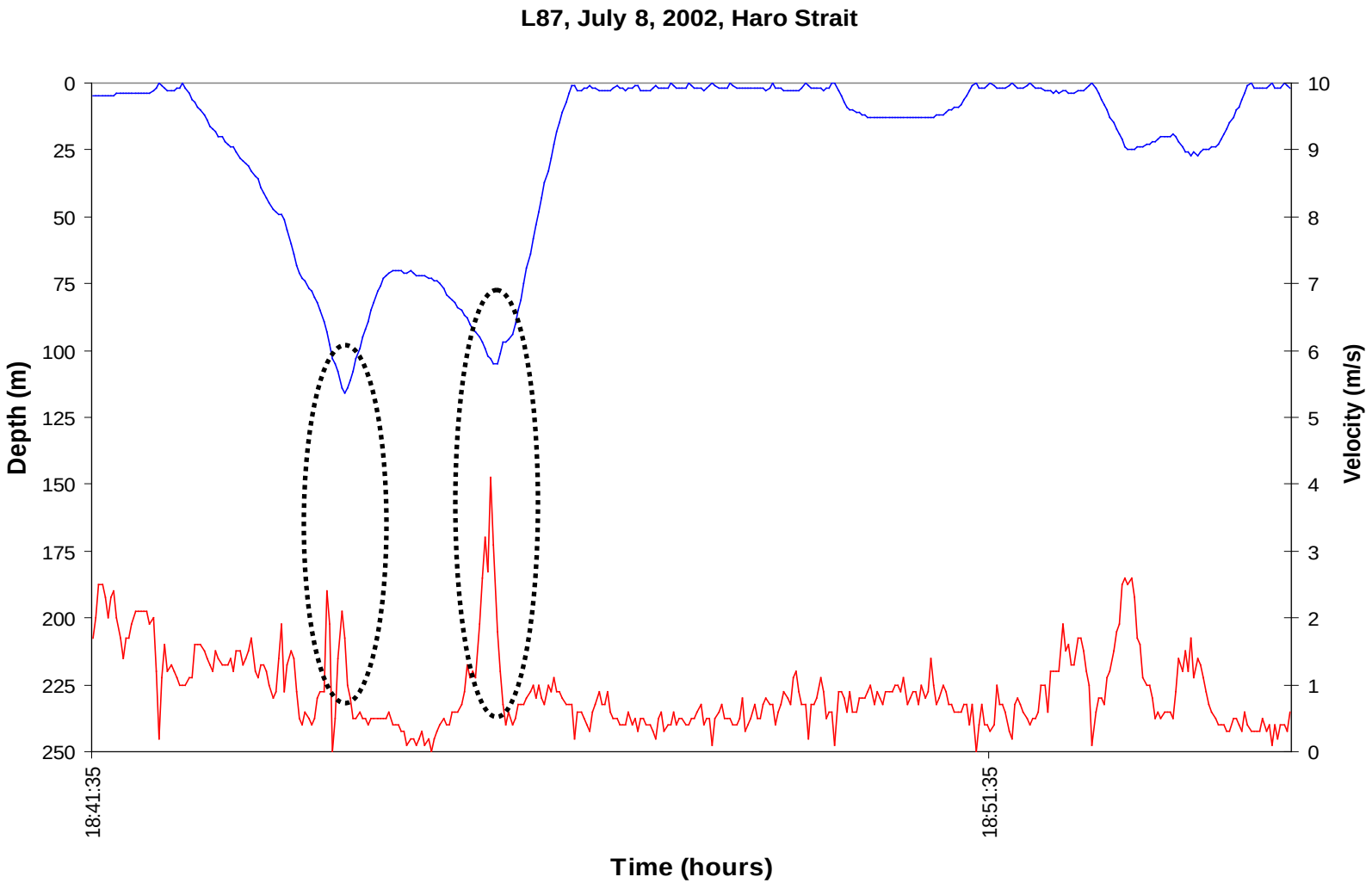
Results – Sample size

40 deployments 1993 -2002

419 hours of data

Median deployment duration >2 hours – 10.5 hours

Results – Time depth recorders



Velocity spikes coincide with dive apexes
Predation attempts?

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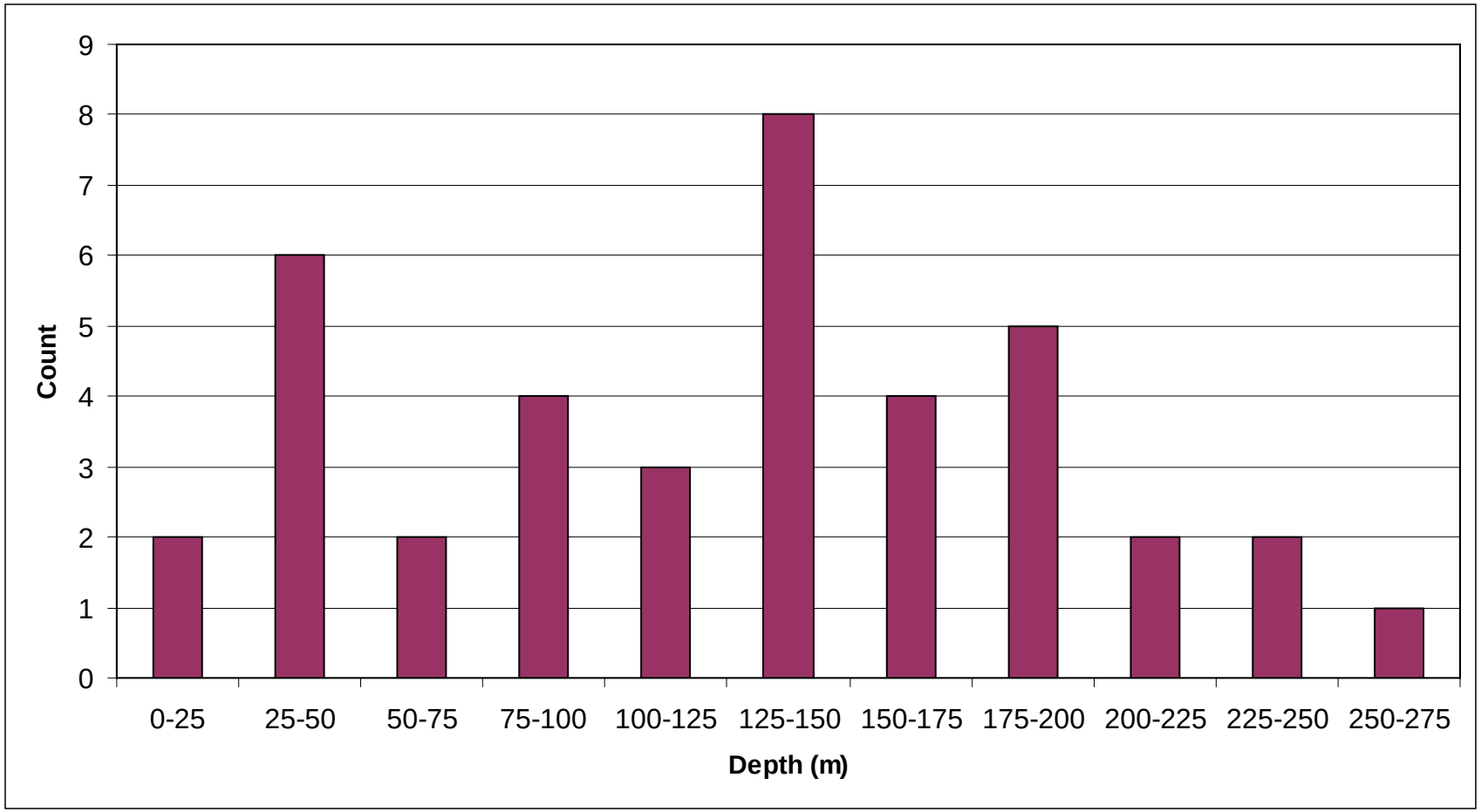
Results – Time depth recorders



90% of deployments had a maximum dive that exceeded 25m – *note large number a 125-150m*

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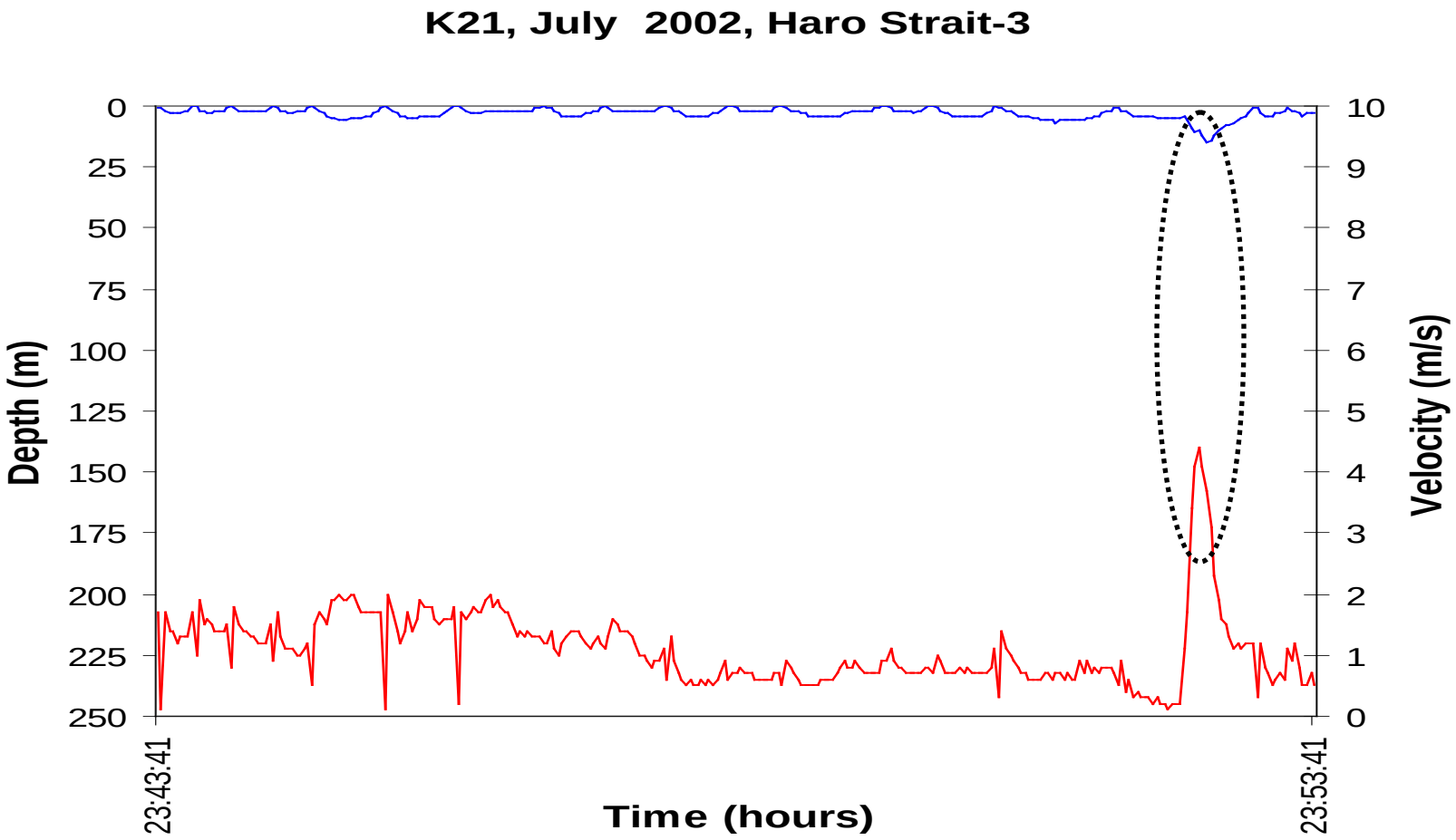
Vertical Spatial separation in salmon species may make it possible to infer whale diet based on dive behavior

Mean Depth of tagged salmon

Sockeye	**16 m (SD 6.7-28.6)** (Quinn et al. 1989)
Chinook	**70 m (SD 57)** (Candy and Quinn 1999)

Results – Time depth recorders



Velocity spikes coincide with dive apexes on some shallow dives – sockeye predation?

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An additional approach was to use a Crittercam - See www.cascadiaresearch.org

Crittercam deployed by pole on K25

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Crittercam deployment
Southern resident killer whale K25, 9 July 2002

The good news - ~1.5 hr deployment

The bad news - No foraging, only socializing

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SRKW Focal Follow behavioral foraging study

During May-September 2004-2008 we followed in the flukeprints of SRKW in a 6m vessel in the inland waters of Washington State to address 3 objectives:

1) Collect behavioral information associated with foraging by known individuals

- We looked for and classified behavioral cues; i.e., changes in speed and direction, associations with other whales, dive durations

Objective was to better define "foraging" behavior

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Project collaborators

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Cascadia Research Collective

John Ford **John Candy** **Brian Gisborne**
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Center for Whale Research

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University of Washington

And lots of volunteers

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Foraging behavior can be very subtle

Previous studies indicated that foraging was typically associated with High Energy behaviors such as chases, fast directional and fast non-directional surfacings

Success of prey remains collection based on behavior cues

Behavior state	# of cues observed	# associated collections
High energy i.e., chase, fast directional, fast non-directional	37	18 (49%)
Low energy i.e., moderate directional or non-directional, *whales converging, surfacing after a long dive*	99	31 (31%)

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Focal Follow behavioral foraging study

Whales converging – Likely prey sharing – observed by Ford and Ellis 2006 in Northern Resident killer whales

Prey sharing allowed for collection of tissues as well as scales

Following in fluke prints allowed for collection of "other items" - *feces, mucous, regurgitations*

The use molecular genetic techniques was needed for the identification of these tissues and "other items"

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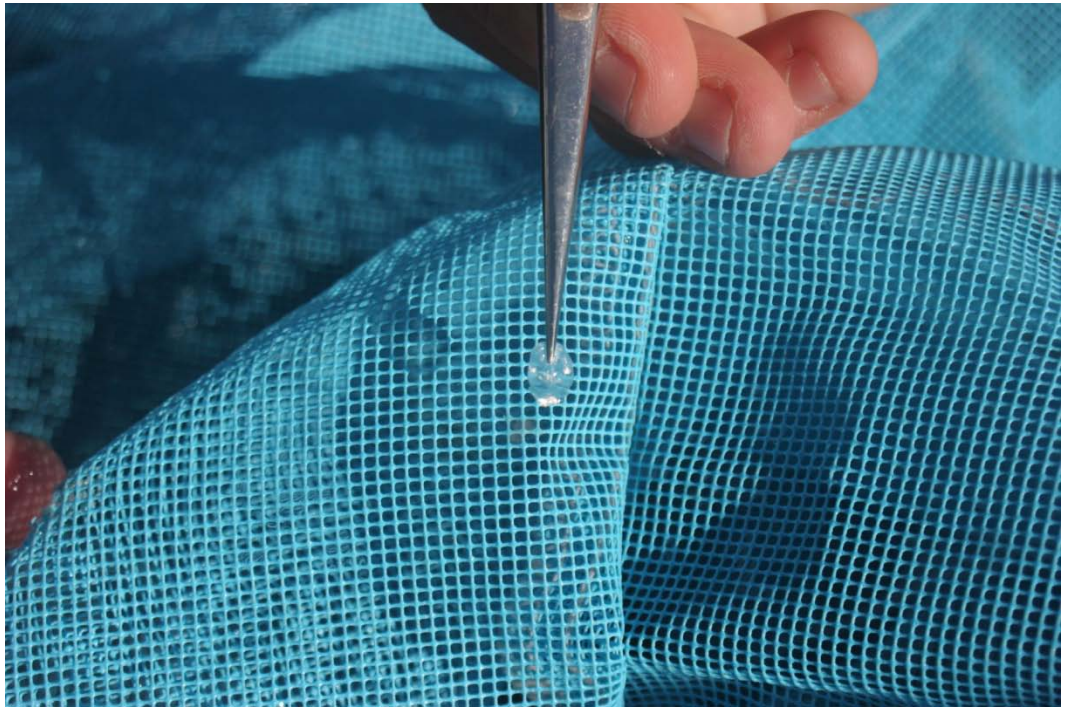
2) Collect remains from predation events to determine prey selection

- prey remains (scales, tissue) were collected with a fine mesh net

Species identification and age were determined from:

- identifying characteristics of fish scales



Fish scale being removed from a sampling net

Objective was to obtain a contemporary sample of sufficient size to accurately determine prey preferences

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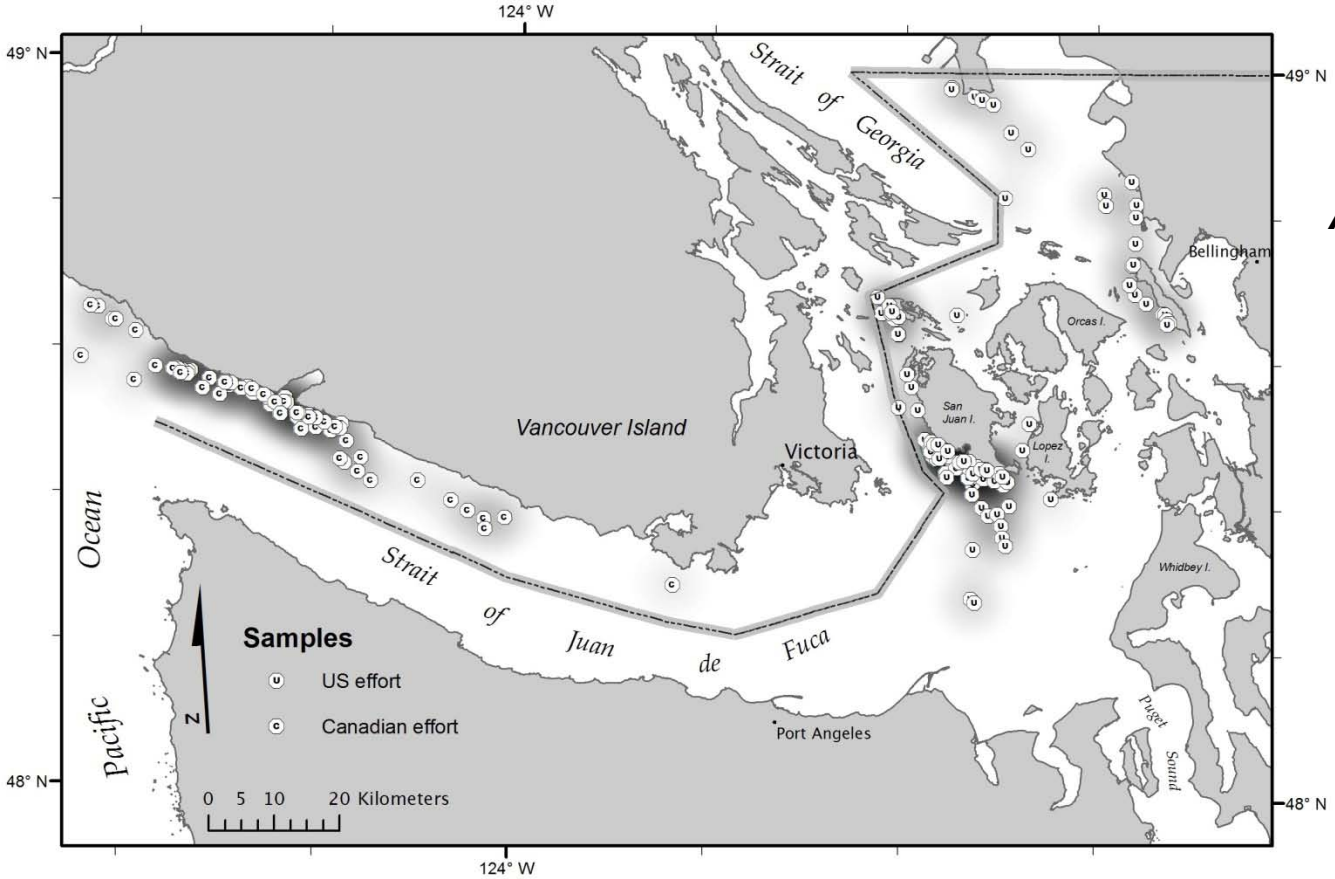
Summer predation event locations in inland waters



A collaborative effort between DFO and U.S. researchers

DFO predation event collections were in western Strait of Juan de Fuca

U.S. collections were located throughout the San Juan Islands but primarily in "core habitat" off the southwest side of the San Juan Islands

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3) Collection of *feces and "other items" - regurgitations, mucous* – some of which could also be used to identify prey items

Advantages to feces and regurgitations

1) Avoids potential biases of surface predation events

2) Integrates foraging over a longer duration

These samples also allowed us to the test the hypothesis that SRKW have a broader, less Chinook-dominated diet

Fecal sample being removed from a net with a gauze pad

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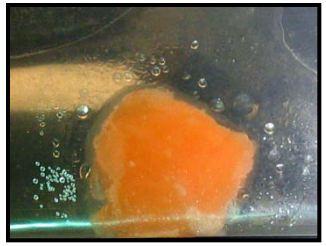
Genetic Analysis of Killer Whale Prey Samples:

Scales

Tissue Fragments

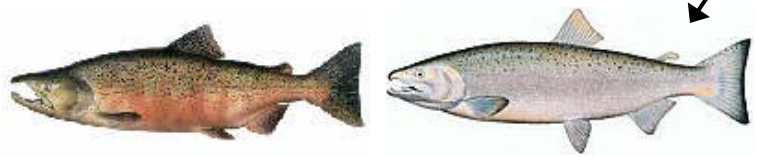


Fecal

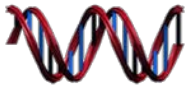
Chinook ?

?

Coho ?



1. DNA Extraction



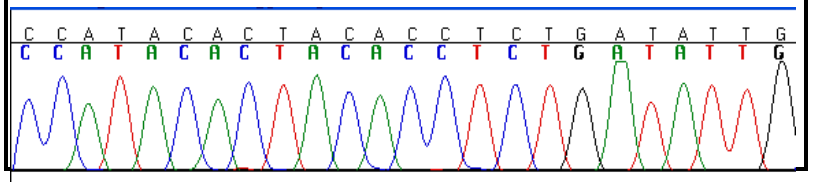
2. Polymerase Chain Reaction (PCR) & Sequencing

3. Species ID

To identify the species from unknown prey fragments their DNA was compared to DNA from known species standards

Sequence Diagnostic Sites for Species ID of Salmonids

Nucleotide site:	26	47	50	68	80	86	92	110	113	134	140	143
Chinook	C	C	A	G	A	T	C	G	C	A	T	T
Coho	C	A	A	A	A	T	C	A	T	A	T	T
Chum	C	A	A	A	T	T	T	A	T	A	T	T
Pink	A	A	A	A	T	T	C	A	T	G	T	T
Sockeye	C	G	A	A	T	C	C	A	T	A	T	T
Cutthroat	C	A	T	A	T	T	C	A	T	A	T	T



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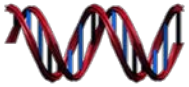
Genetic Analysis of Killer Whale Prey Samples:

Fecal

1. DNA Extraction



2. PCR & Sequencing

3. Species ID

? Fecal samples also screened for a number of other fish species previously reported in resident-type killer whales diets including:

- **Rockfish – 15 species**
- **Sole - 5 species**

- **Starry Flounder**
- **Pacific Halibut**
- **Irish Lords**
- **Sculpin**
- **Sablefish**
- **Greenling**
- **Lingcod**
- **Cabezon**
- **Pacific Herring**

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Use of molecular genetic techniques doubled sample size

Sampling Month	# Days of effort	# of Scale samples collected	# of Tissue samples collected	# of Fecal samples collected	# of Other samples collected
May 2006-8	11	4	11	2	3
Jun 2005-8	30	43	27	26	4
July 2005-8	17	19	1	6	0
Aug 2004-8	8	17	5	20	5
Sep 2005-8	12	14	16	47	1
Total	**114**	**97**	**60**	**101**	**13**

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Based on Scales and Tissues the prey selected were mostly salmon, primarily Chinook, in most months

Number of Prey identified from scales and genetic analyses of fish Scales, or Tissue

Sampling Month	Chinook	Steelhead	Chum	Sockeye	Pink	Coho	Other
May 2006-8	9	6					
Jun 2005-8	49	3	3			1	1
July 2005-8	21			1			
Aug 2004-8	25			3		2	
Sep 2004-8	27	3				4	
Total	131	12	3	4		7	1

- Few Sockeye and no Pink salmon in sample

- Only one non-salmonid fish

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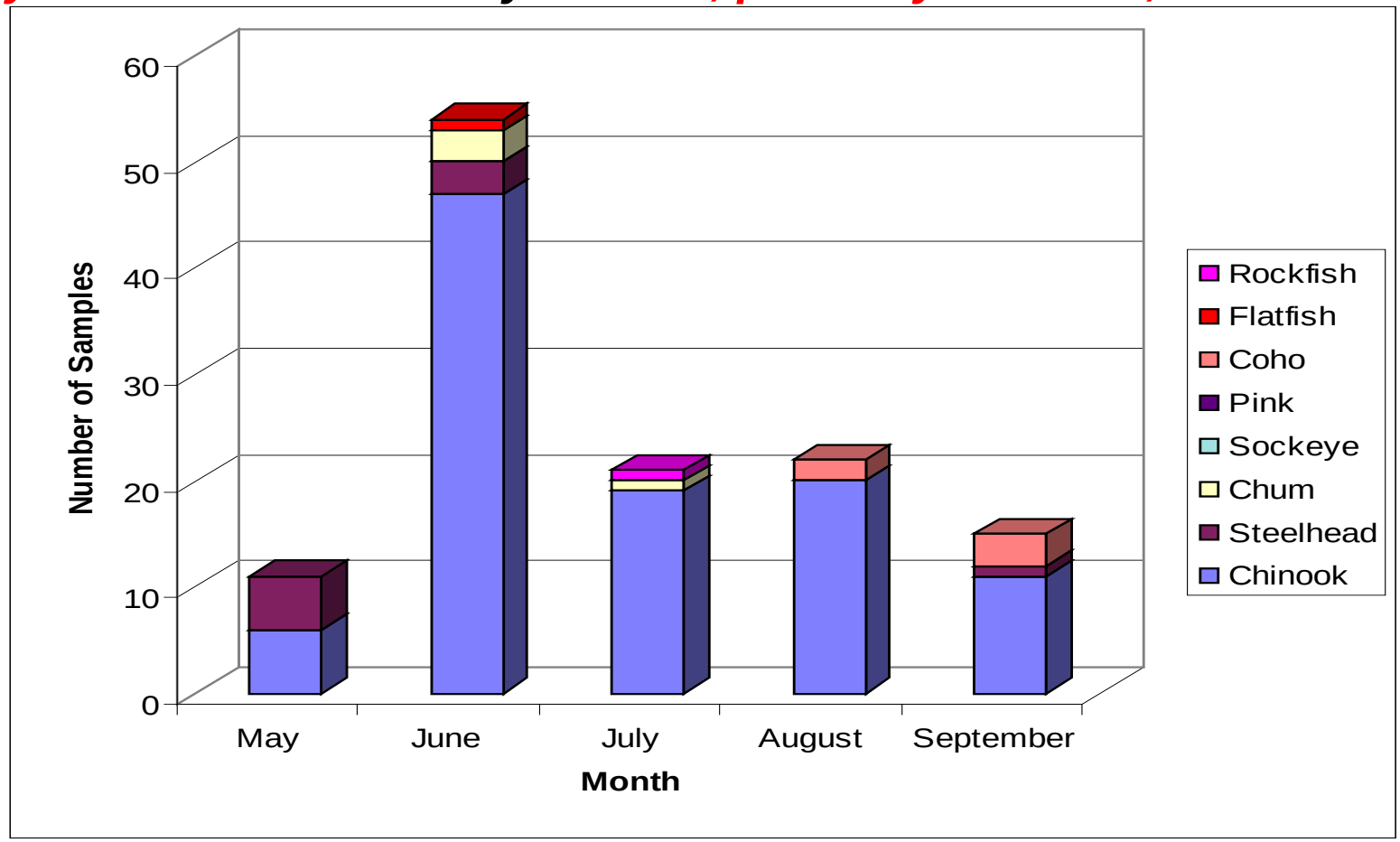
Number of Prey identified from scales and genetic analyses of fish Scales, or Tissue

Prey selected were mostly salmon, primarily Chinook, in most months



Note - Some Steelhead in May and June
Some Coho in August and September

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Based on Feces the prey selected were mostly salmon, primarily Chinook, in most months

Number of Prey identified from scales and genetic analyses of fish Scales, or Tissue

Sampling Month	Chinook	Steelhead	Chum	Sockeye	Pink	Coho	Other
May 2006-8	2						
Jun 2005-8	17						1
July 2005-8	4						
Aug 2004-8	11						2
Sep 2004-8	14	2	2			16	5
Total	48	2	2			16	8

- No Sockeye or Pink salmon in sample

- Only a few non-salmonid fish

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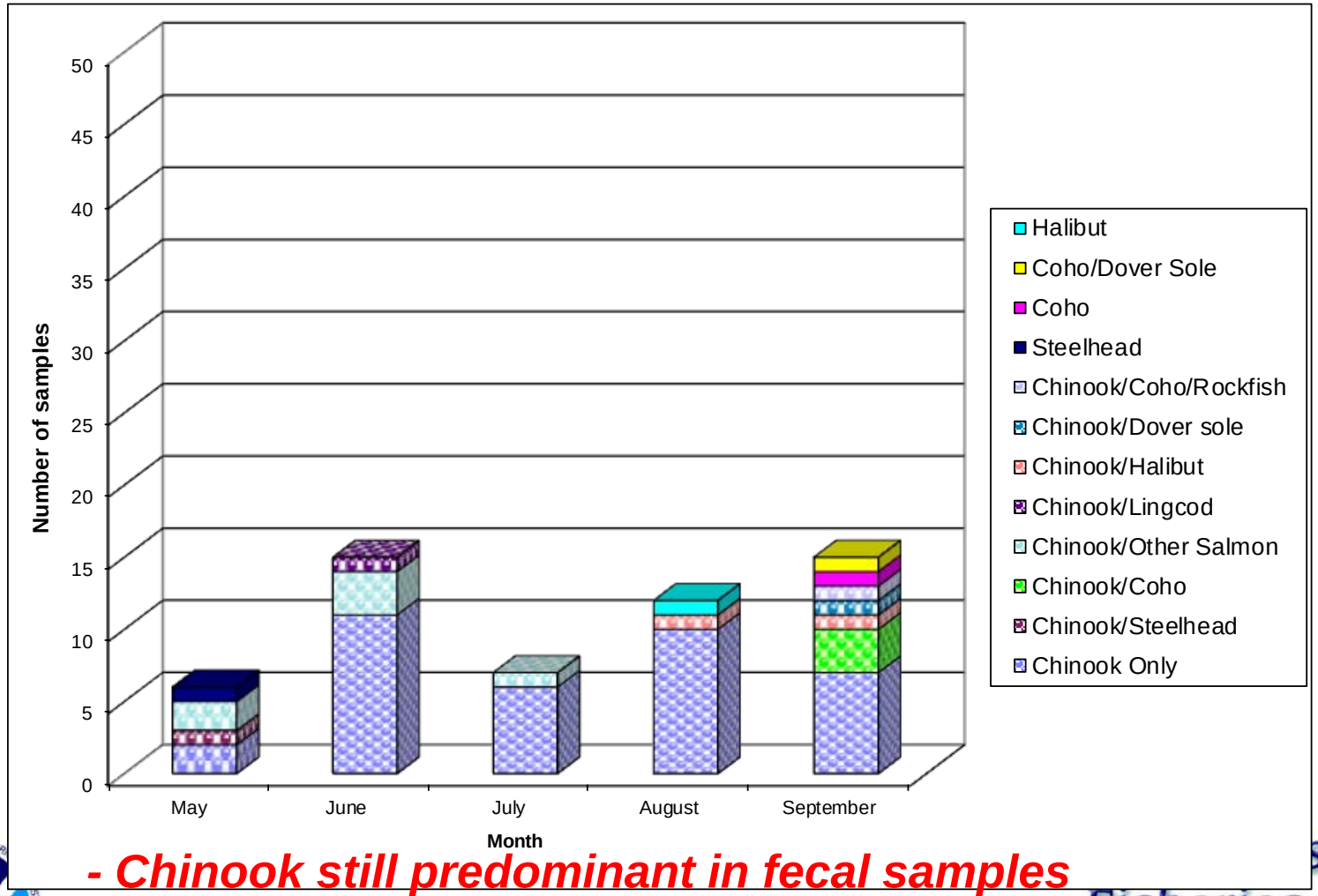
Prey in Feces included a wider variety of species in May and September



- Chinook still predominant in fecal samples

- Important to note that presence is number of samples not proportional contribution to diet

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SRKW Focal Follow behavioral foraging study

Alternative analysis to better assess the relative proportion each prey item represented in the diet used cloning libraries

16 September samples (from 2007 and 2008) were pooled

Species	Frequency of Occurrence Number samples (%)	Quantitative DNA Cloning Percentage of DNA in pooled sample
Chinook	14 (61%)	83%
Coho	5 (22%)	16%
Halibut	1 (5%)	0.8%
salmonid	-	<0.4%
Dover sole	2 (9%)	Not detected
Rockfish	1 (5%)	Not detected

-Chinook and Coho have similar contribution to diet as Cloning
-Frequency of Occurrence over-represented prey species infrequently eaten

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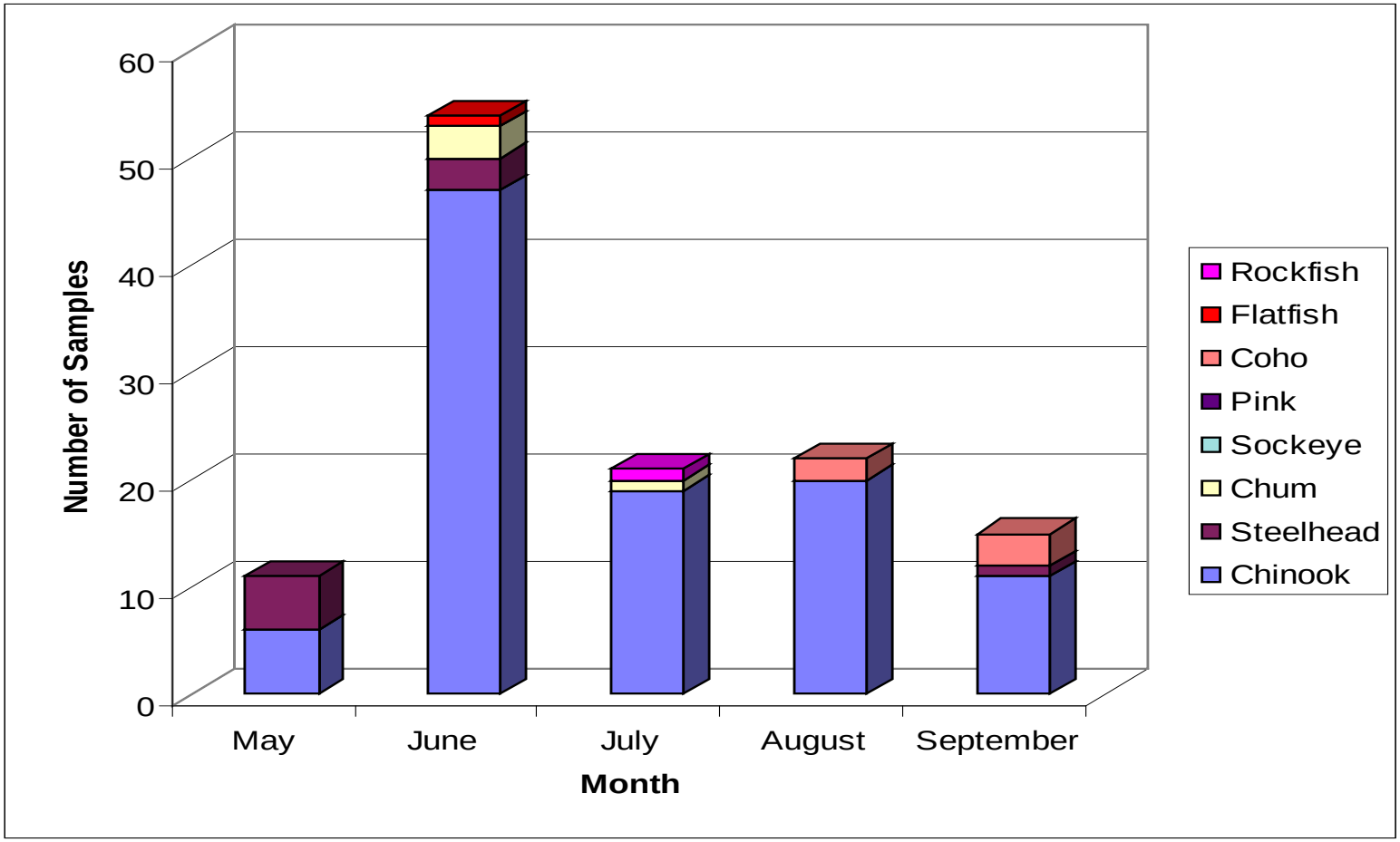
Which stocks were these Chinook from?

Number of Prey identified from scales and genetic analyses of fish Scales, or Tissue



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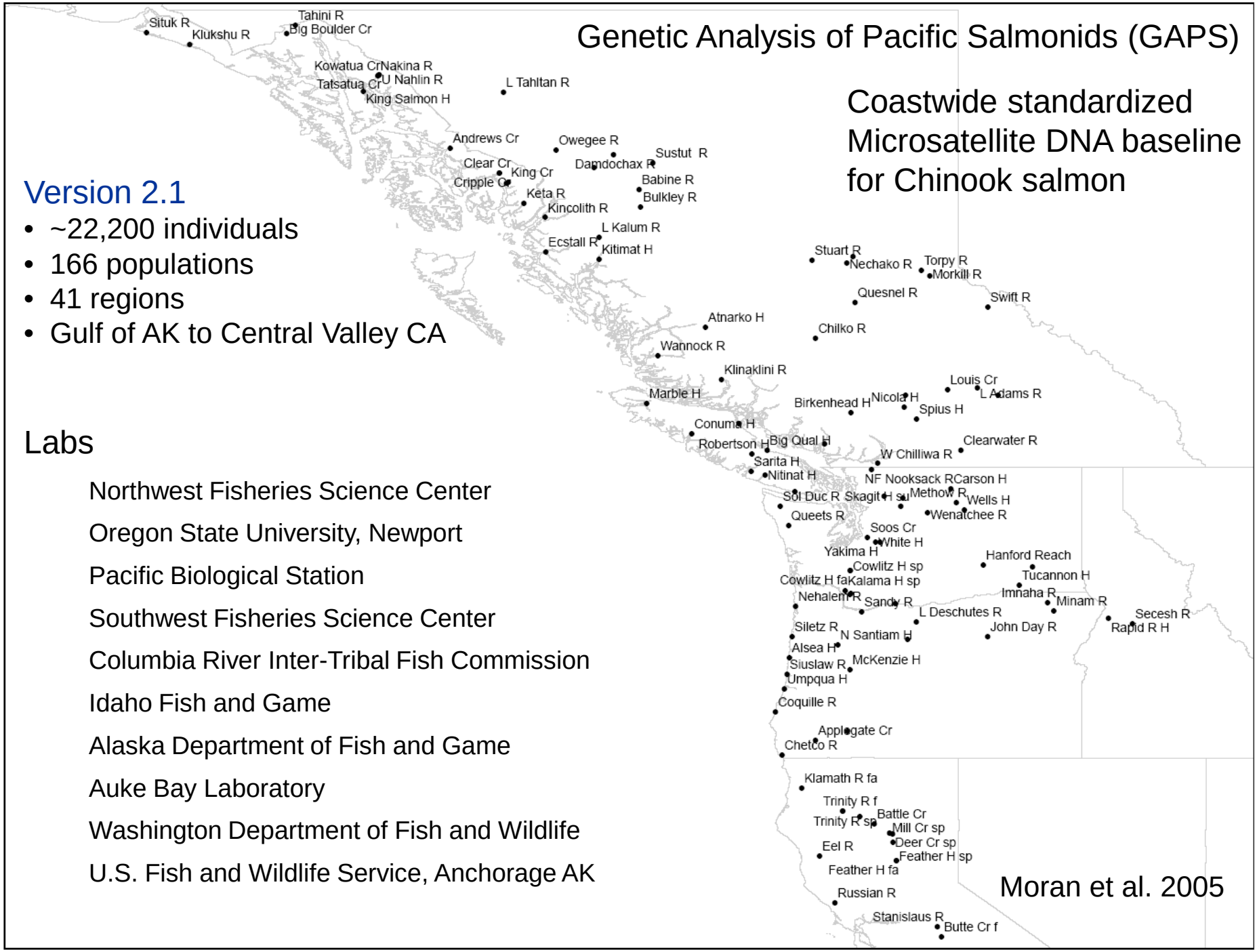
Genetic Analysis of Pacific Salmonids (GAPS)

Coastwide standardized Microsatellite DNA baseline for Chinook salmon



Version 2.1

- ~22,200 individuals
- 166 populations
- 41 regions
- Gulf of AK to Central Valley CA

Labs

Northwest Fisheries Science Center

Oregon State University, Newport

Pacific Biological Station

Southwest Fisheries Science Center

Columbia River Inter-Tribal Fish Commission

Idaho Fish and Game

Alaska Department of Fish and Game

Auke Bay Laboratory

Washington Department of Fish and Wildlife

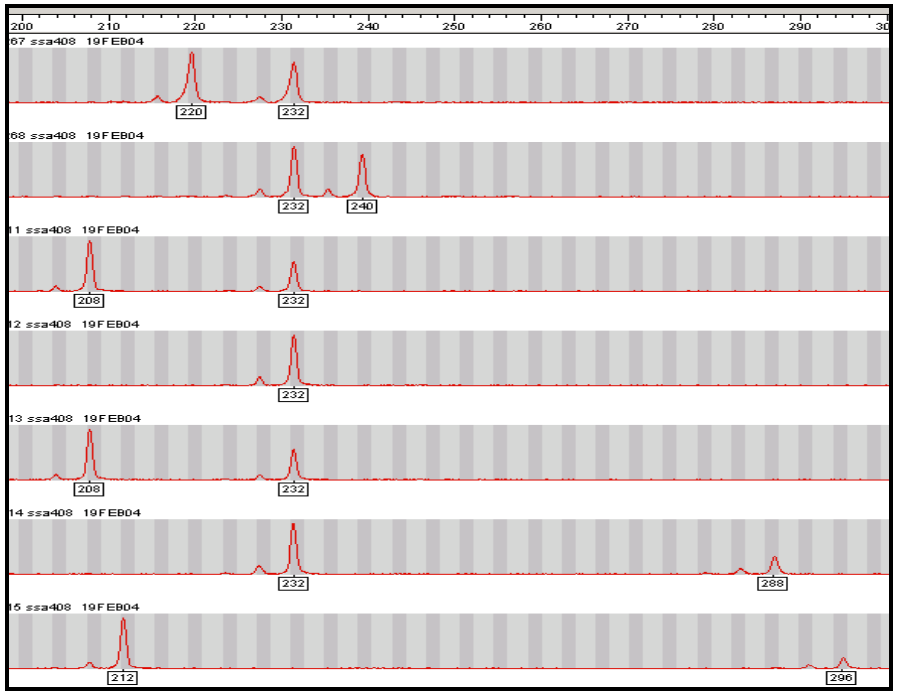
U.S. Fish and Wildlife Service, Anchorage AK

Moran et al. 2005

Genetic Stock Identification of Chinook Prey Samples:

Genotyping Chinook Prey Samples

13 polymorphic microsatellites



Genetic Stock Identification (GSI)

Genotypes of the prey samples are compared to the allele frequencies of the baseline samples to determine which region the sample is most genetically similar to, and thus is its most likely region of origin.

Proportional contributions of the reporting groups to overall prey sample were estimated using the Bayesian method in the program cBayes

Examples:

Sample 1 = Upper Fraser p=1.0

Sample 2 = North Puget Sound p=0.95 South Puget Sound p=0.05

Sample 3 = North Thompson p=0.70 Central Valley p=0.30

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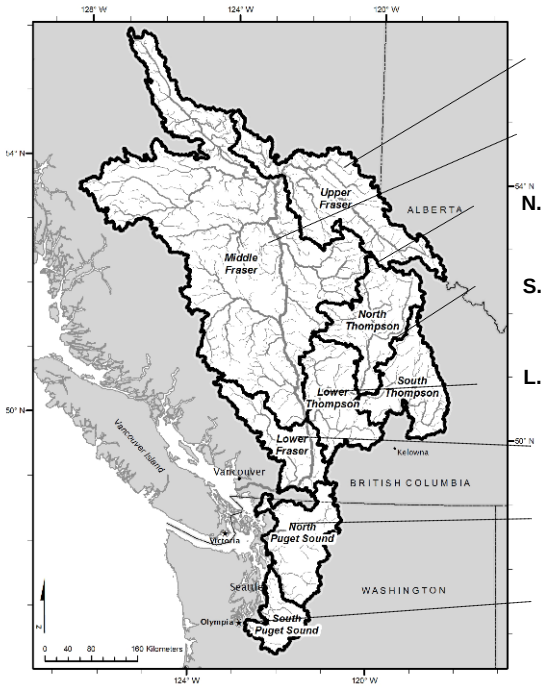
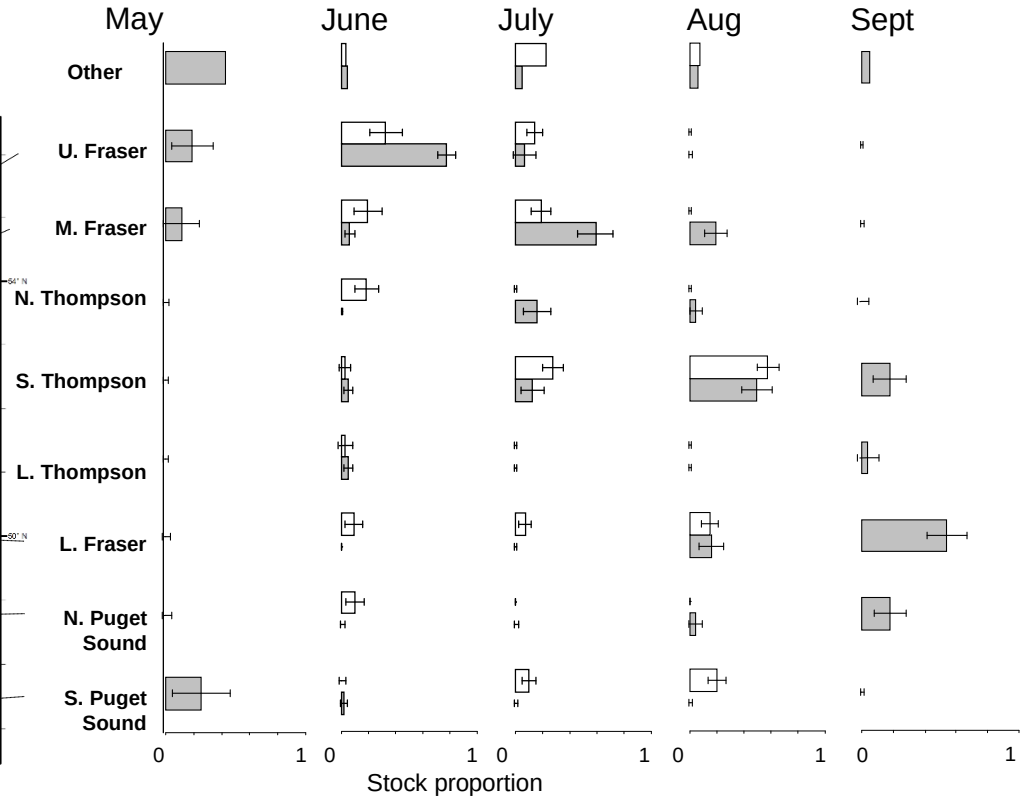
Fraser River is of primary importance





Prey sampling location

Strait of Juan de Fuca

San Juan Islands

Upper, Middle, and Lower Fraser, and South Thompson are seasonally important

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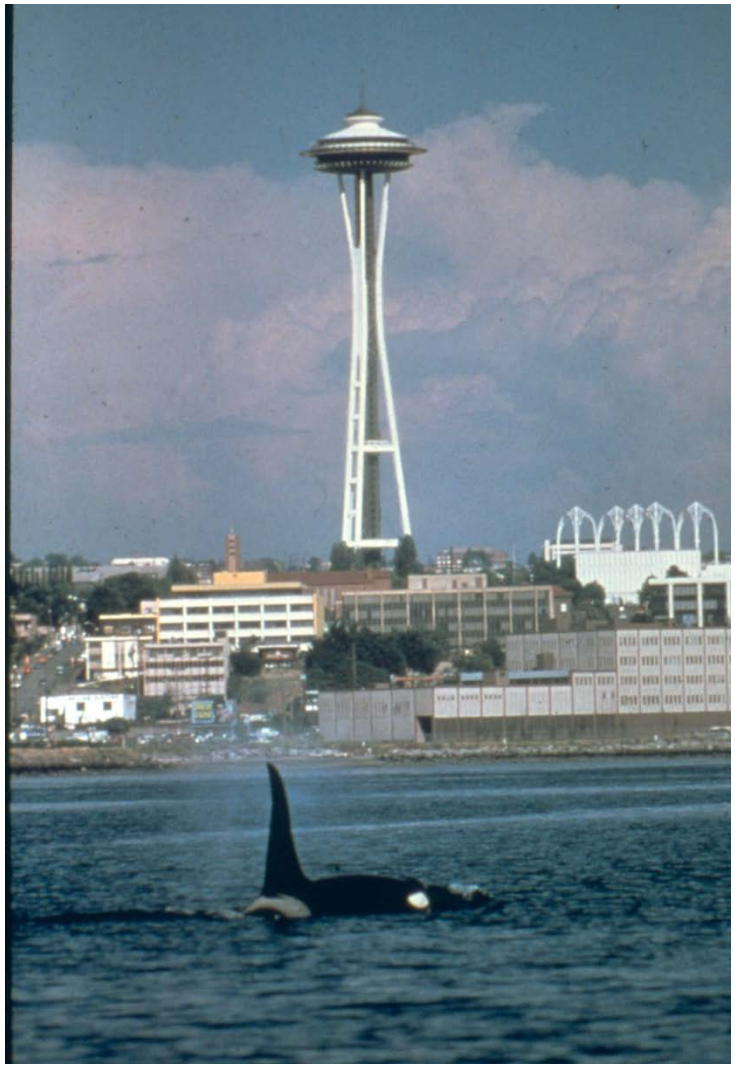

Photo by Ken Balcomb

What do SRKW eat when they are in Puget Sound?

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Project contributors

Mark Sears Maya Sears Annie Stateler

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Orca Network

Jeff Hogan Amy Carey

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Ken Balcomb
Center for Whale Research

Robin Baird Greg Schorr
Cascadia Research Collective

And lots of volunteers

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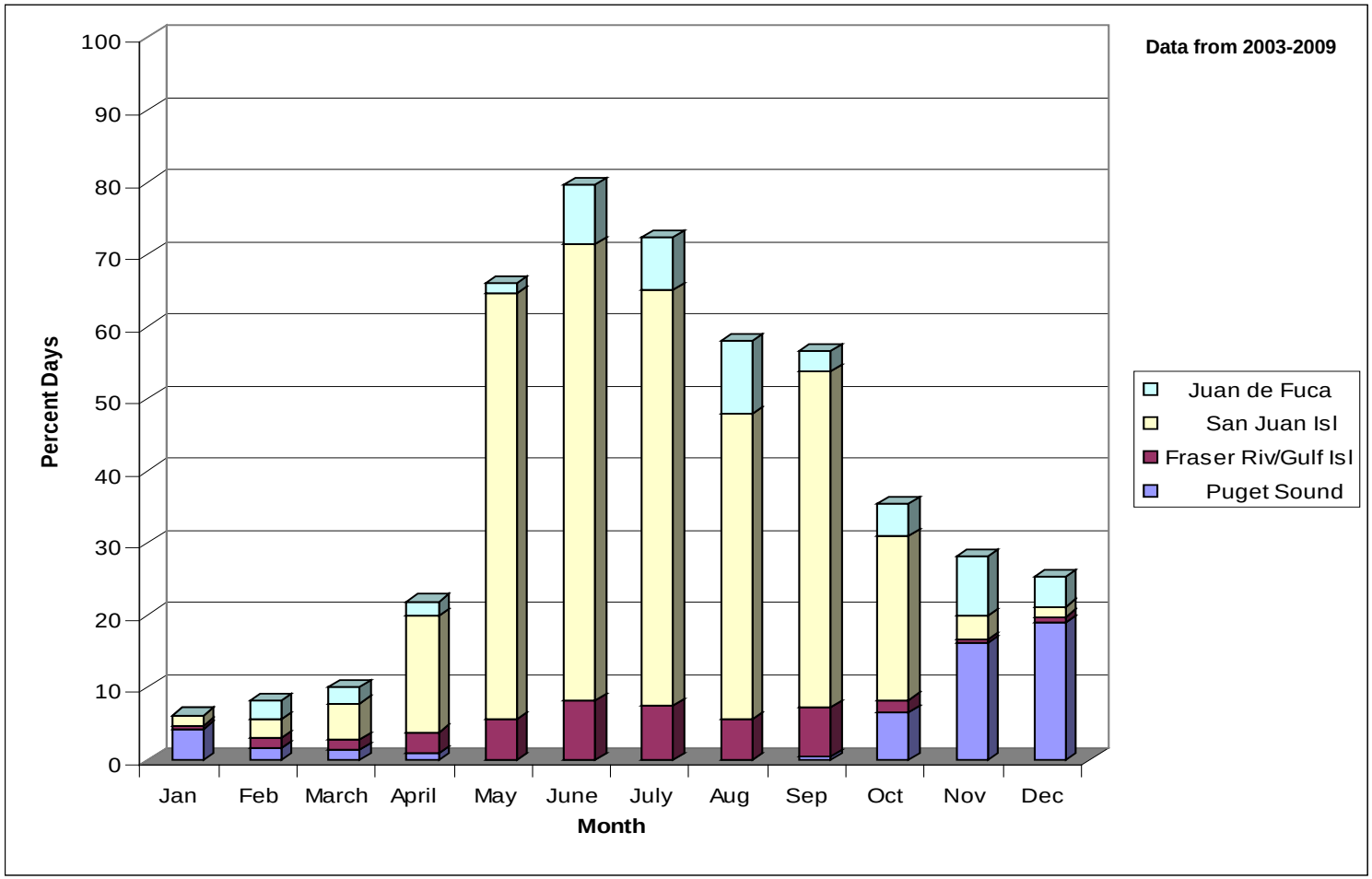
Percentage of time any Southern resident killer whale pods were present in fours areas of inland waters



SRKWs present in Puget Sound more than any other area of inland waters in the fall

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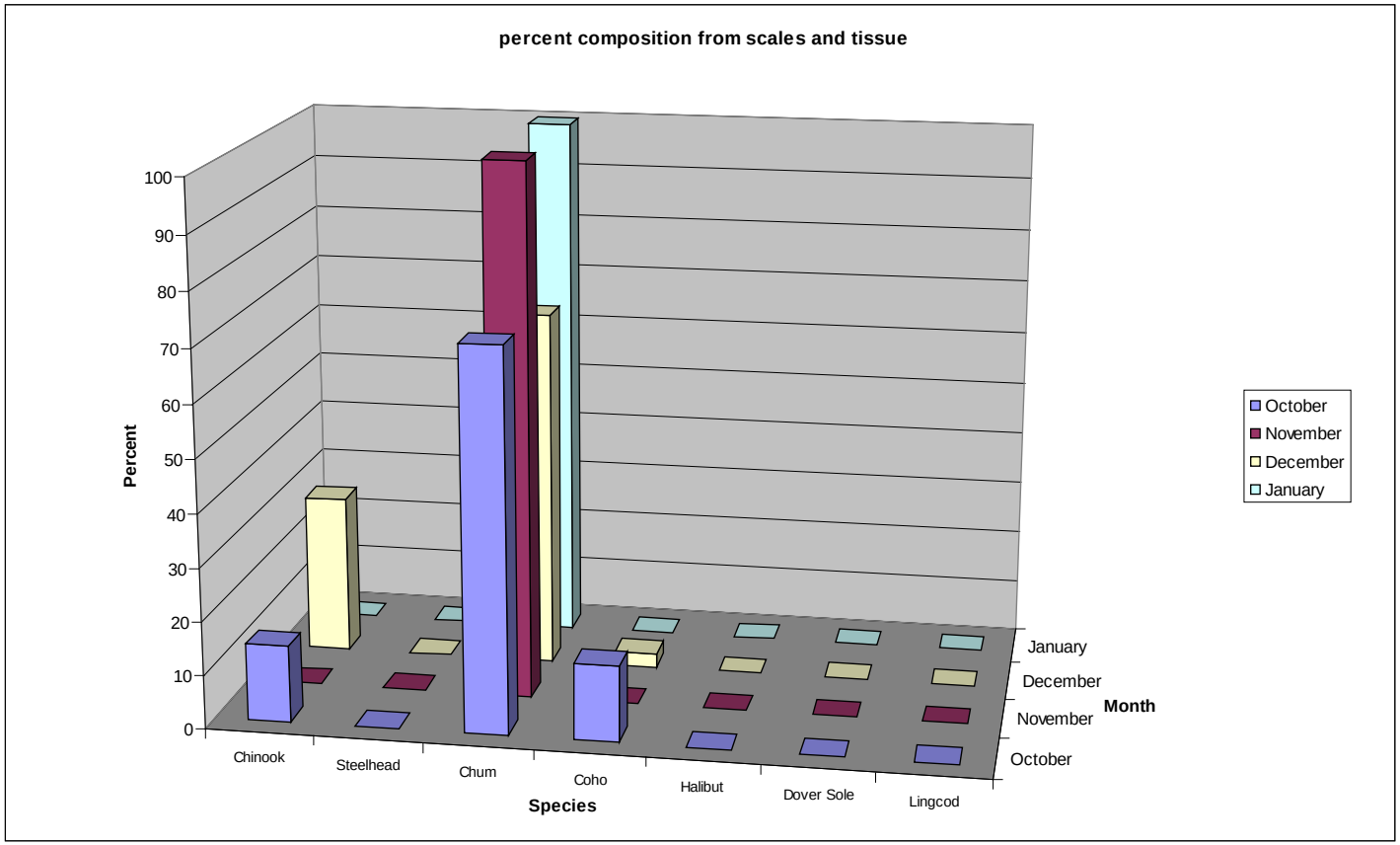
Which prey species do SRKW eat in Puget Sound?

Number of Prey identified from scales and genetic analyses of fish Scales, or Tissue



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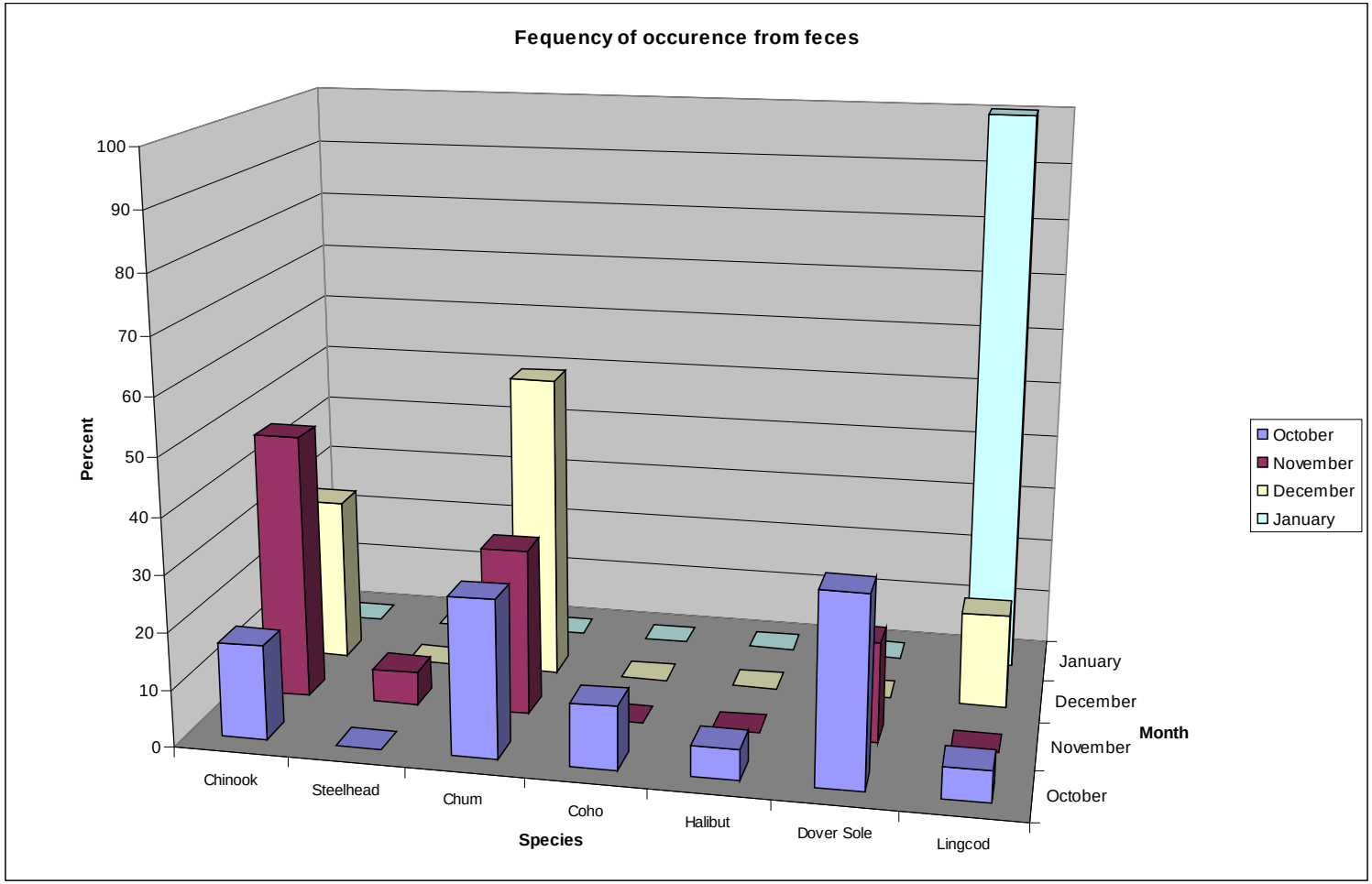
Prey in Feces included a wider variety of species in October-January



- Chinook more prevalent in fecal samples

- Note that percent is based on frequency of occurrence not proportional contribution to diet

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SRKW Focal Follow behavioral foraging study

Alternative analysis to better assess the relative proportion each prey item represented in the diet used cloning libraries

16 samples (seven from November and nine from December) were pooled

Species	Frequency of Occurrence Number samples (%)	Quantitative DNA Cloning Percentage of DNA in pooled sample
Chinook	11 (69%)	52%
Steelhead	1 (6%)	< 0.01%
Chum	10 (63%)	47%
Coho	Not detected	< 0.01%
Dover sole	6 (13%)	Not detected
Lingcod	4 (25%)	< 0.01%

-Chinook and Chum have similar contribution to diet
-Frequency of Occurrence over-represented less frequently eaten prey items

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What do SRKW eat when they are on the outer coast?

Ocean-class vessel cruises

Since 2004 the NWFSC has had five 8-21 day cruises on the McArthur II

SRKWs located on 4 of 5 cruises - 7 additional sightings since 2004 as well as short-term movement patterns and prey samples

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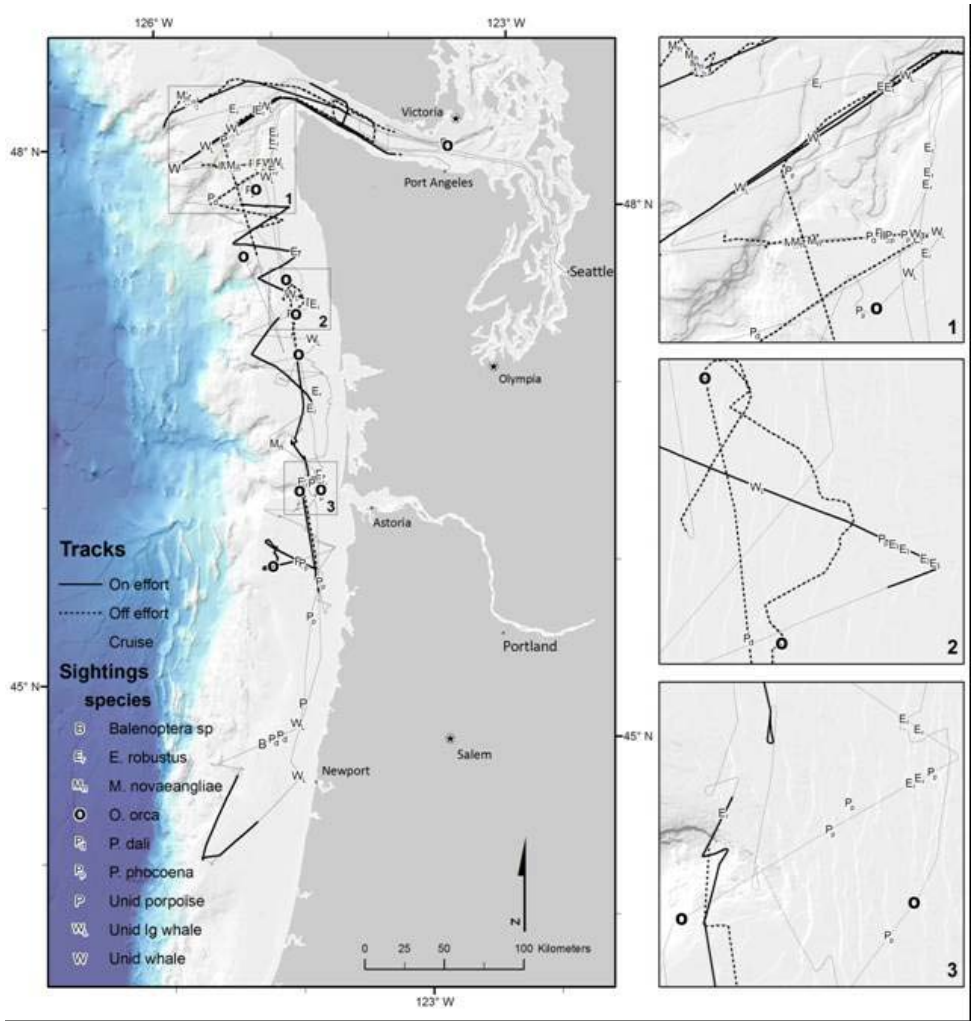

2 scale/tissue samples collected during March 2009 cruise off the Washington coast

Both samples were Columbia River Chinook

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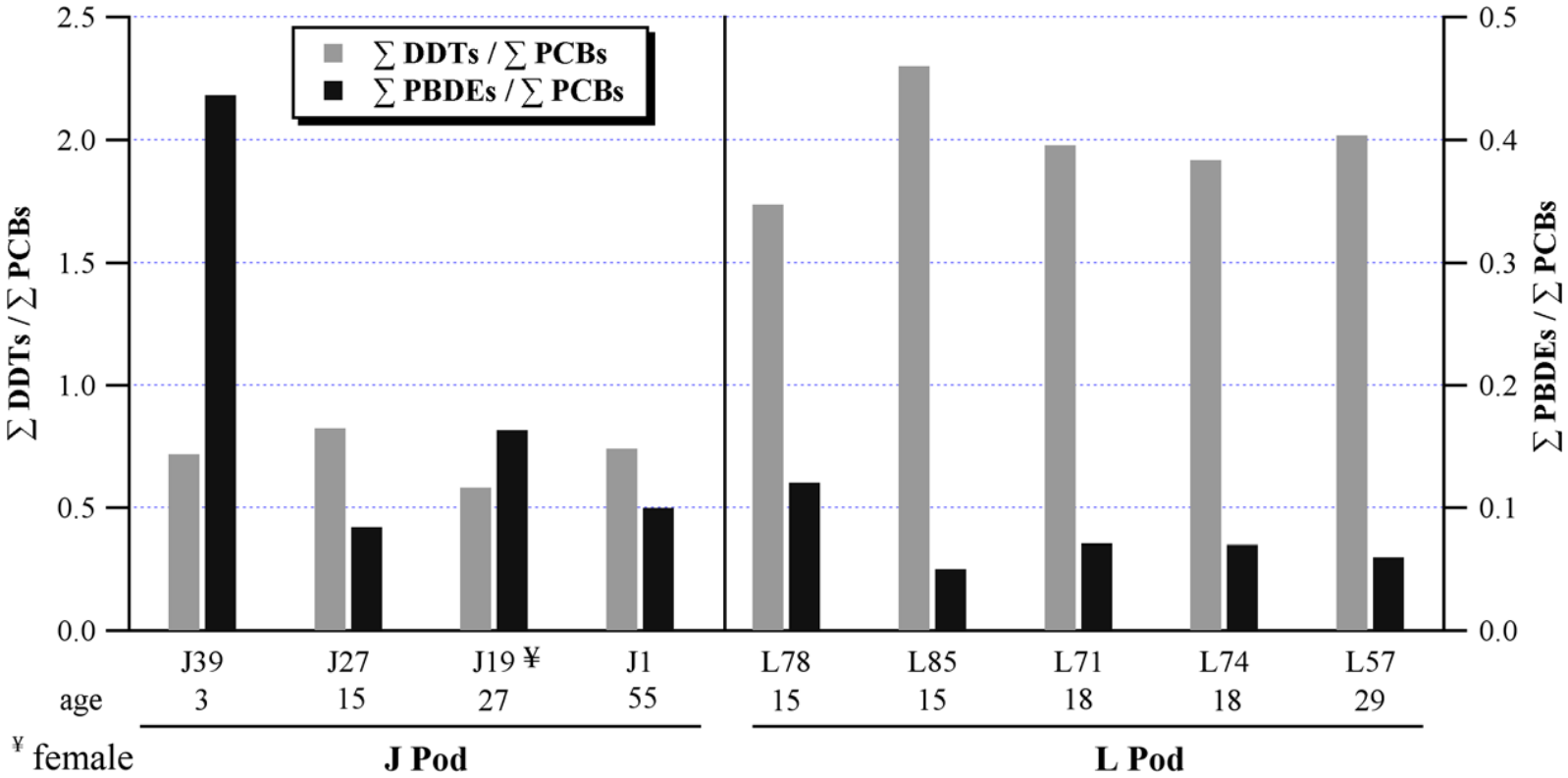
Use of Contaminant ratios to infer diet of SRKWs



Higher DDT/PCB ratios in L pod indicate that they foraging on prey that occur further south than J pod – consistent with California sightings of L and K pods

Higher PBDE/PCB ratio in J pod suggests their prey are closer to an urban source

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Questions?

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