Resident killer whale feeding habits:
Assessment methods, winter diet, and chum stock ID

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Methods of assessing diet in killer whales

1. Chemical tracers (fatty acids, stable isotopes, contaminants) from skin and blubber biopsies
2. Prey remains in stomachs of stranded animals
3. Direct observation at surface
4. Prey fragments (scales and tissue) recovered from predation sites
5. Fecal sampling

Strengths and weaknesses of diet assessment methods

1. Chemical tracers (fatty acids, stable isotopes, contaminants) from skin and blubber biopsies

Method	Advantages	Limitations
Contaminant ratios	• Can provide spatial information on foraging region	• Coarse resolution • only distinguishes areas differing in contaminant levels
Stable isotopes	• Provides information on trophic level, some spatial (latitude, inshore/offshore) • Integrates diet over long period (> 75 days)	• Low resolution inference of diet (trophic level)
Fatty acid signatures	• Potentially greater resolution of prey types than SIs	• Stratification of blubber in killer whales limits utility

Strengths and weaknesses of diet assessment methods

2. Prey remains in stomachs of stranded animals

Advantages	Limitations
• Integrates diet over past few meals • Prey identifiable from hard parts and/or DNA	• Differential prey digestion and retention • Individual's diet may not represent population • Difficult to distinguish indirect prey • Strandings very rare, stomachs often empty

Strengths and weaknesses of diet assessment methods

3. Direct observation

Advantages	Limitations
• Surface observation simple; does not require sample collection	• Limited to prey pursued at or brought to surface • Species ID may be limited to genus or family • ID of sex, stock not possible

Strengths and weaknesses of diet assessment methods

4. Prey fragments (scales and tissue) recovered from predation sites

Advantages	Limitations
• High resolution prey identification: species, sex, age, stock • Individuals involved in predation can be ID'd • Can be used to determine feeding rates, CPUE	• Predation at depth may be under represented • Differences in prey handling and consumption may introduce bias e.g., large prey may be broken up and over represented; spp differences • Potential for species that readily shed scales or tissue fragments to be over represented • Whales must be sampled while foraging during daylight hours

Strengths and weaknesses of diet assessment methods

5. Fecal sampling

Advantages	Limitations
• Sampling not restricted to foraging activity • Integrates predation over longer periods • No bias due to distribution of prey in water column • Individual whale ID possible from DNA • New analytical techniques allow rapid quantification of DNA in samples (e.g., multiplex PCR, high throughput sequencing)	• Resolution currently limited to presence/absence or "semi-quantitative" proportions of prey in feces • DNA in subsamples of feces may not be representative of whole[1] • Prey-specific differences in contribution of DNA to feces due to differential DNA density and/or survival post-digestion[2] • Potential biases in scat type (e.g., solid, floating vs dispersed cloud)

• [1]Deagle et al. 2005. Mol. Ecol.
• [2] Deagle and Tollit 2007. Conserv. Genetics; Deagle et al. 2010. Conserv. Genetics

How reliable are prey fragments in diet assessment of resident killer whales?

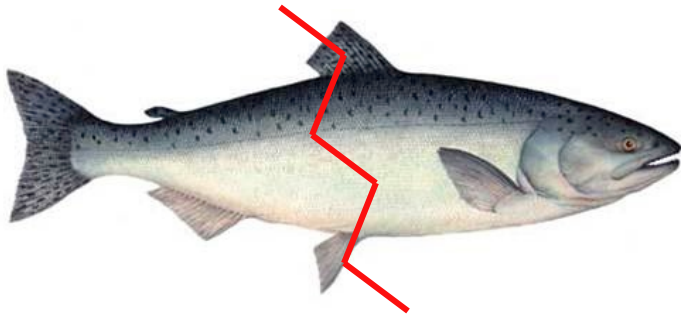
1. Are surface-oriented prey over-represented?
2. Are large prey sizes over-represented?
3. Are fish with scales that are easily shed over-represented?

1. Are surface oriented prey over-represented?

- Focal animal and group observations and u/w video indicate salmon prey routinely brought to surface and broken up, usually for sharing
- Adult females shared 90% of prey, males 24%, and subadults 59% (n = 213 feeding events)

1. Are surface oriented prey over-represented?

- Stomach contents of three stranded residents consistent with sharing of salmonids, but not necessarily other species:
  - A09: 19 Chinook, anterior bones only; 15 lingcod (only 2 large), mostly complete
  - C16: 6 Chinook, anterior bones only; 5 halibut, 18 Dover sole, apparently complete
  - Unknown SR female: 1 Chinook, posterior bones only



1. Are surface oriented prey over-represented?

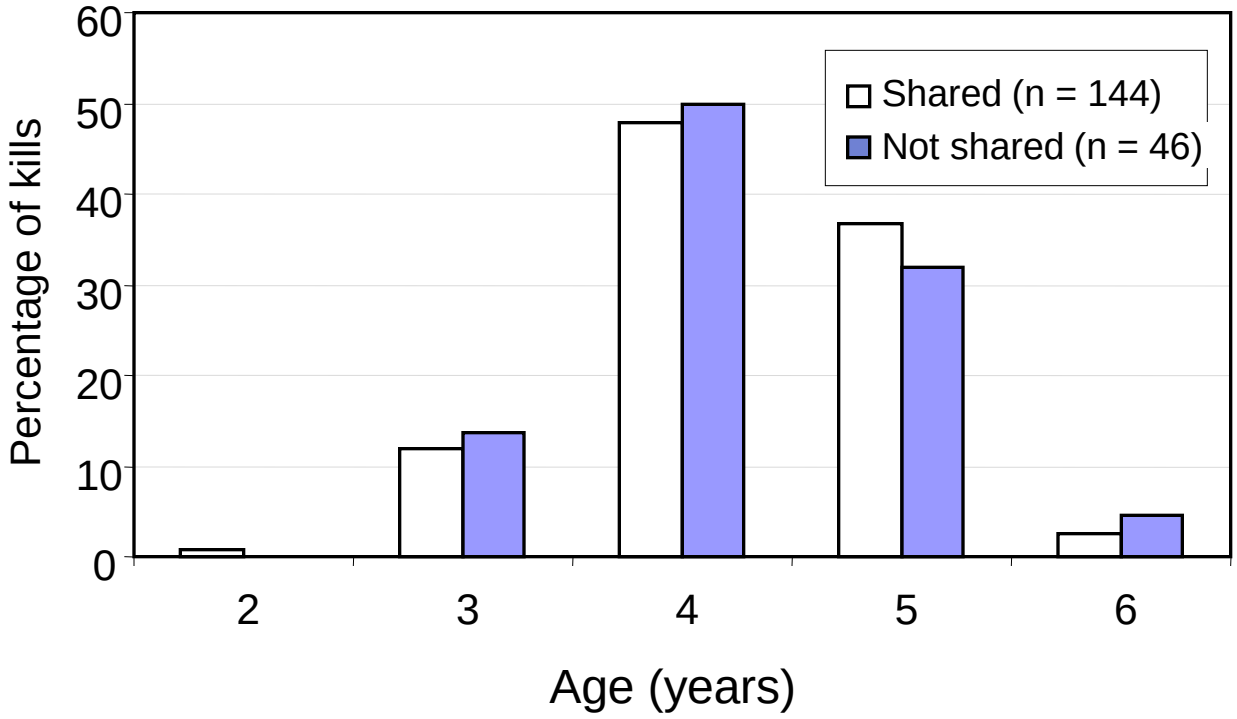
- Tracking studies in Johnstone Strait indicate that Chinook swim at a mean depth of 69.9 m (± SD 57.3), max 398 m
- Sockeye tracked in same area swam at mean depth of 14.9 m (± SD 57.3)
- Sockeye rarely appear in prey samples, despite being > 4 times shallower than Chinook on average

Source: Candy and Quinn. 1999. Can. J. Zool.

2. Are large prey sizes over-represented?

- Sharing observed in all salmonid species taken by RKW
- No significant difference in age distribution of shared vs non-shared

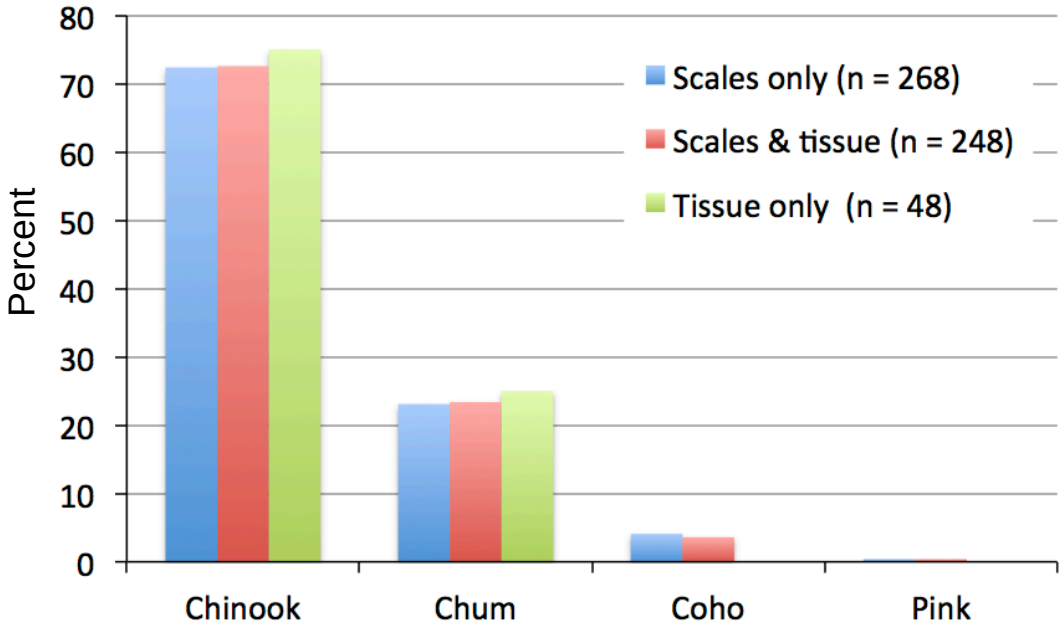
Mean Chinook ages:
shared = 4.28 yrs (±0.07SE, n = 117)
not shared = 4.27 yrs (±0.16SE, n = 32), p=0.87



Source: Ford and Ellis 2006. MEPS 316:189-199

3. Are fish with scales that are easily shed over-represented?

- Both scales and tissue were collected in ≈ 50% of feeding events involving salmonids (2004–2011)
- Frequency distribution similar between scales only, scales & tissue, and tissue only samples



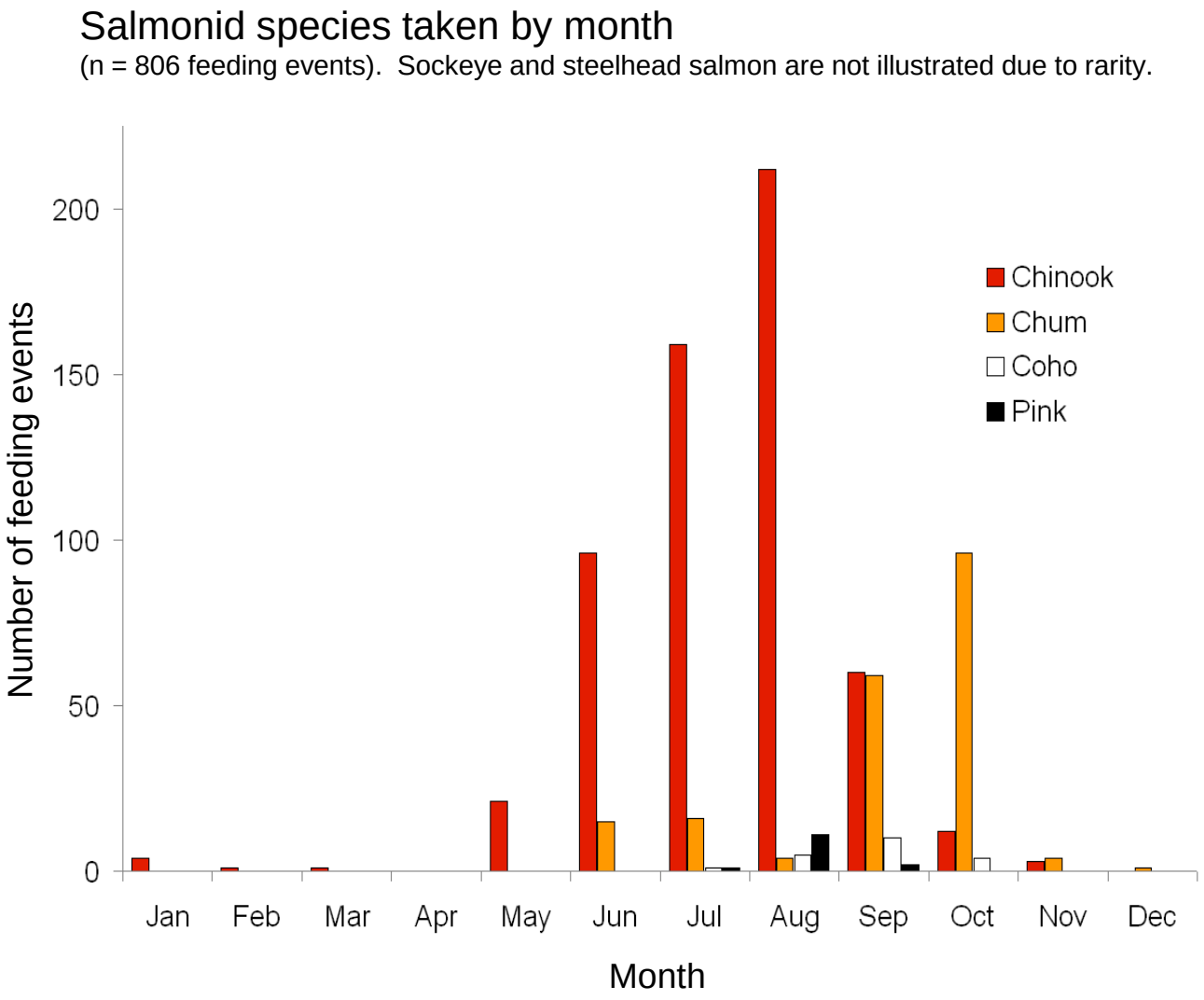
How reliable are prey fragments in diet assessment of resident killer whales?

- No evidence that frequency of salmonids in prey fragment sampling is seriously biased
- Prey species IDs from fecal DNA generally consistent with results of prey fragment sampling (Hanson 2011 Workshop 1)
- Fecal samples revealed more non-salmonids than did prey sampling, but proportions of DNA suggest minor contribution to diet (Hanson 2011 Workshop 1)
- Stomach contents also suggest non-salmonids may be under represented in prey fragment sampling

Conclusion

- Both prey fragment and fecal sampling equally important techniques
- Fragment sampling better for accurately determining proportions of salmonids in diet, rates of prey capture in foraging bouts, and identifying when and where prey are captured
- Fecal sampling better for determining presence of non-salmonids, identifying prey taken over periods of up to several days

What are resident killer whales eating in winter?



Source: Ford et al. 2010 CSAS Res Doc 2009/101

Winter – Spring Predation by RKW

late November

- Northern residents, Dixon Entrance 22 Nov 2009

- 5 kills, all Chinook:
  - 0.2 SOTH (L_Thompson)
  - 1.1 Up Willamette (Sandy)
  - 0.2 NOTH (Barriere)
  - 0.2 ECVI (Puntledge_F)
  - 1.2 Up Col-Su/F (Hanford Reach)

Winter – Spring Predation by RKW

late November

- Northern residents, Clarence Strait, SE Alaska, 30 Nov 2009

- 2 kills, both Chinook:
  - R.2 Skeena Mid (Skeena@Terrace)
  - ?.? SOMN (Klinaklini)

Winter – Spring Predation by RKW

late November

- Southern residents (K pod), Puget Sound, 17-20 Nov 2004

- 5 kills, all salmon:
  - 0.2 yr Chinook
  - ? Yr Chinook, LWFR-F (W Chilliwack)
  - 5 yr Chum
  - ? Yr Chum
  - Unidentified salmon

Winter – Spring Predation by RKW

late November

- Southern residents (J pod), Juan de Fuca Strait, 20 Nov 2004

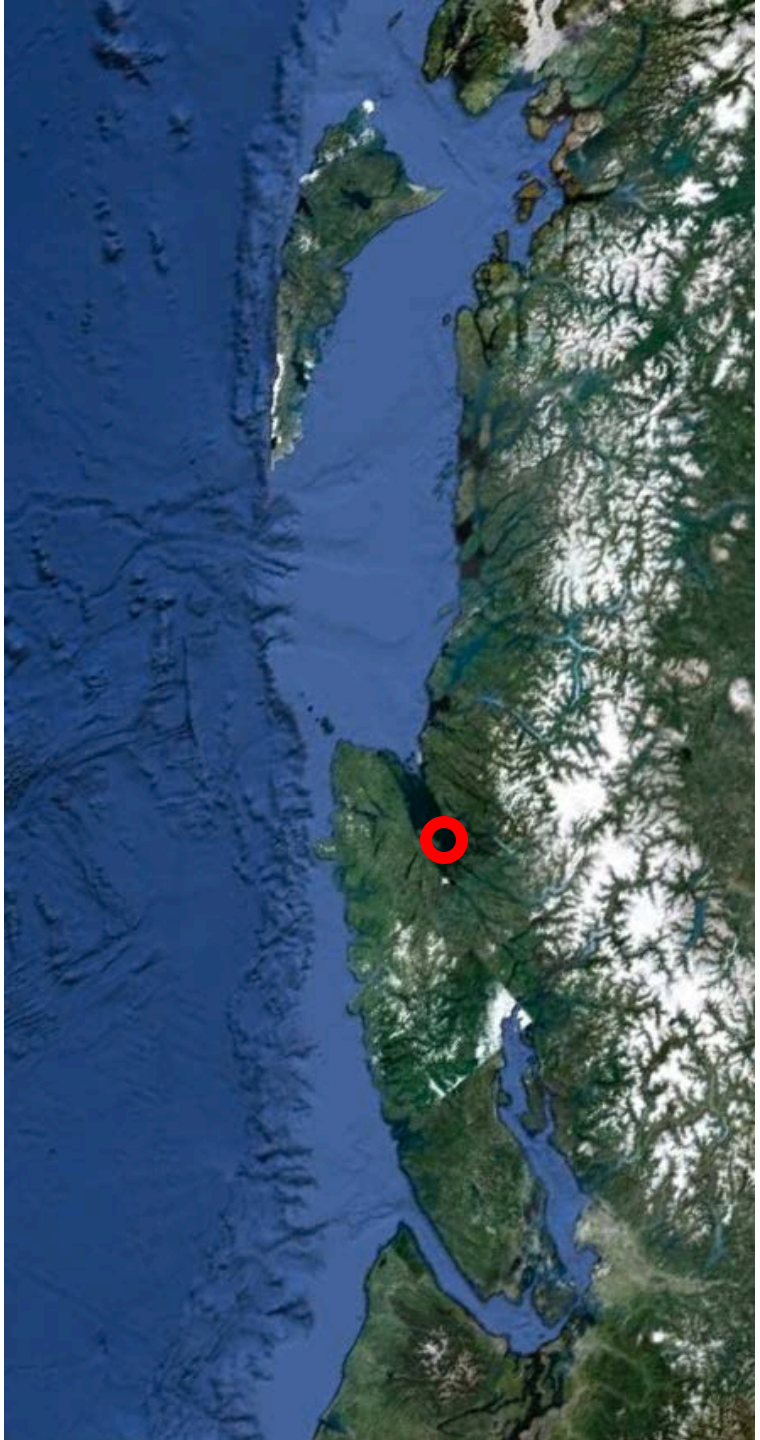
- 1 kill, Chinook
  - 0.2 yr LWFR-F (Harrison)

Winter – Spring Predation by RKW

December

- NRKW female A9 (post-reproductive)
- Carcass recovered 7 Dec 1990 (dead < 1 week)

- Prey remains:
  - 18 Chinook salmon
  - 15 Lingcod (only 2 large)
  - 5 Greenling
  - 8 English sole
  - 1 Sablefish
  - Various small fishes, likely prey of Lingcod



Winter – Spring Predation by RKW

December

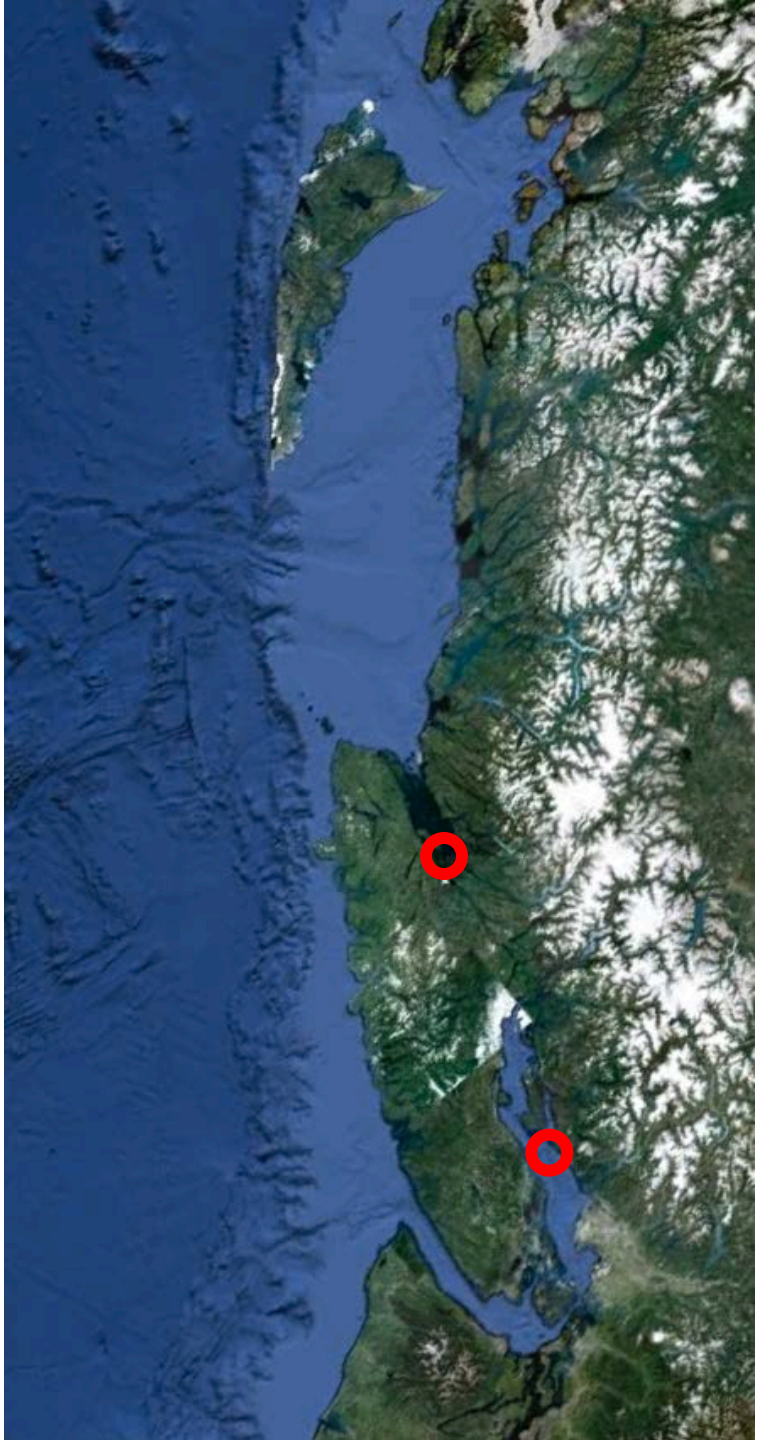
- Southern residents (J pod), Str of Georgia, 28 Dec 1977
  - 1 kill: 2.2 Chinook
- Southern residents (J pod), Puget Sound, 1 Dec 2004
  - 1 kill: 0.3 Chum

Winter – Spring Predation by RKW

January

- Northern residents (I11 and I31 pods), Queen Charlotte Strait, 27-30 Jan 2007-2011
- 7 kills, all Chinook:
  - 2 X 1.3 LWFR-Sp (Birkenhead)
  - 2 X 0.3 ECVI (Big Qual@Lang)
  - 3 X 0.3 – stock to be ID'd

- Northern residents (A5 pod), Strait of Georgia, 23 Jan 2009
- 2 kills, both Chinook:
  - 2 X 0.3 ECVI (Big Qual@Lang)



Winter – Spring Predation by RKW

February

- Southern residents (L pod), Strait of Georgia, 8 Feb 2009

- 1 kill: Chinook 0.3 LWFR-F (Chilliwack@Stav)

Winter – Spring Predation by RKW

March

- Southern residents (J pod), Strait of Georgia, 11 Mar 2009

- 1 kill: Chinook 0.3 NOMA (U_Dean)

Winter – Spring Predation by RKW

April

- Southern residents (J pod), Juan de Fuca Strait, 23 Apr 2011

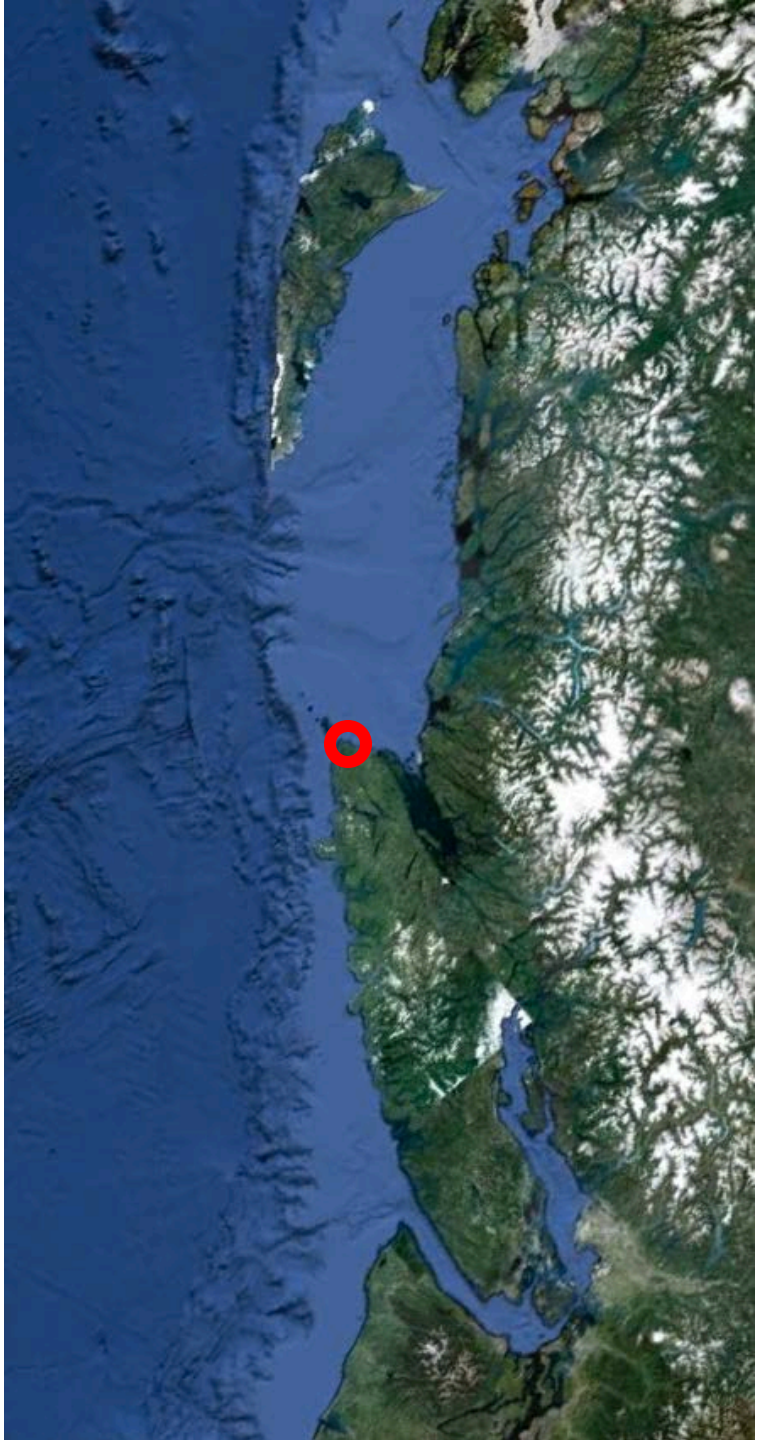
- 1 kill: Steelhead

Winter – Spring Predation by RKW

April

- SRKW female (genetic ID)
- Carcass recovered 21 May 1996 (probably dead > one month)

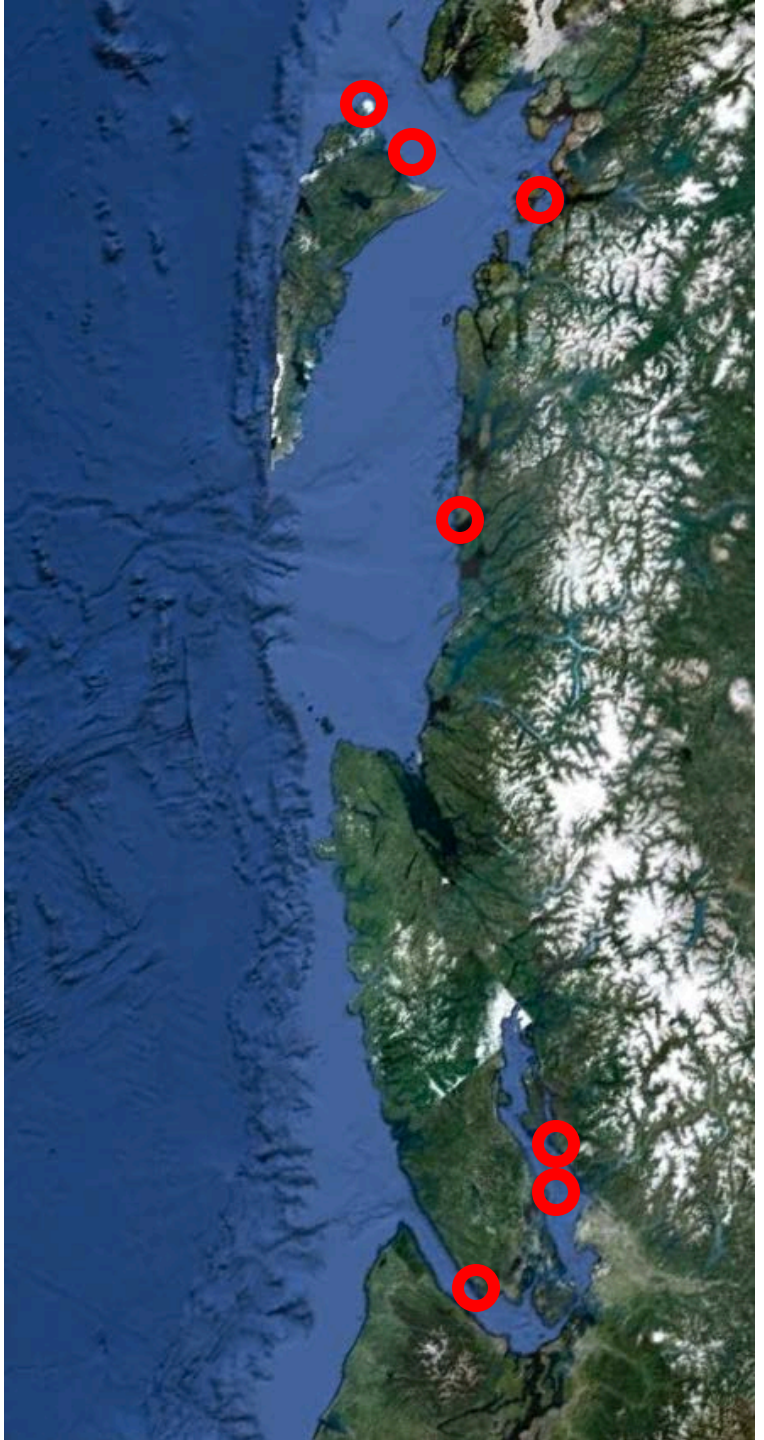
- Prey remains:
  - 1 Chinook salmon
  - 1 Boreopacific Armhook Squid (*Gonatopsis borealis*)



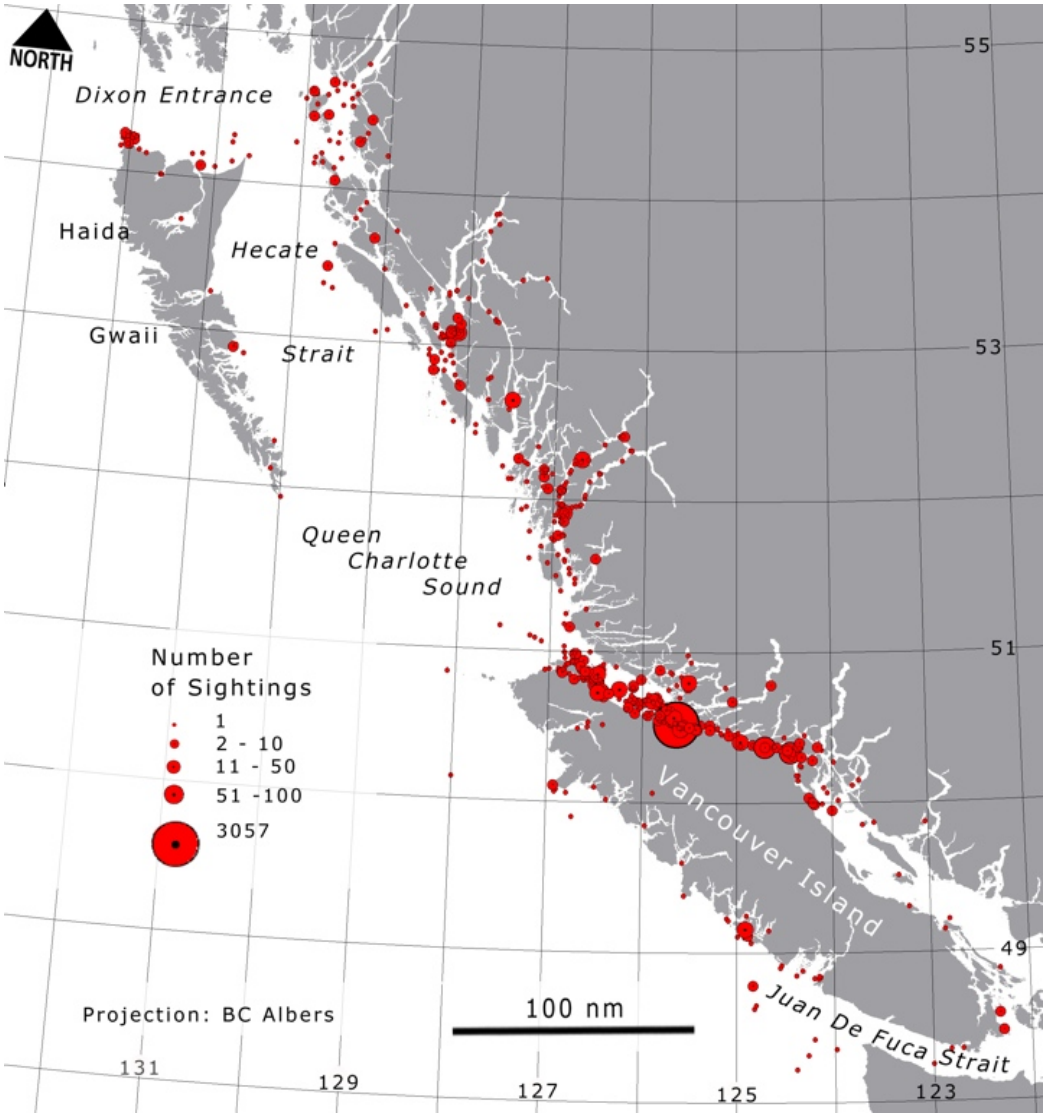
Winter – Spring Predation by RKW

May

- 36 kills, May 1981-2011 (34 NR, 4 SR)
- 30 Chinook, 6 unident. salmonid



Genetic stock identity of chum taken off northeastern Vancouver Island (PFMA 12) by NRKW, 2003-2010



Genetic stock identity of chum taken off northeastern Vancouver Island (PFMA 12) by NRKW, 2003-2010

- Analyzed with cbayes using 14 microsatellite markers, against baseline of 104 populations

Region	Population
Johnstone Stait	Ahnuhati, Ahta, Glendale, Kakweiken, Klinaklini, Mackenzie_Sound, Nimpkish, Viner_Sound, Waump, Algard, Cheakamus, Haydon, Homathko, Indian, Kwalate, Mamquam, Mashier, Orford, Shovelnose, Sliammon, Southgate,
South Coast B.C.	Squamish, Stawamus, Theodosia, Tzoonie, Wortley,
East Coast Vancouver I	Big Qualicum, Campbell, Chemainus, Cold, Cowichan, Goldstream, Little Qualicum, Nanaimo, Puntledge, Cayeghle,
West Coast Vancouver I	Colonial, Demamiel, Goodspeed, Hathaway, Nahmint, Nitinat, Pegattum, Smith, Sugsaw
Fraser River	Alouette, Blaney, Chehalis, Chilliwack, Chilqua, Harrison, Harrison-lates, Hicks, Hopedale, Inch, Kanaka, Kawkawa, Lower_Lillooet, Norrish-Worth, Serpentine, Silverdale, Squawkum, Stave, Vedder, Wahleach, Widgeon_Slough, Worth_Cr
US	County_Line, Grant, Nooksack, Siberia, Skagit, Skykomish, Tulalip, Green, Kennedy, Minter, Big_Quilcene, Hoodsport, Elwha, Salmon, Bitter, Ellsworth, Quinault, Satsop

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