Apr 4th, 3:45 PM - 4:00 PM

Southern Resident killer whale SRKW females and the tragedy of the commons

Kenneth C. Balcomb
Center for Whale Research, kenbalcomb@gmail.com

Tragedy of the Commons

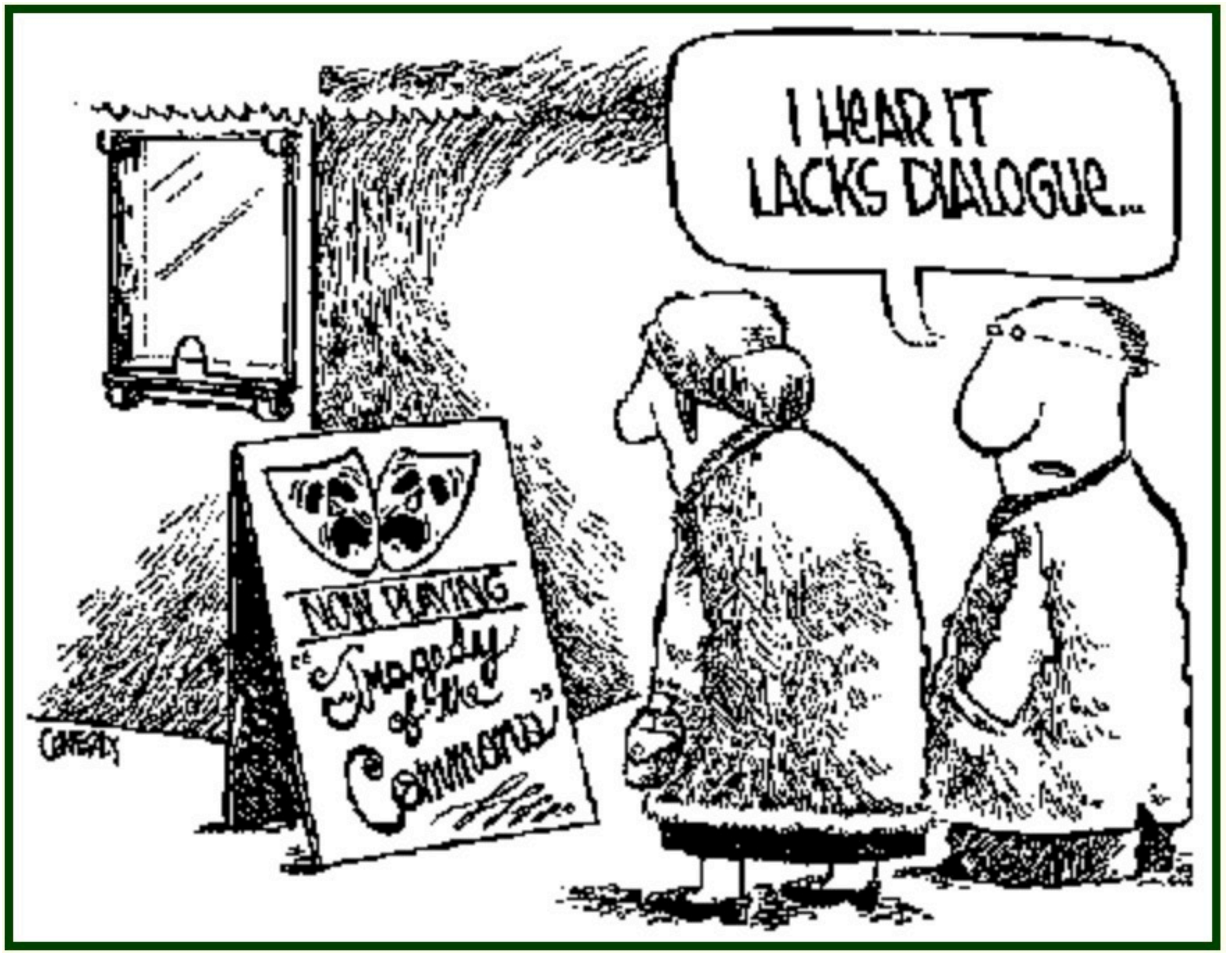
SRKW Fecundity and Mortality

by
Kenneth C. Balcomb
Center for Whale Research

W.F. Lloyd, 1832; G. Hardin, 1968

The **tragedy of the commons** is a term used in social science to describe a situation in a shared-resource system where individual users acting independently according to their own self-interest behave contrary to the common good of all users by depleting or spoiling that resource through their collective action.

Playing throughout Human History



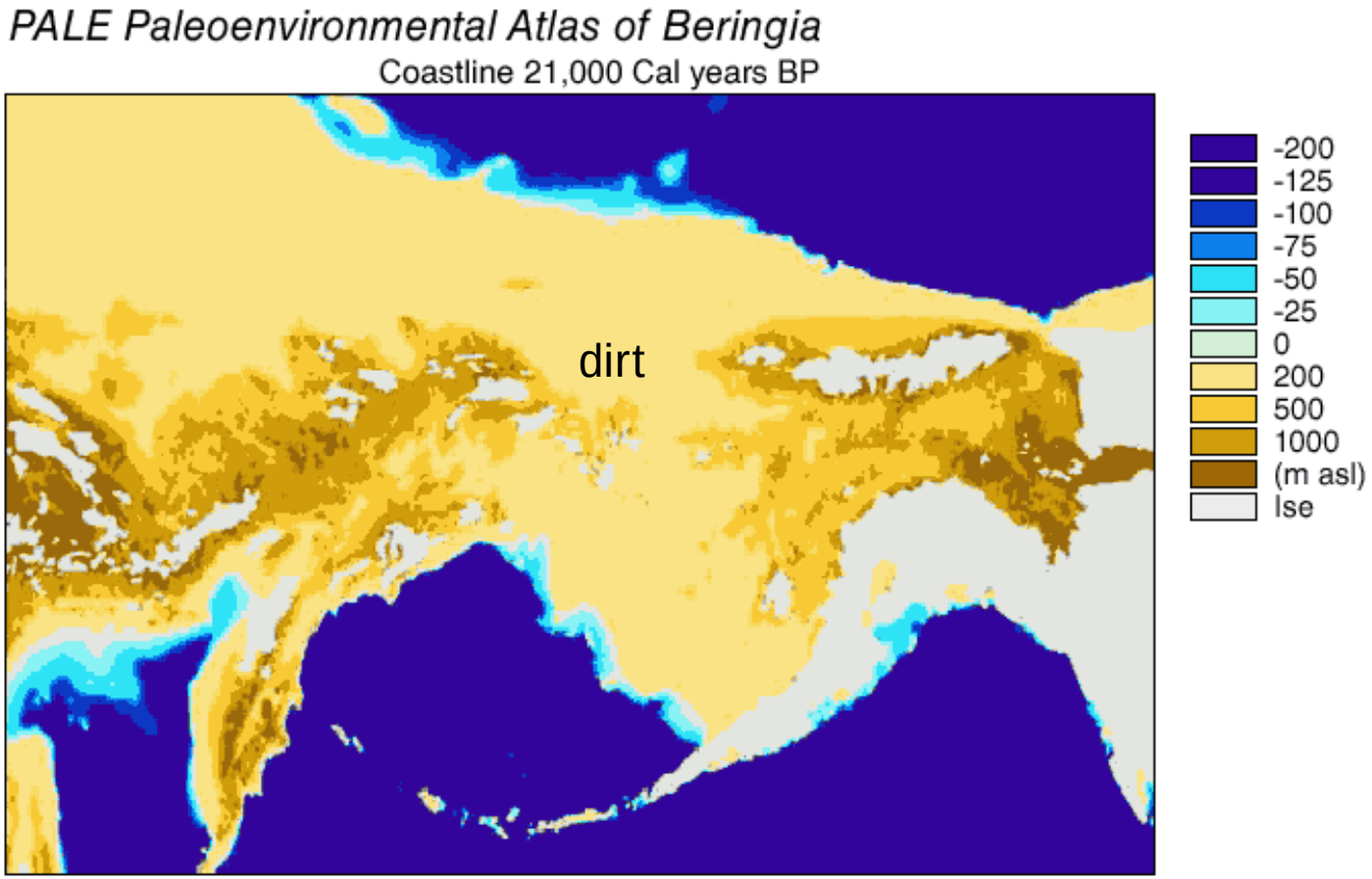
Lloyd (1832) described the situation of grazing cattle on common land versus on private land

It also applies to Fishing, and any natural resource extraction

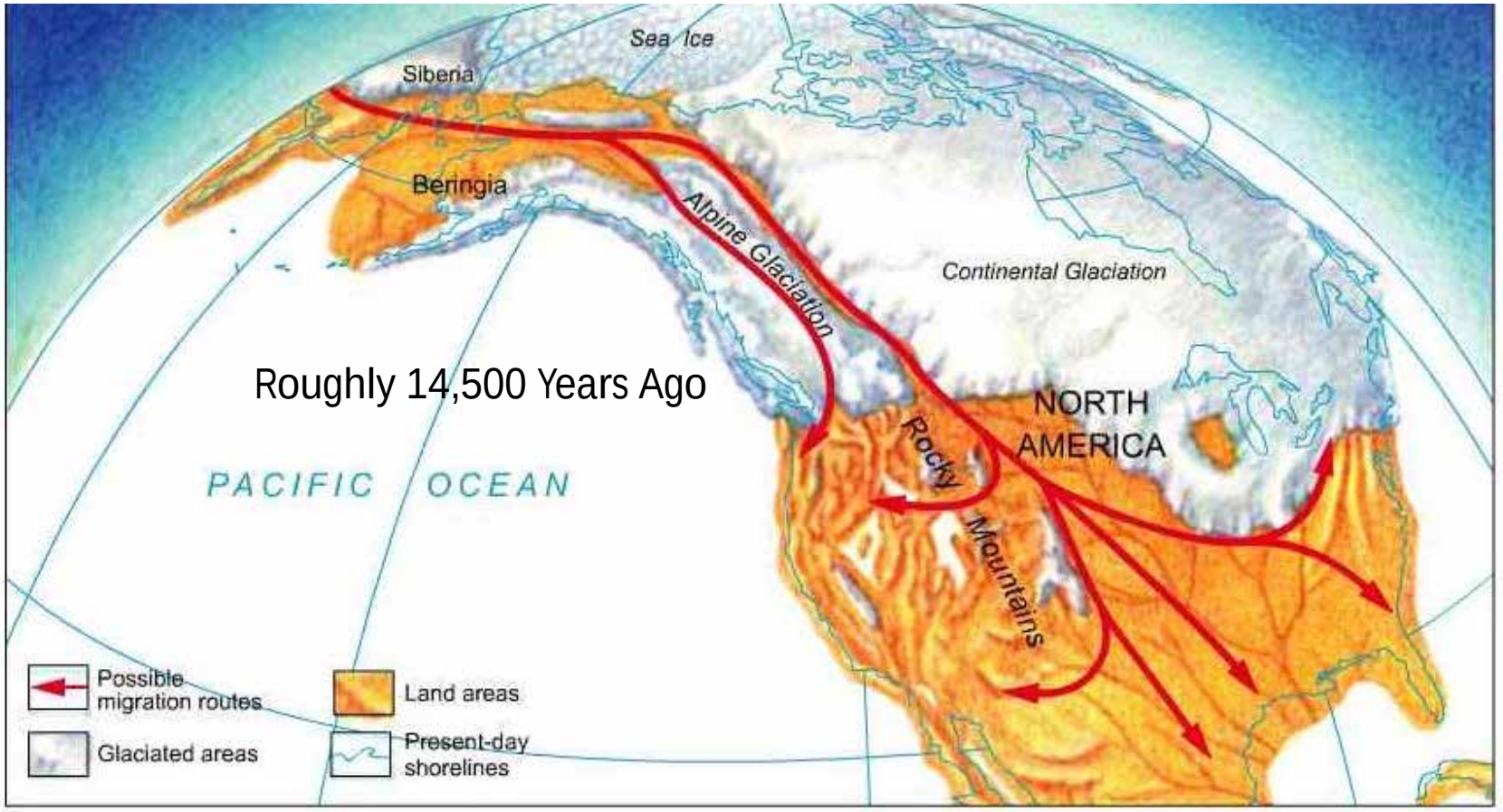
The principle applies everywhere to individuals, corporations and societies

Planet Earth Today

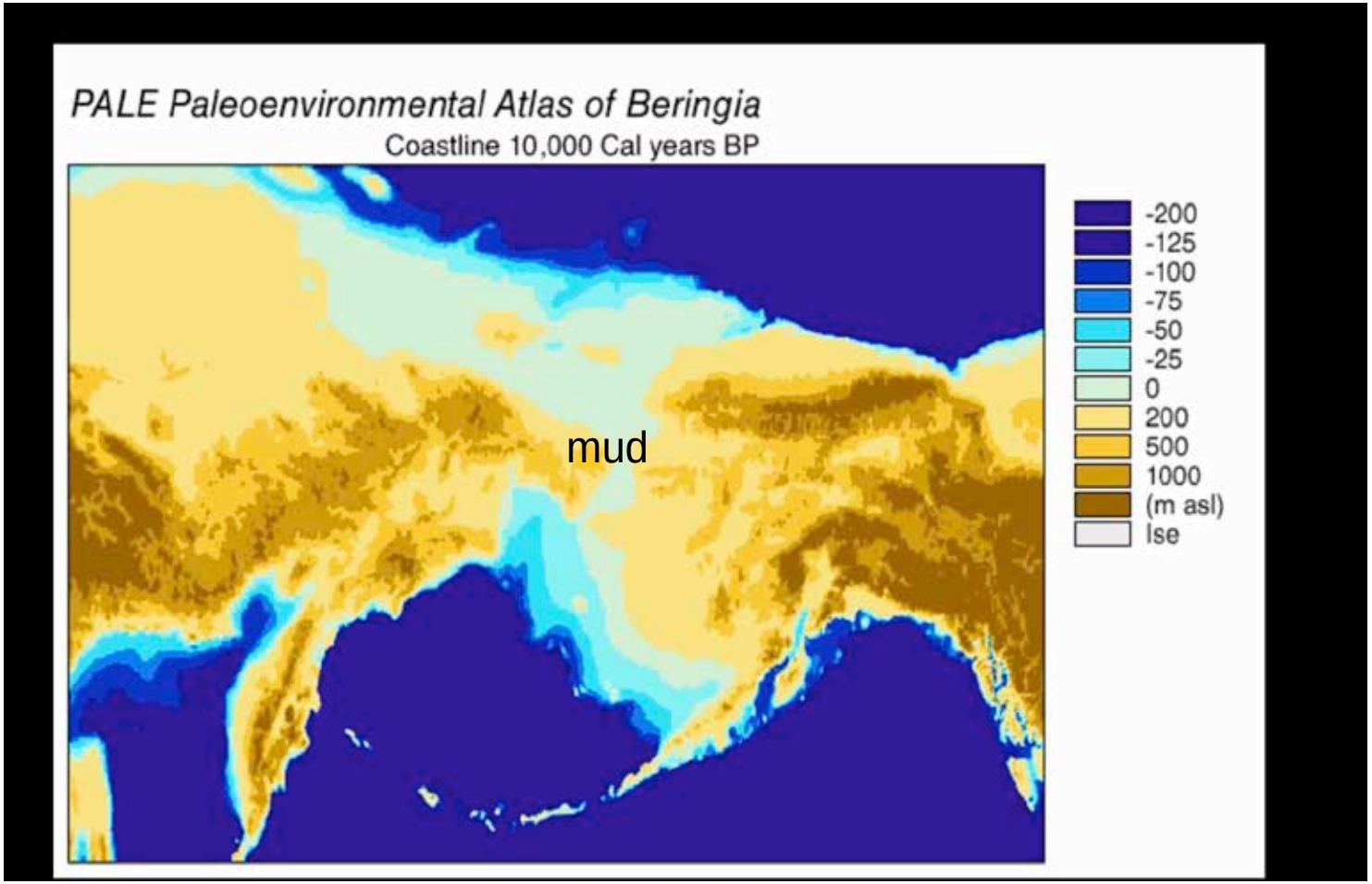
Beringia Twenty-one Thousand years ago



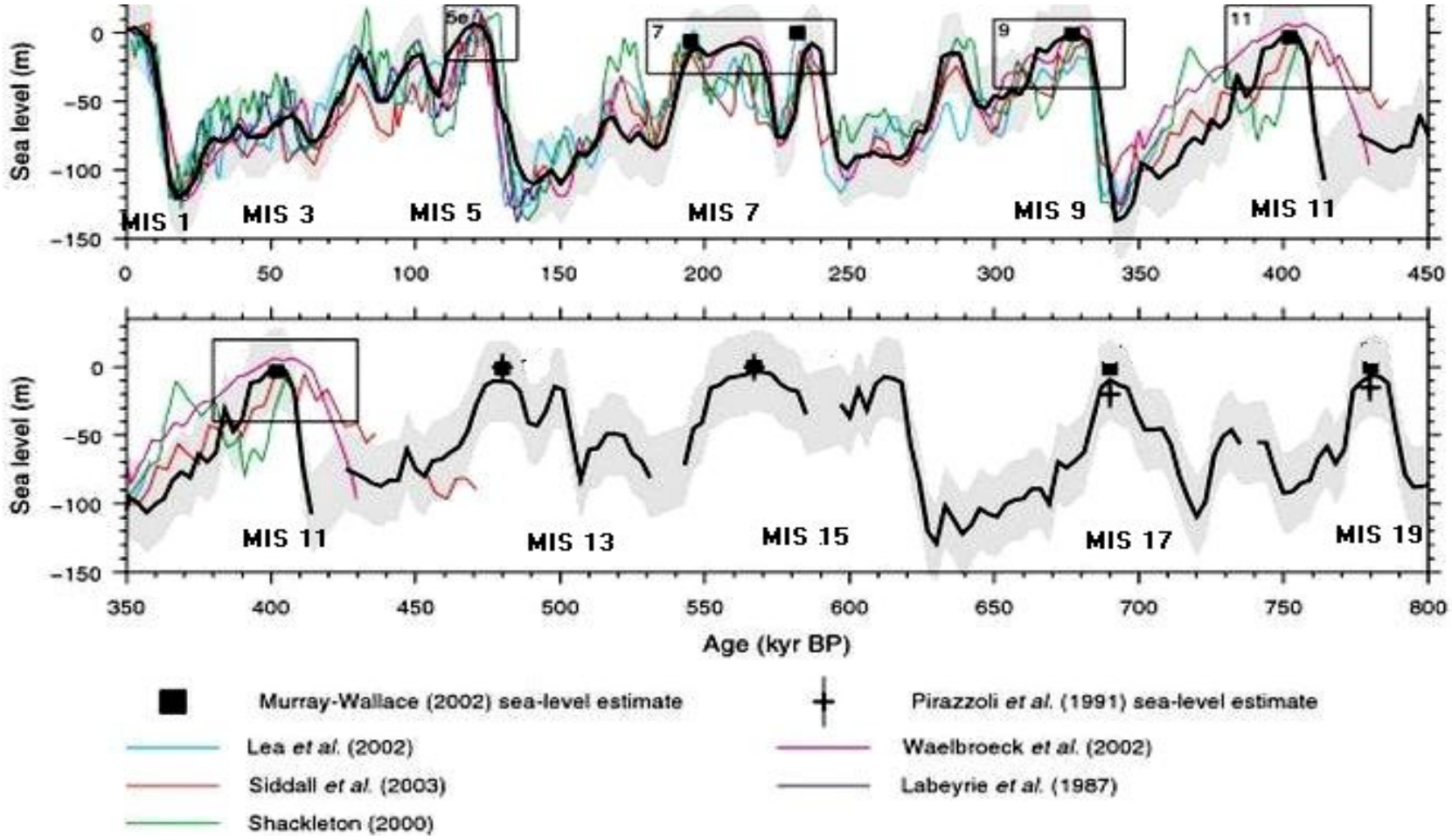
Human Arrival in the Americas



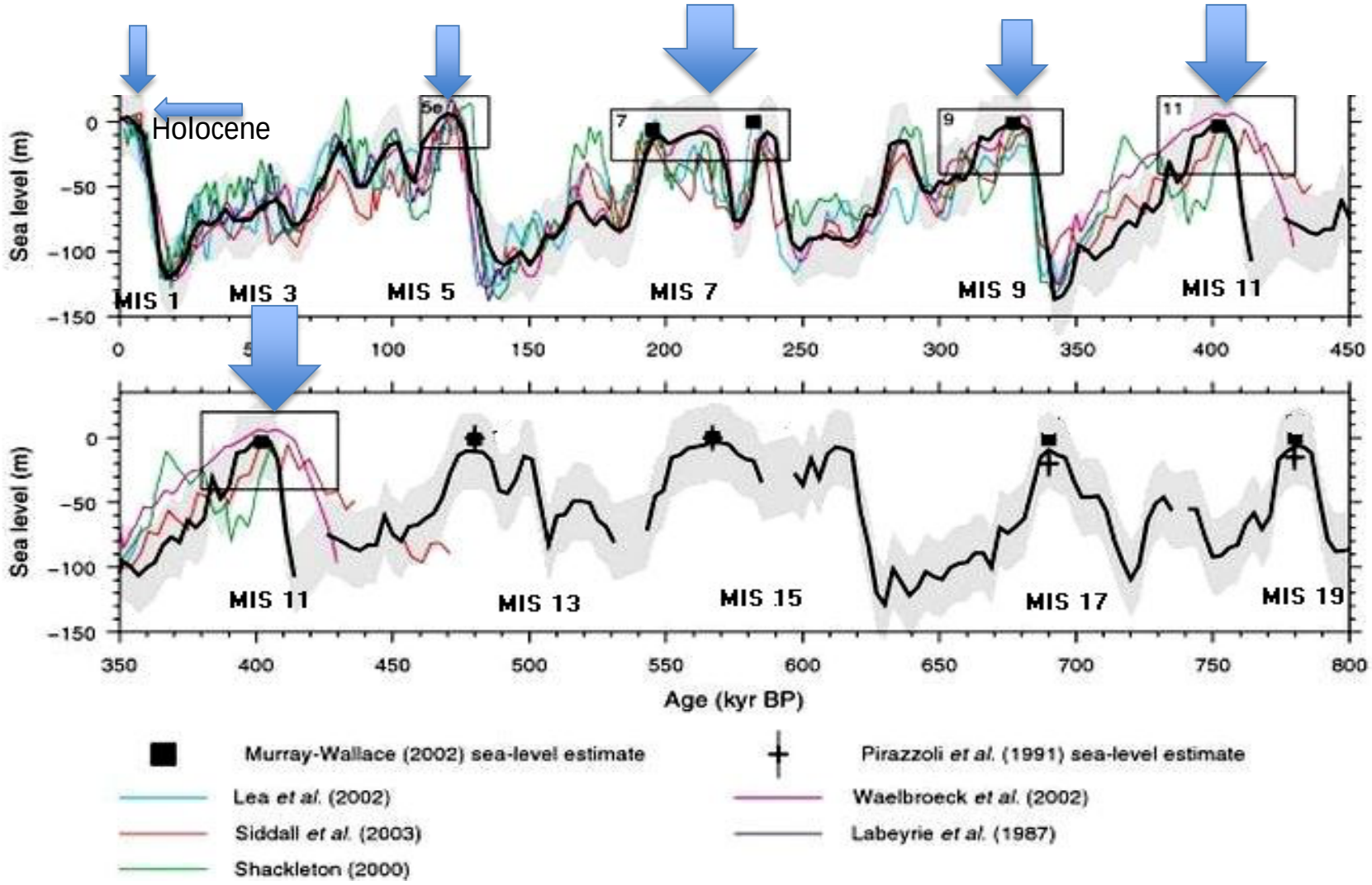
The Bering Strait recently opened



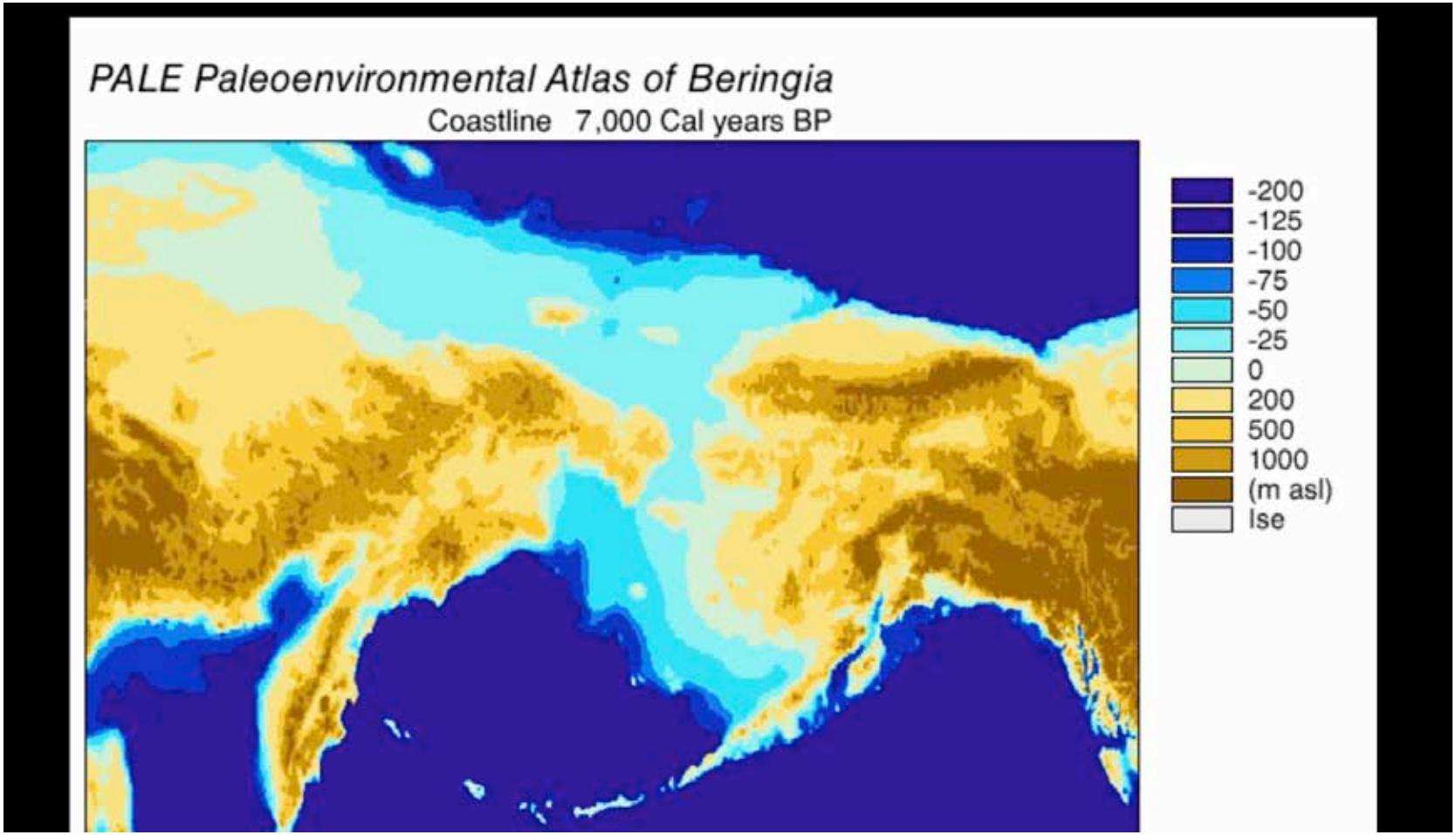
Sea Level in the Pleistocene



Sea Level - the Pleistocene to now



Enough water 7 KYA and 140 KYA for whales to swim through



Killer Whale Ecotypes MRCA

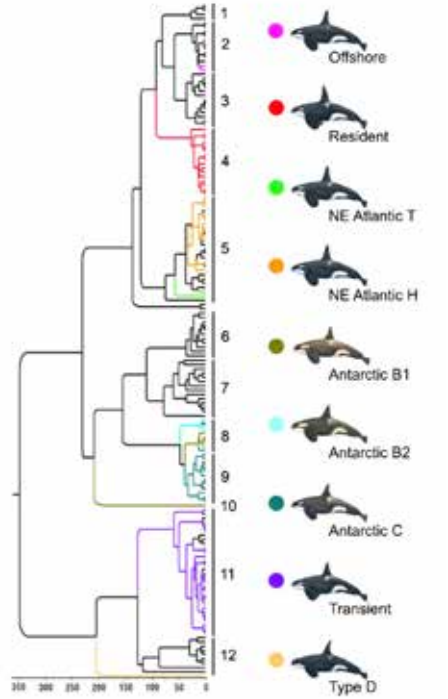


Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic *H*' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Killer Whale Ecotypes MRCA

Most recent common ancestor

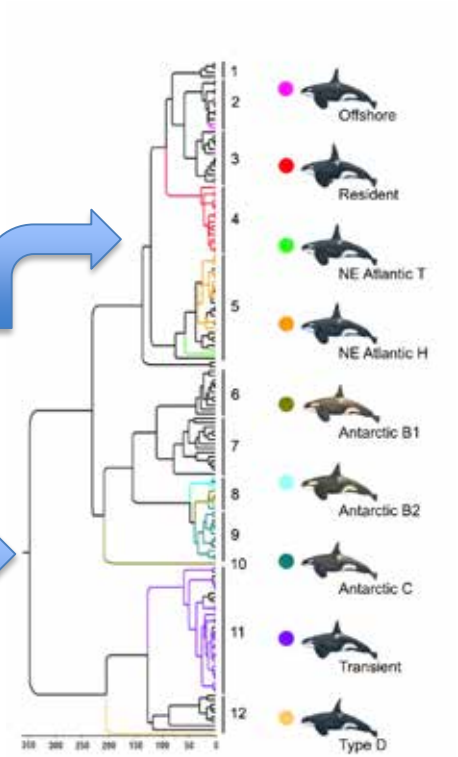
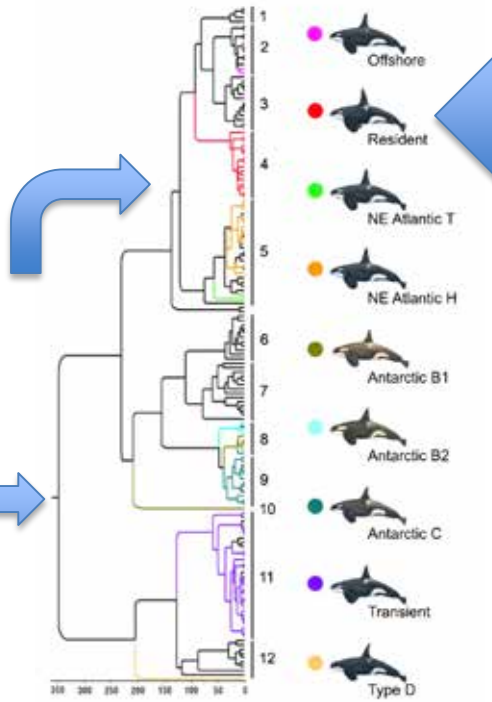


Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic H' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Killer Whale Ecotypes MRCA

Most recent common ancestor

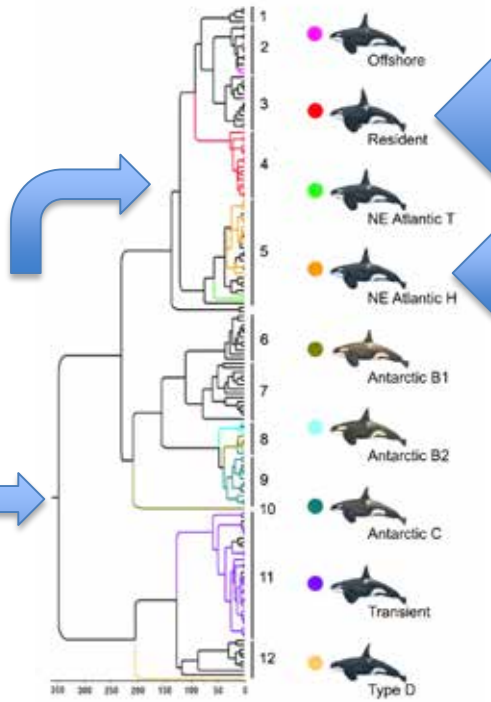


SRKW

Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic H' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Killer Whale Ecotypes MRCA

Most recent common ancestor



SRKW

Ancestral Fish Eaters

Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic H' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Killer Whale Ecotypes MRCA

Most recent common ancestor

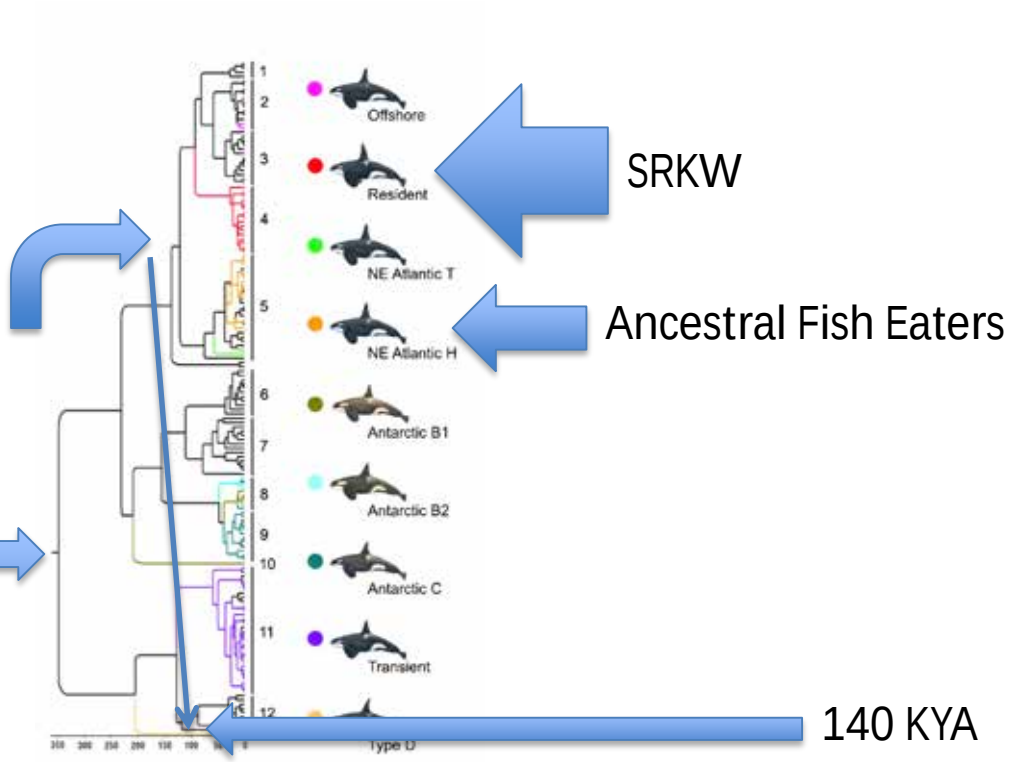


Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic H' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Killer Whale Ecotypes MRCA

Most recent common ancestor

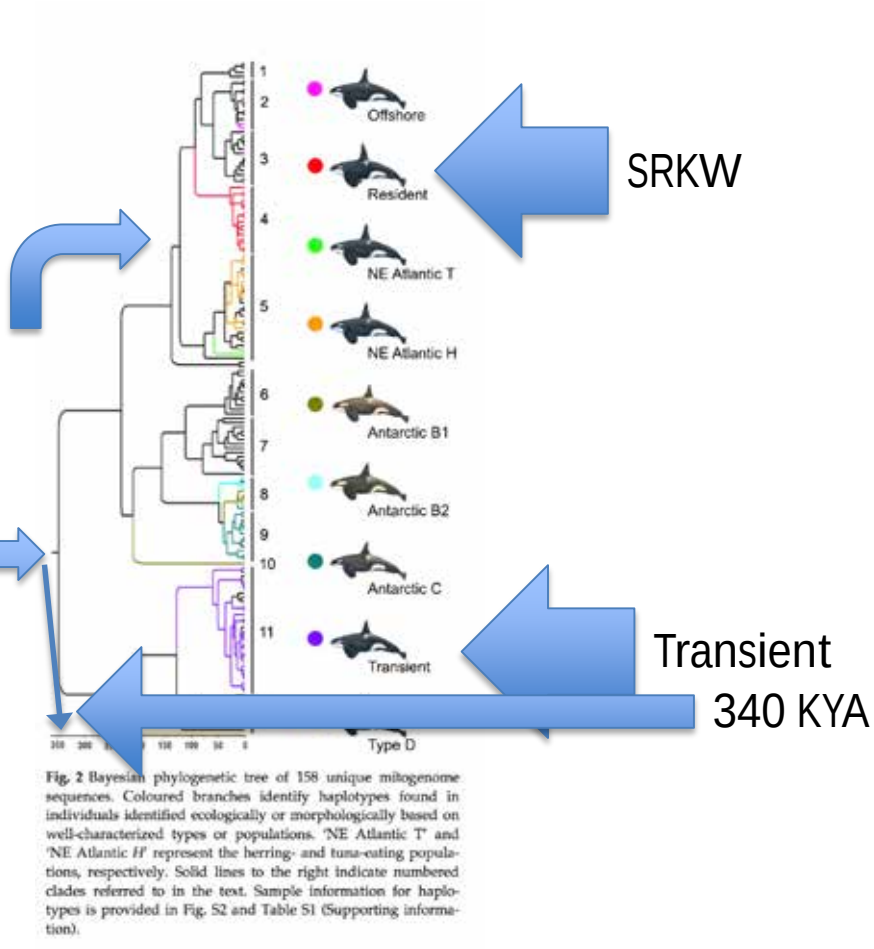
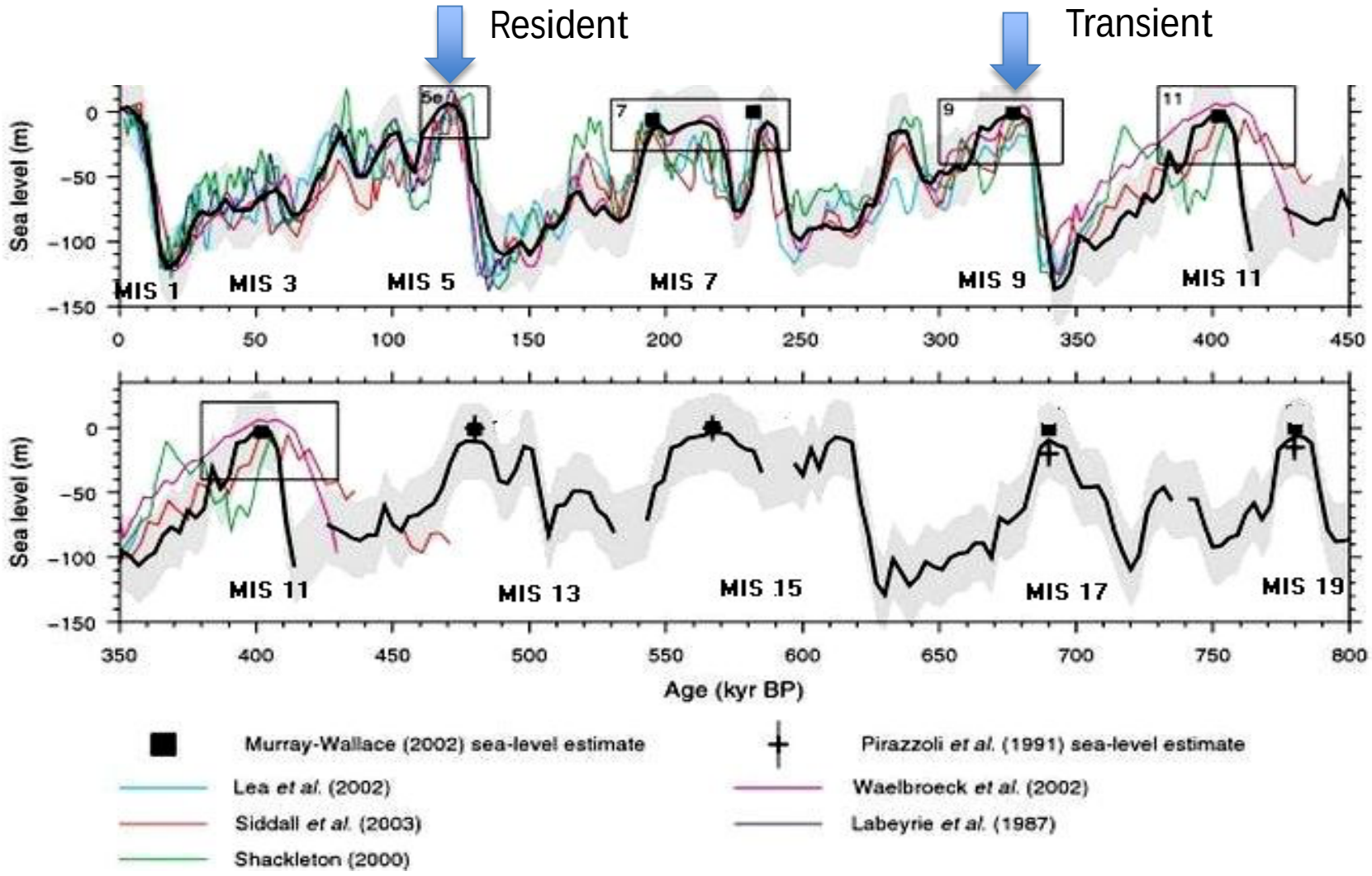


Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic H' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Sea Level in the Pleistocene



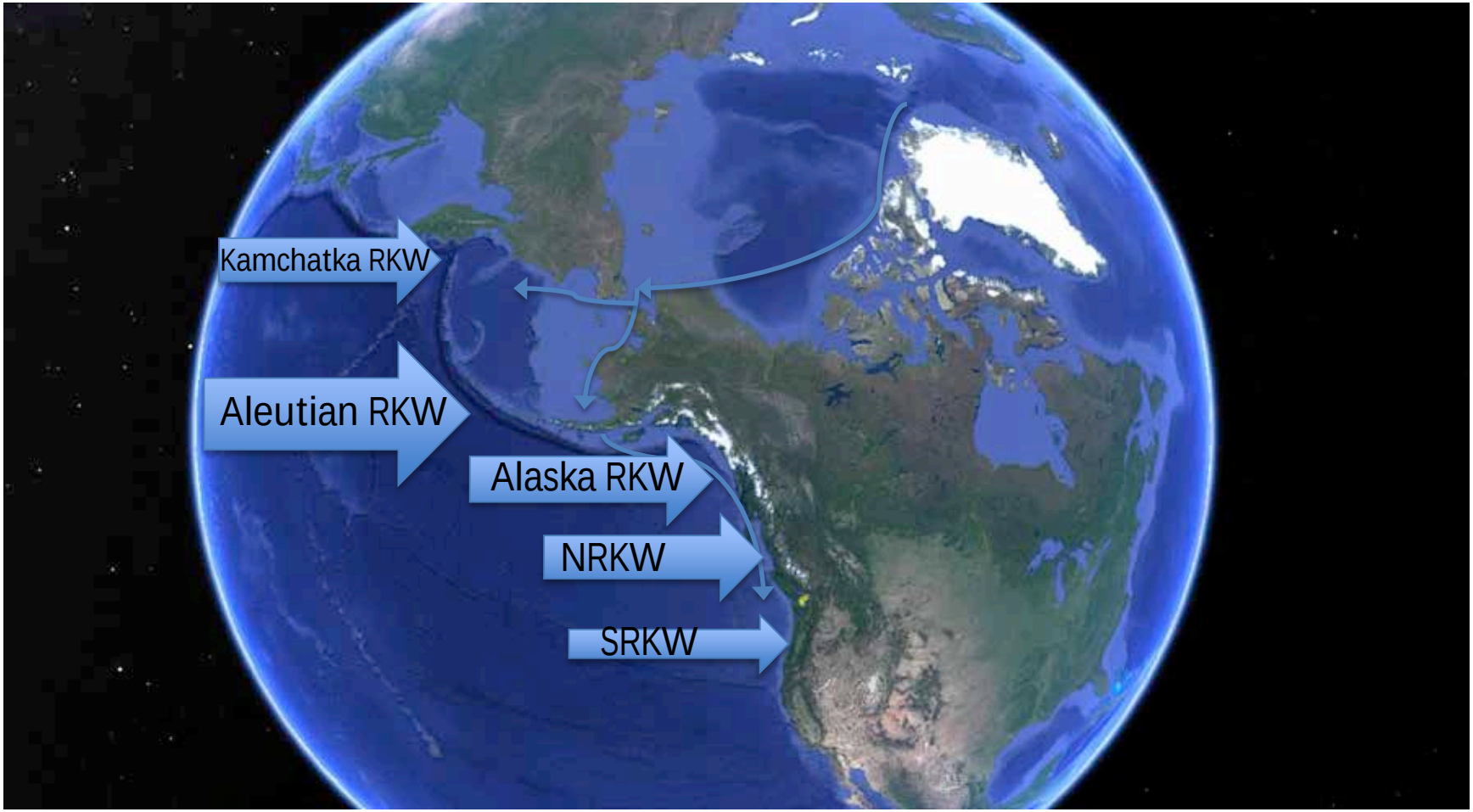
We will stick with the “Resident” Story

We will stick with the “Resident” Story

We will stick with the “Resident” Story

We will stick with the “Resident” Story

We will stick with the “Resident” Story



Following the photo-identification technique pioneered by Dr. Mike Bigg

Orca Survey began in 1976

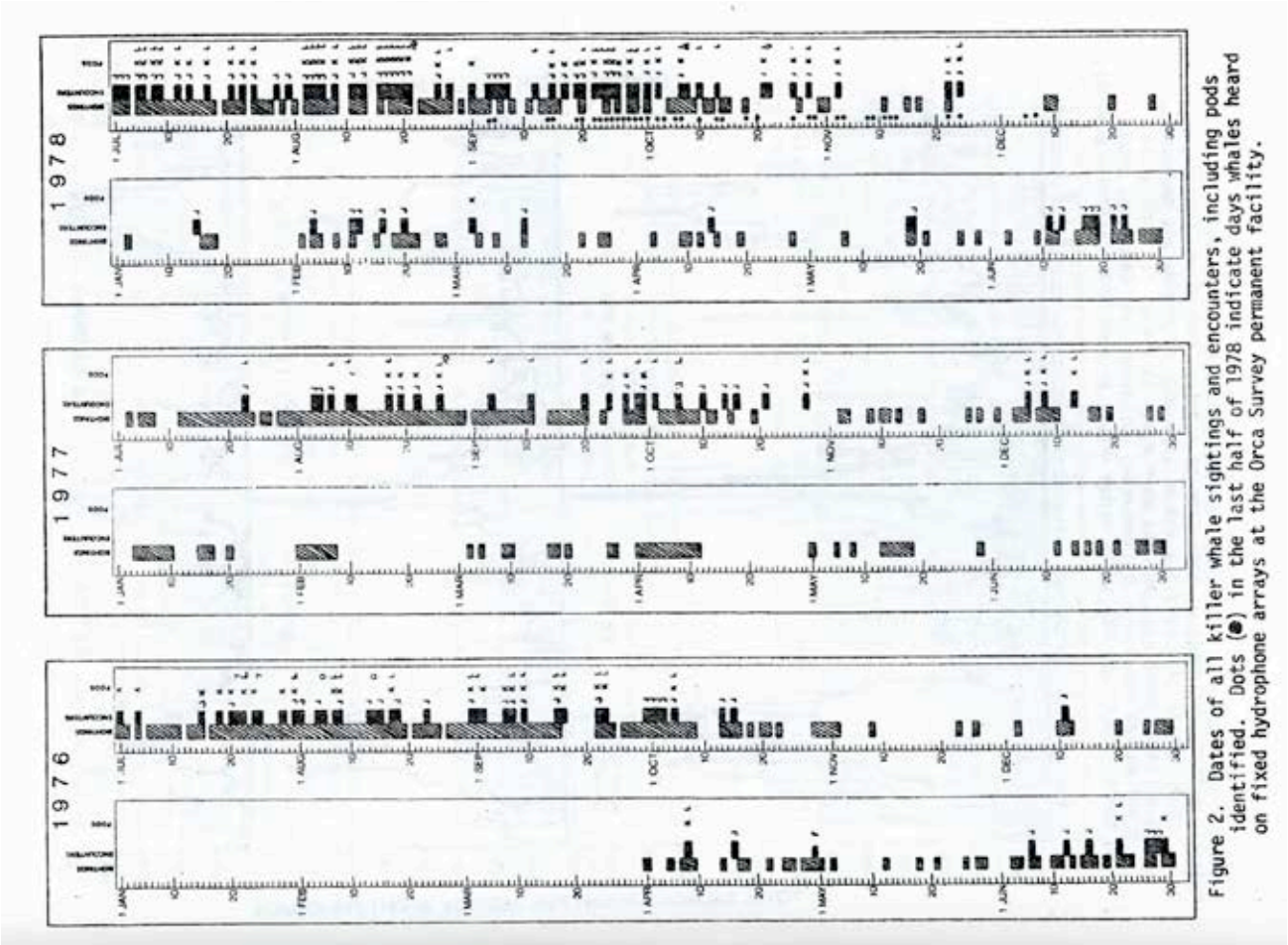


Figure 2. Dates of all killer whale sightings and encounters, including pods identified. Dots (●) in the last half of 1978 indicate days whales heard on fixed hydrophone arrays at the Orca Survey permanent facility.

Orca Survey began in 1976

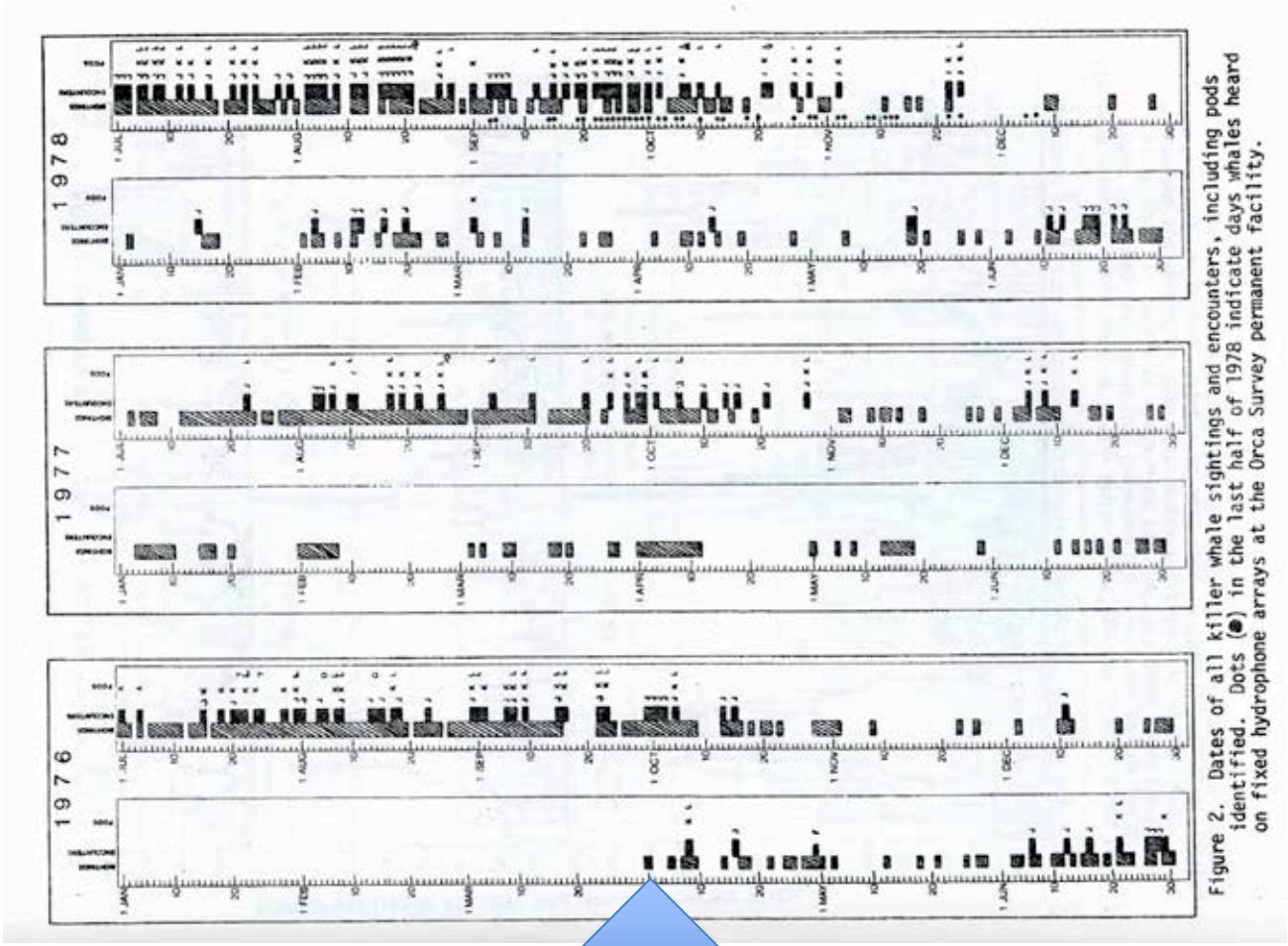


Figure 2. Dates of all killer whale sightings and encounters, including pods identified. Dots (●) in the last half of 1978 indicate days whales heard on fixed hydrophone arrays at the Orca Survey permanent facility.

We began on April Fool's Day!

Whales were detected almost daily in the Salish Sea during summer months

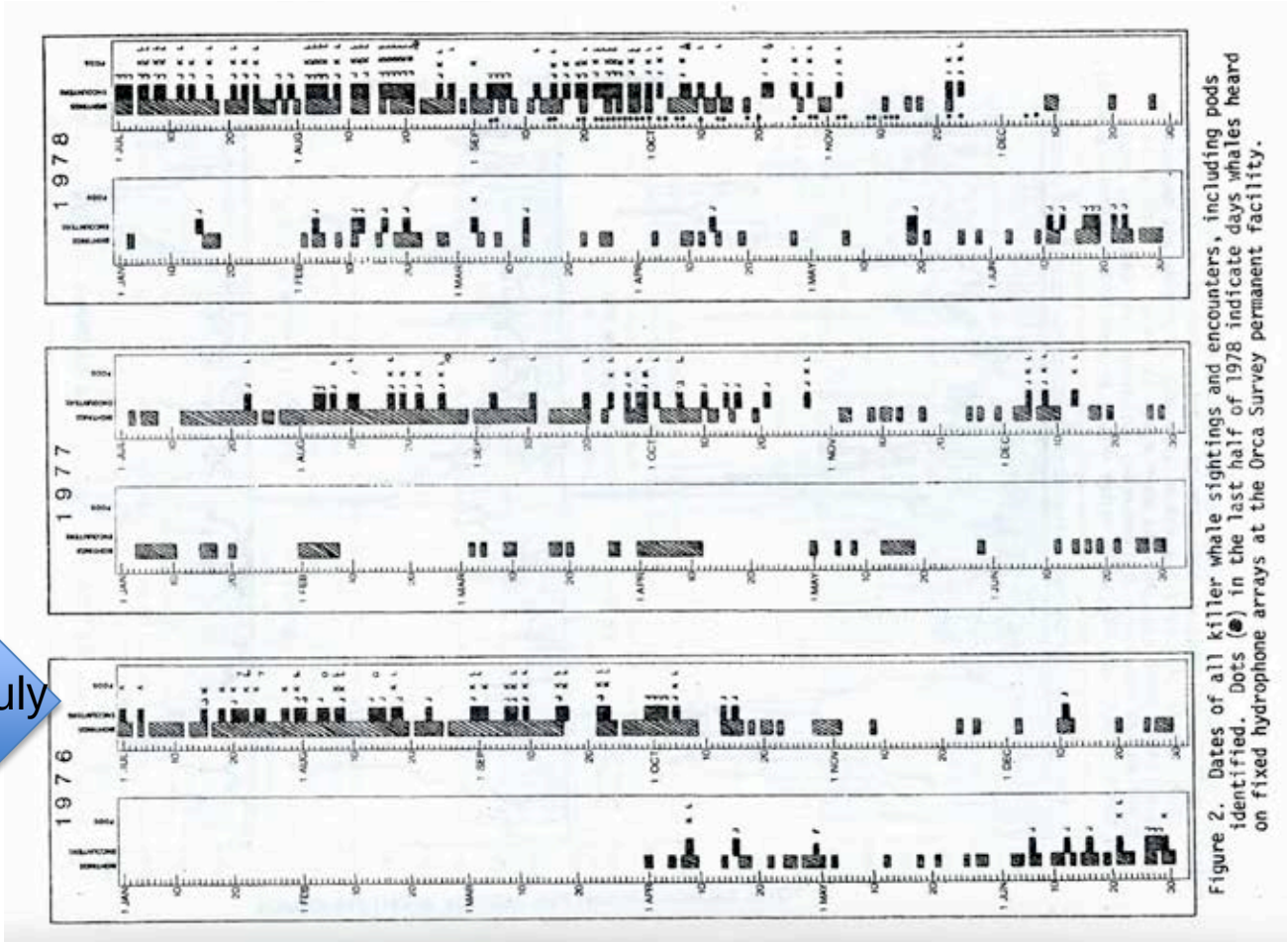
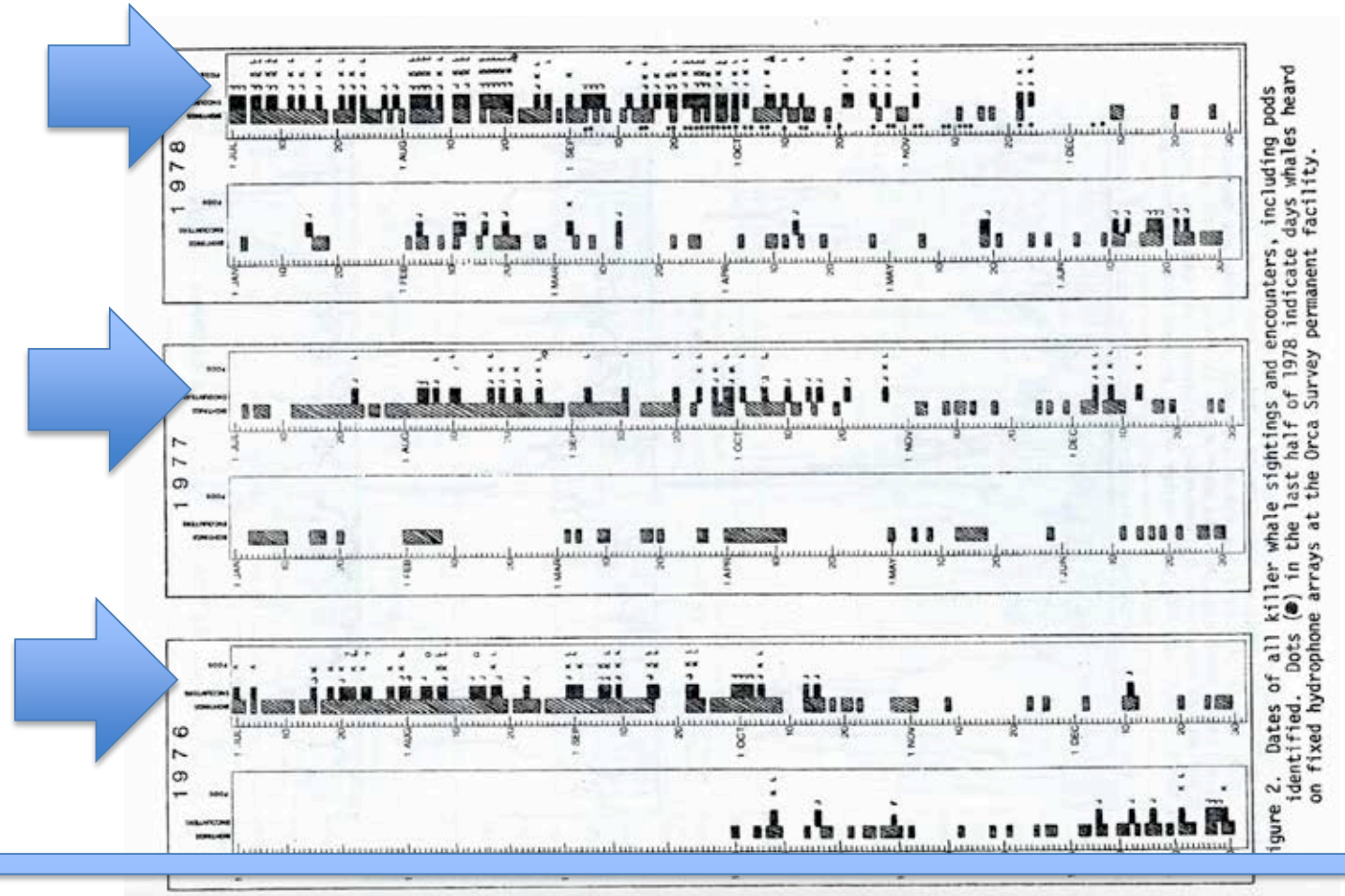


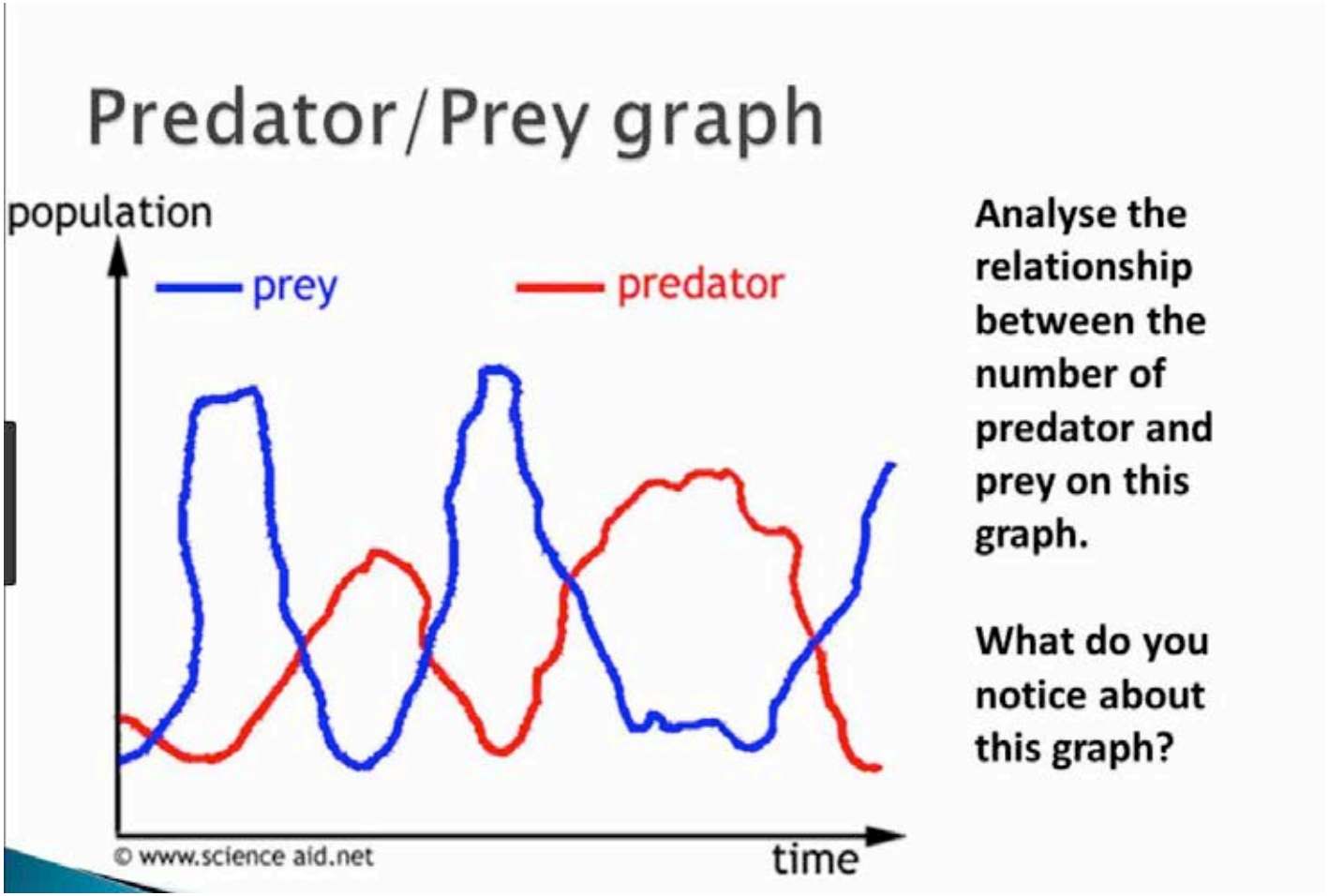
Figure 2. Dates of all killer whale sightings and encounters, including pods identified. Dots (●) in the last half of 1978 indicate days whales heard on fixed hydrophone arrays at the Orca Survey permanent facility.

These Fish-eaters earned the softer name “Resident” orca, but they were still predators



SRKWs were in the Salish Sea virtually every day from June to September

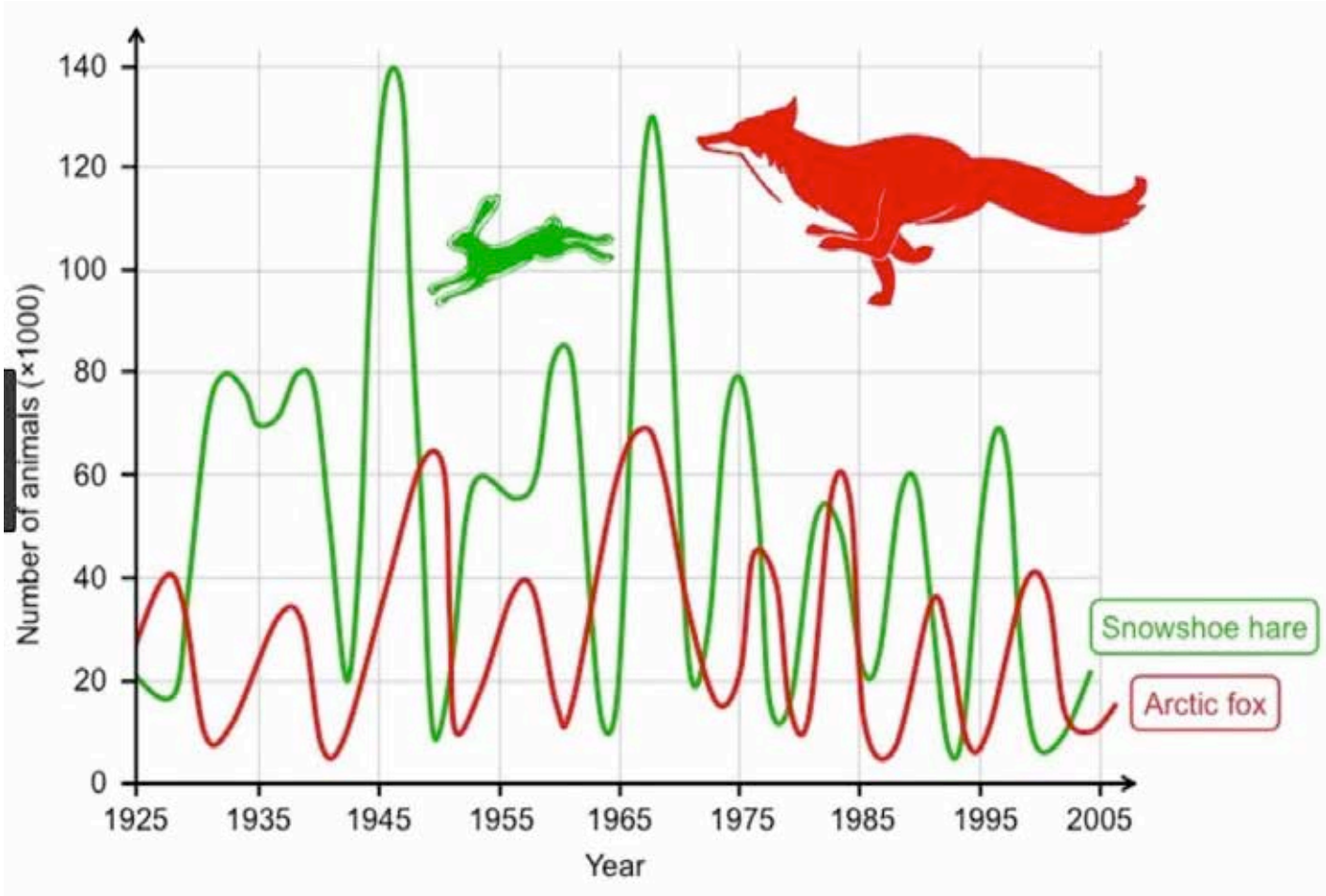
Predators and Prey



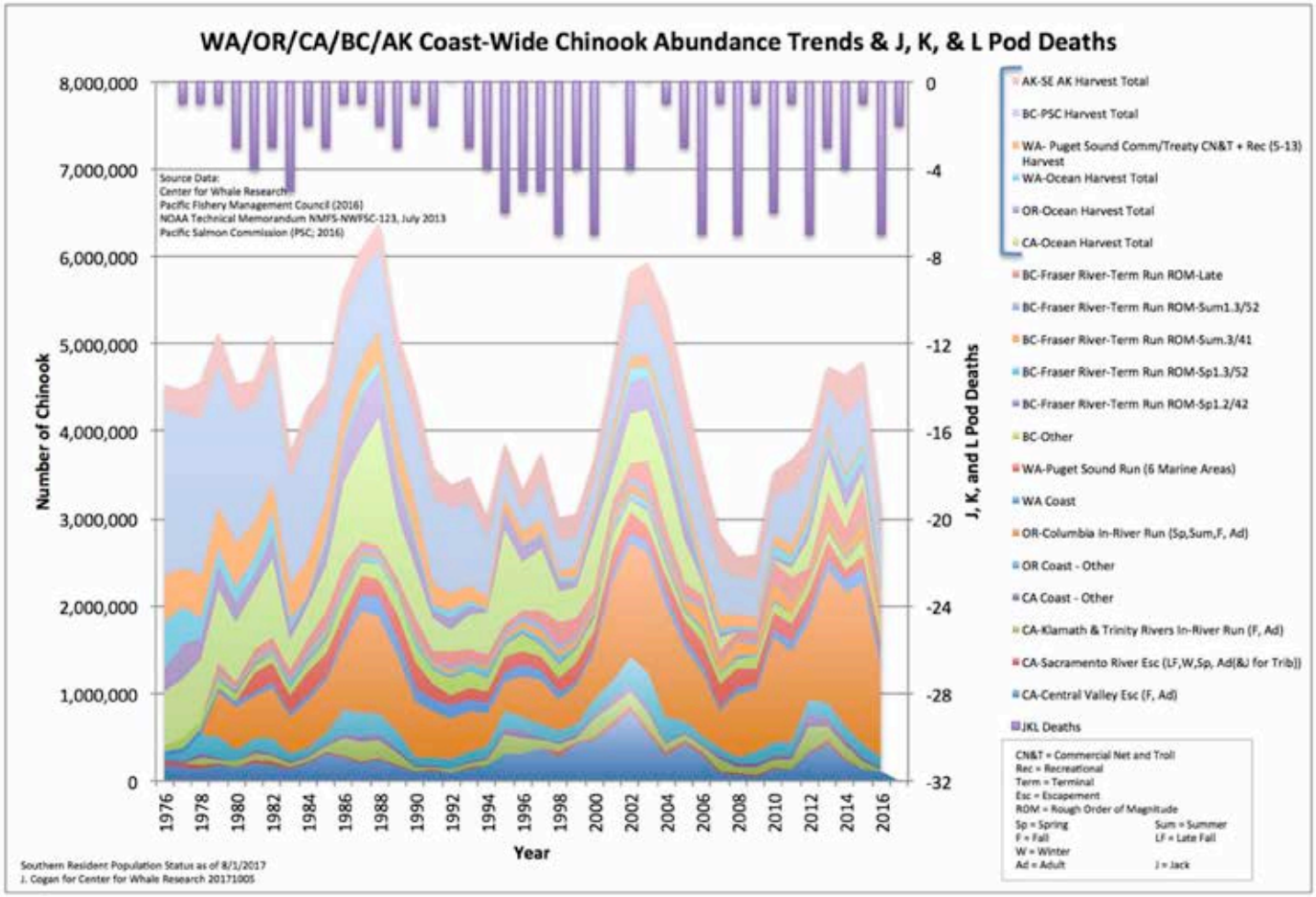
Analyse the relationship between the number of predator and prey on this graph.

What do you notice about this graph?

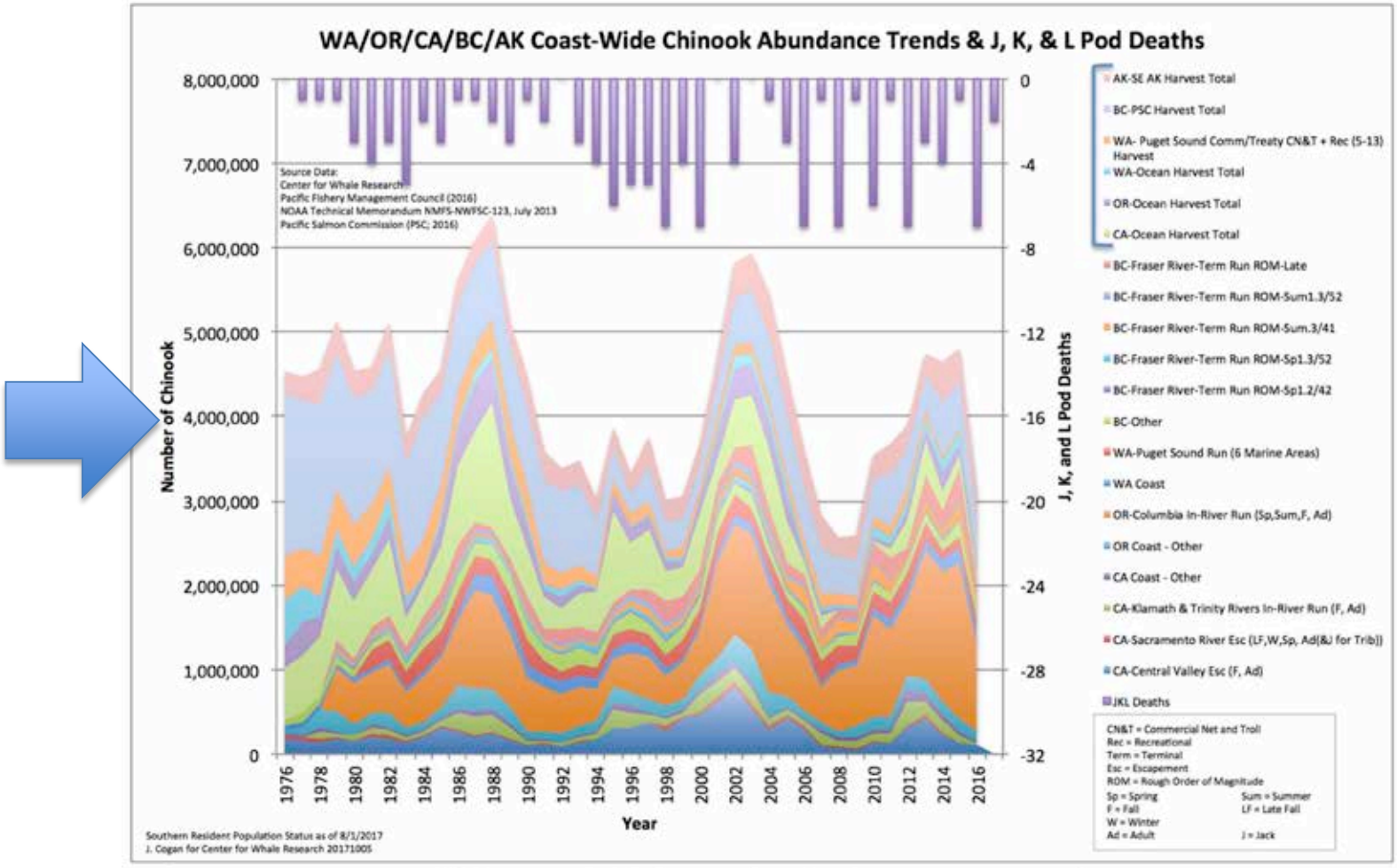
It is a Classic and Basic Relationship



“Resident” KW mortality and Chinook Salmon Abundance

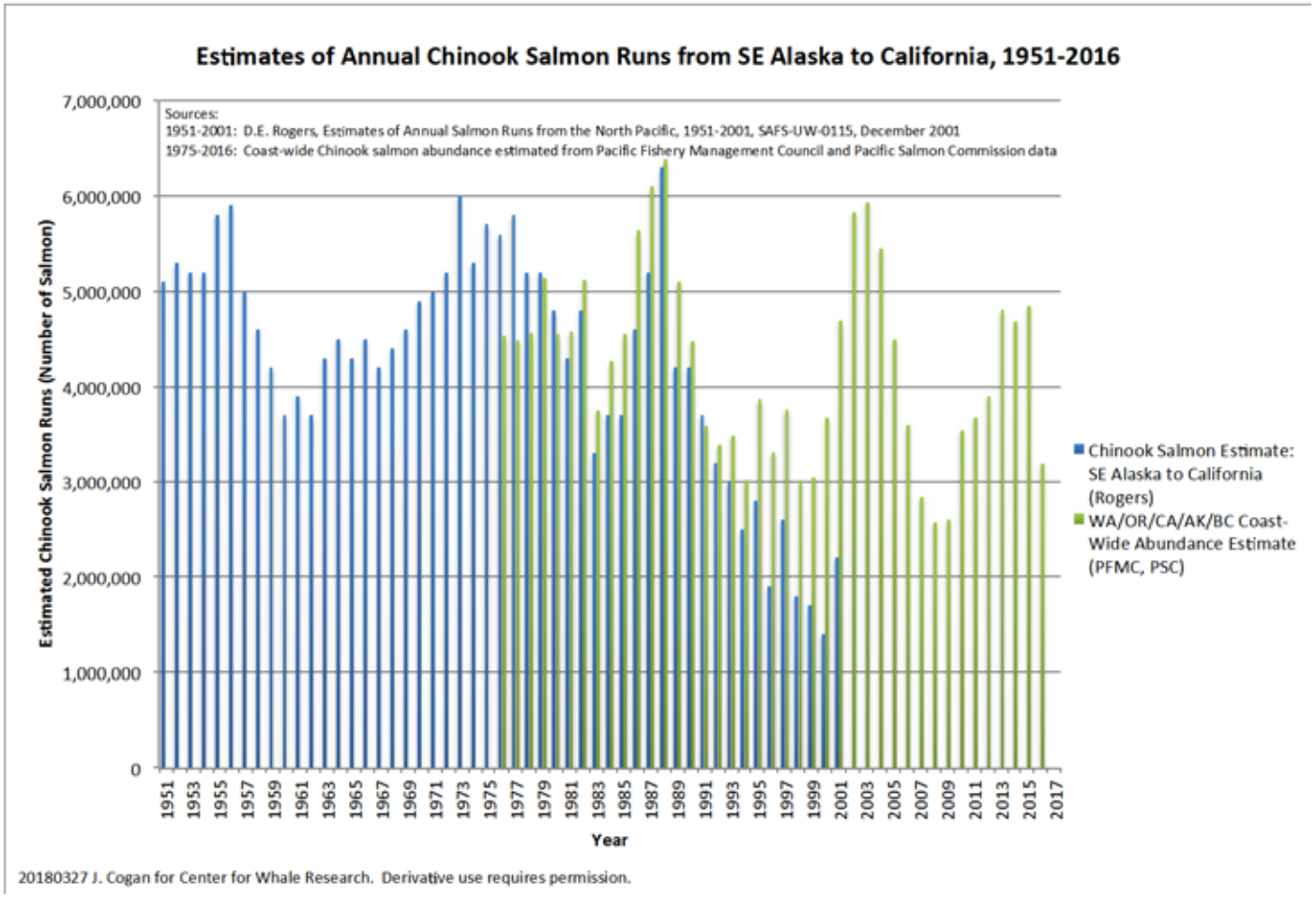


“Resident” KW and Chinook Salmon



Estimates of Annual Chinook Salmon Runs:

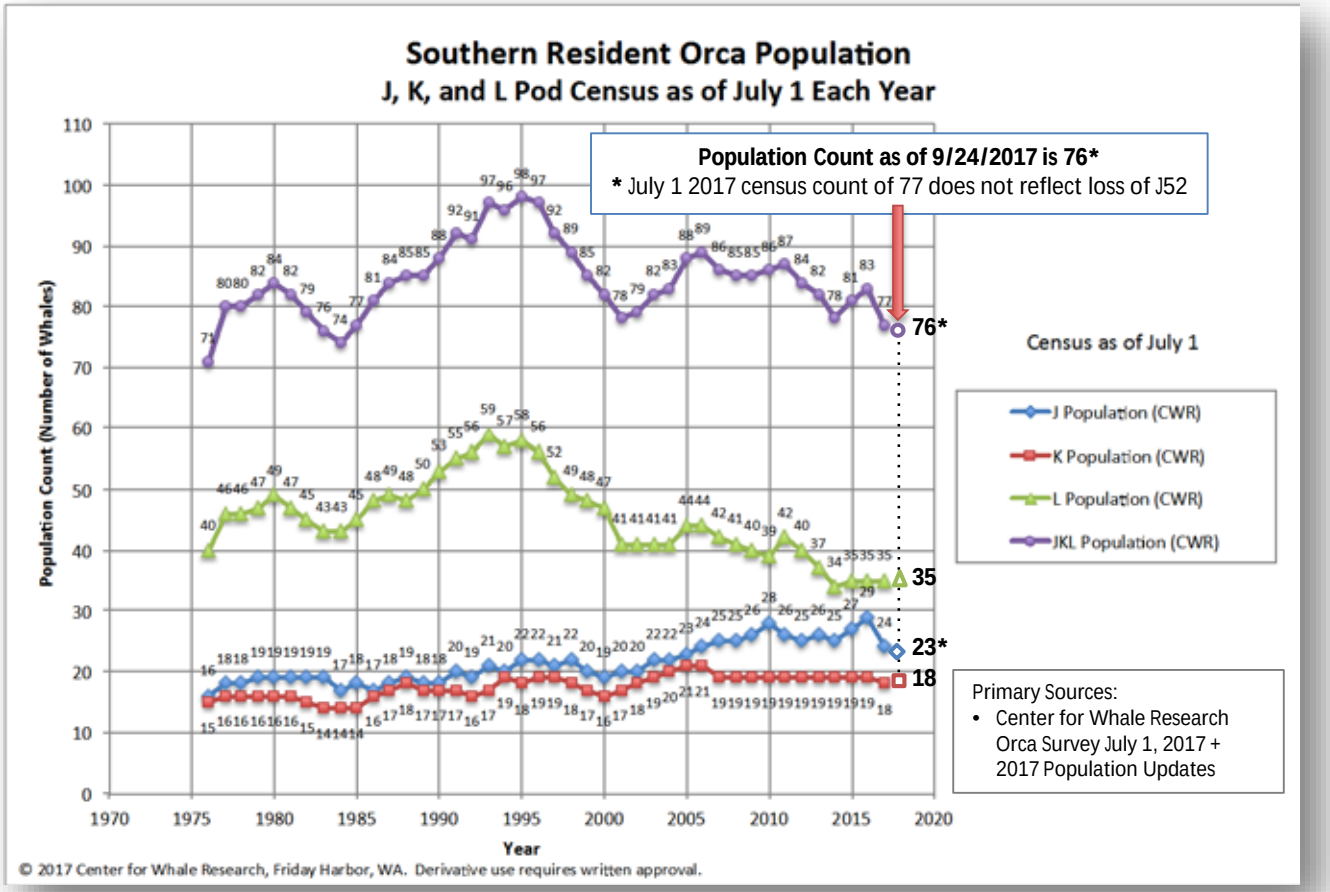
SE Alaska to California (1951 – 2016)



2017 SRKW Census – July 1

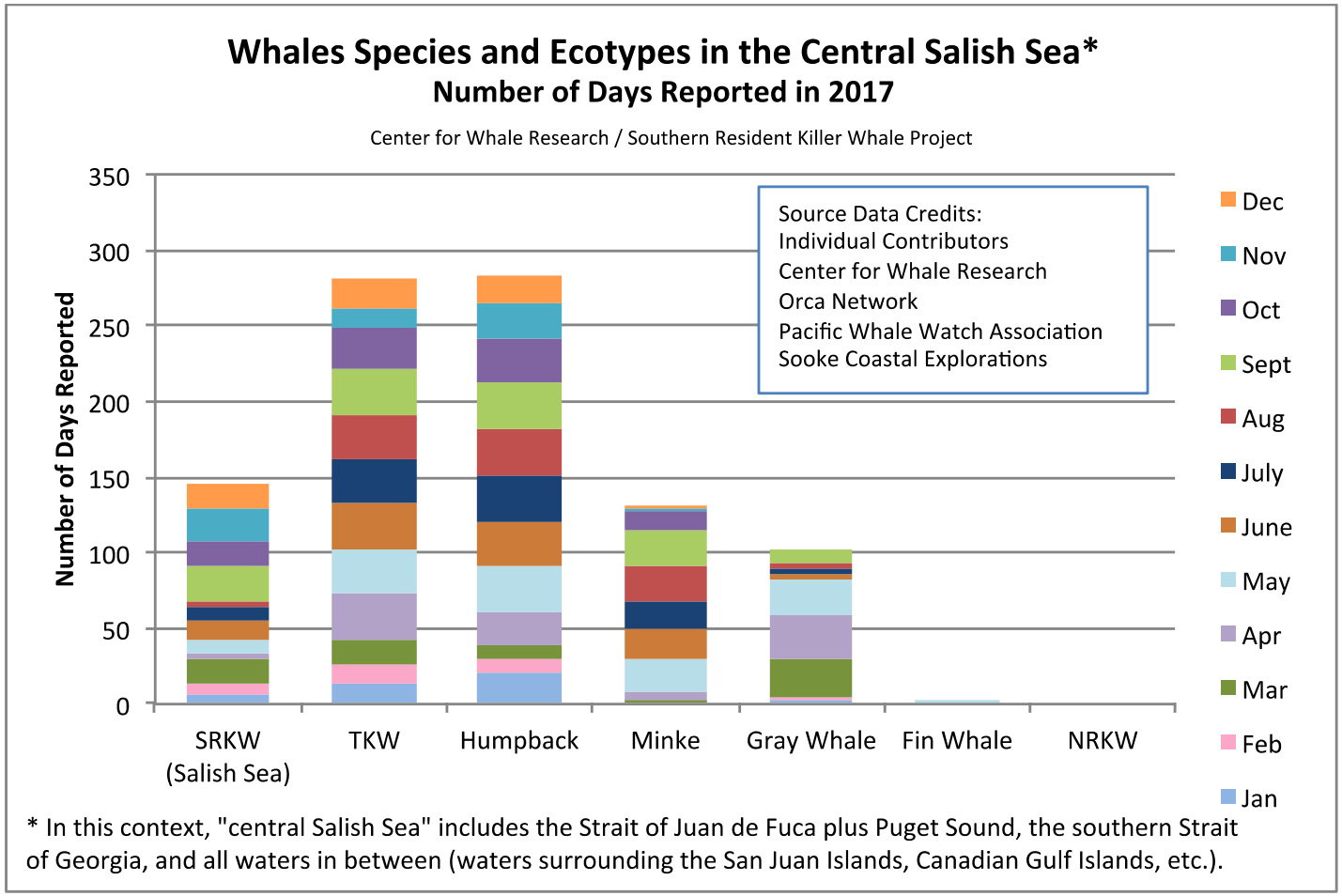
With Post-July Updates

- This is the population chart prepared by CWR each year for NOAA, DFO, and the general public.
- L pod has been driving the overall decline until recently.
- J pod has recently experienced many losses.



Whale Presence:

January-December, 2017

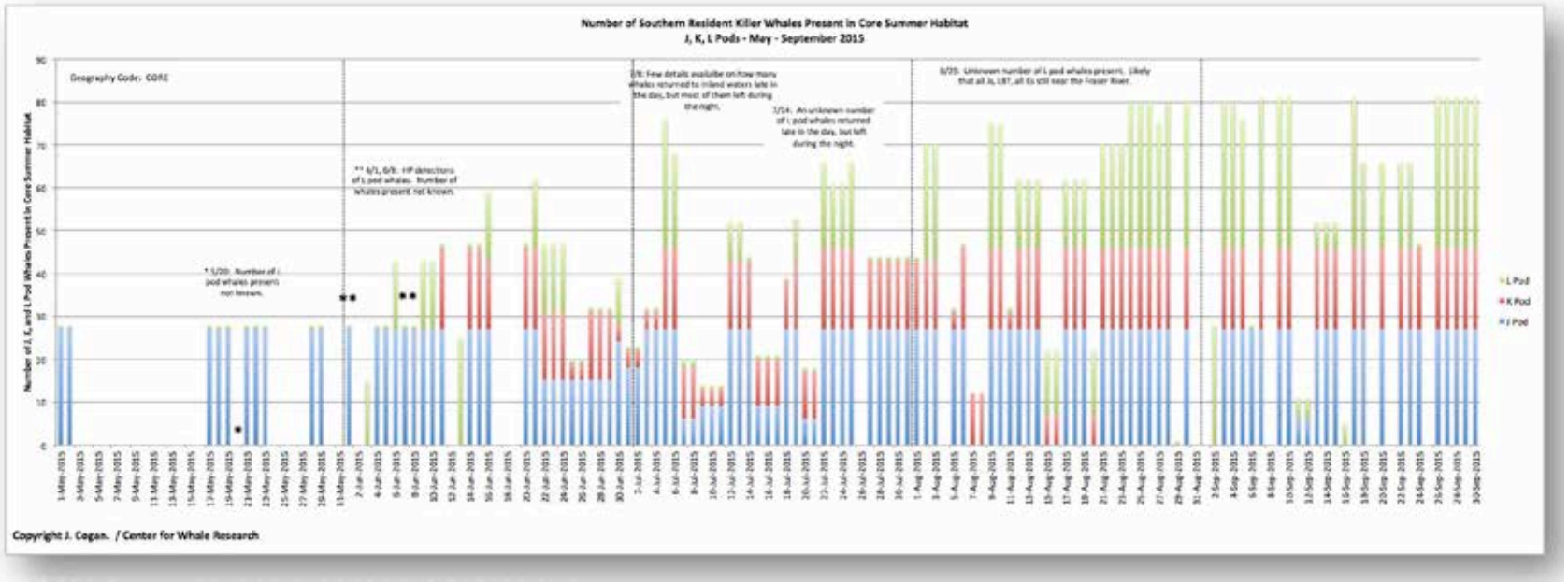


* In this context, "central Salish Sea" includes the Strait of Juan de Fuca plus Puget Sound, the southern Strait of Georgia, and all waters in between (waters surrounding the San Juan Islands, Canadian Gulf Islands, etc.).

We still call them “Resident”

SRKW Presence in Core Summer Habitat

May – September, 2015

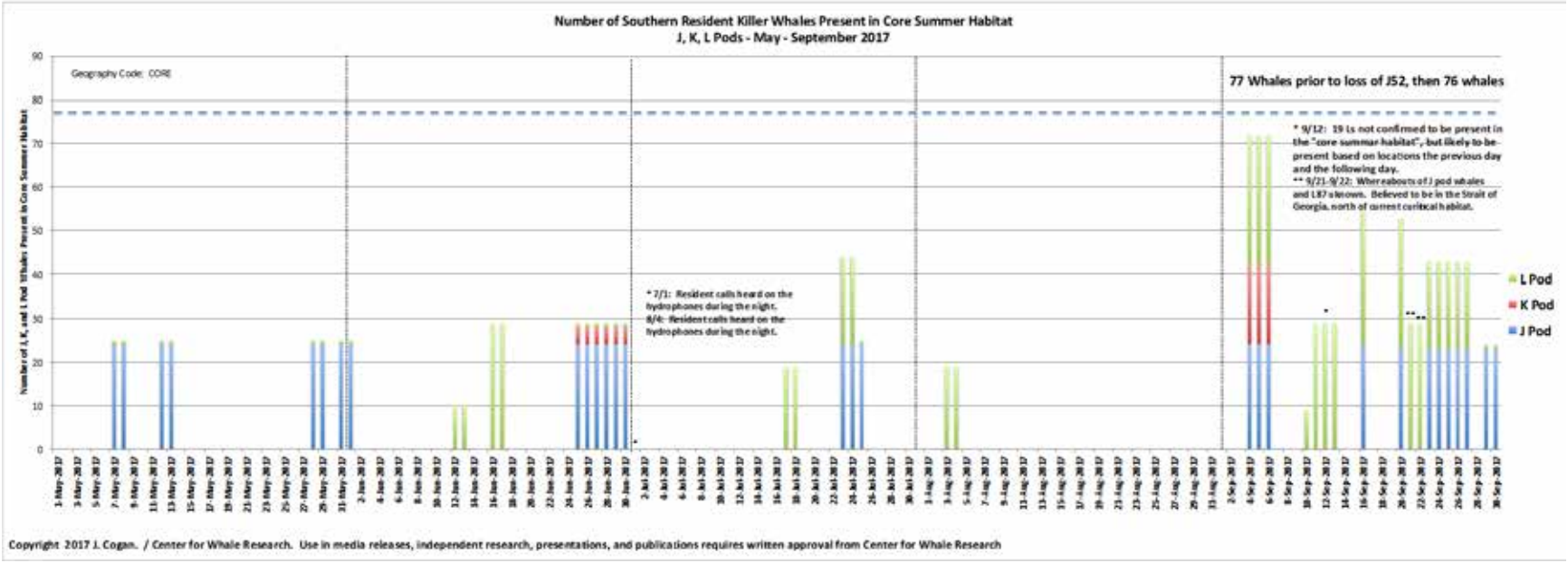


SRKWs in Core Summer Habitat 118 Days, often members of all three pods!

Shall we still call the fish-eaters “Resident”? Do we want them as neighbors?

SRKW Presence in Core Summer Habitat

May – September 2017

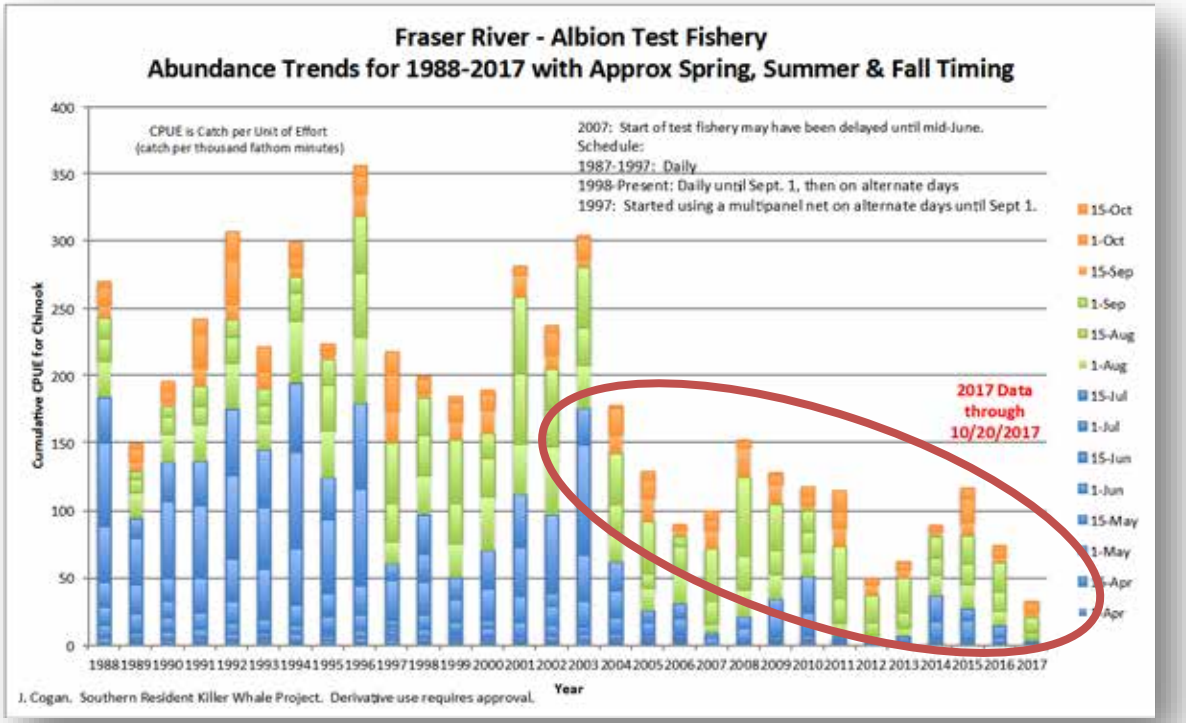


Small groups of SRKWs in Core Summer Habitat on 43 days in 2017!

Fraser River Chinook Salmon:

Albion Test Fishery

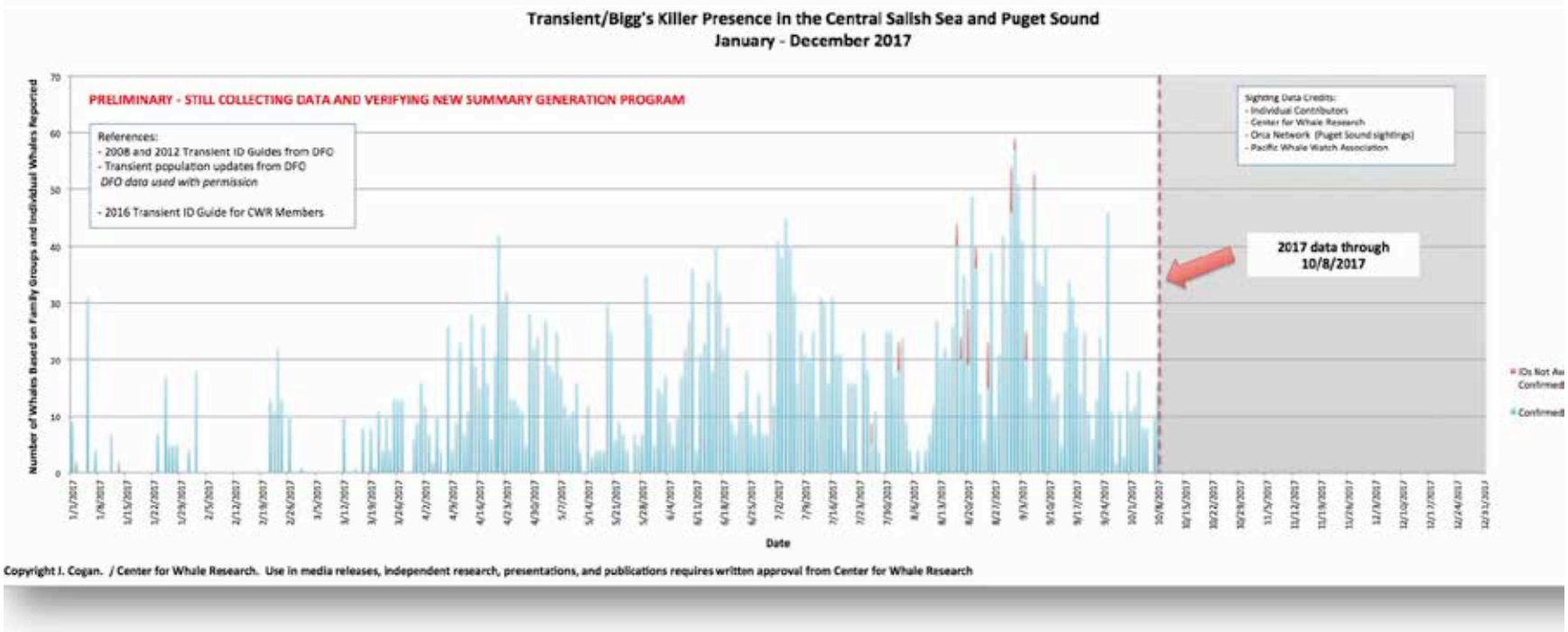
- SRKW occupancy combined with either indices of Chinook abundance or total abundance can provide insight.
- SRKW attendance patterns in the "core summer habitat" from 2004-2017 parallel the trends Fraser River Chinook salmon abundance, using the Albion Chinook Test Fishery data as a proxy for abundance as measured from the perspective of the SRKWs.



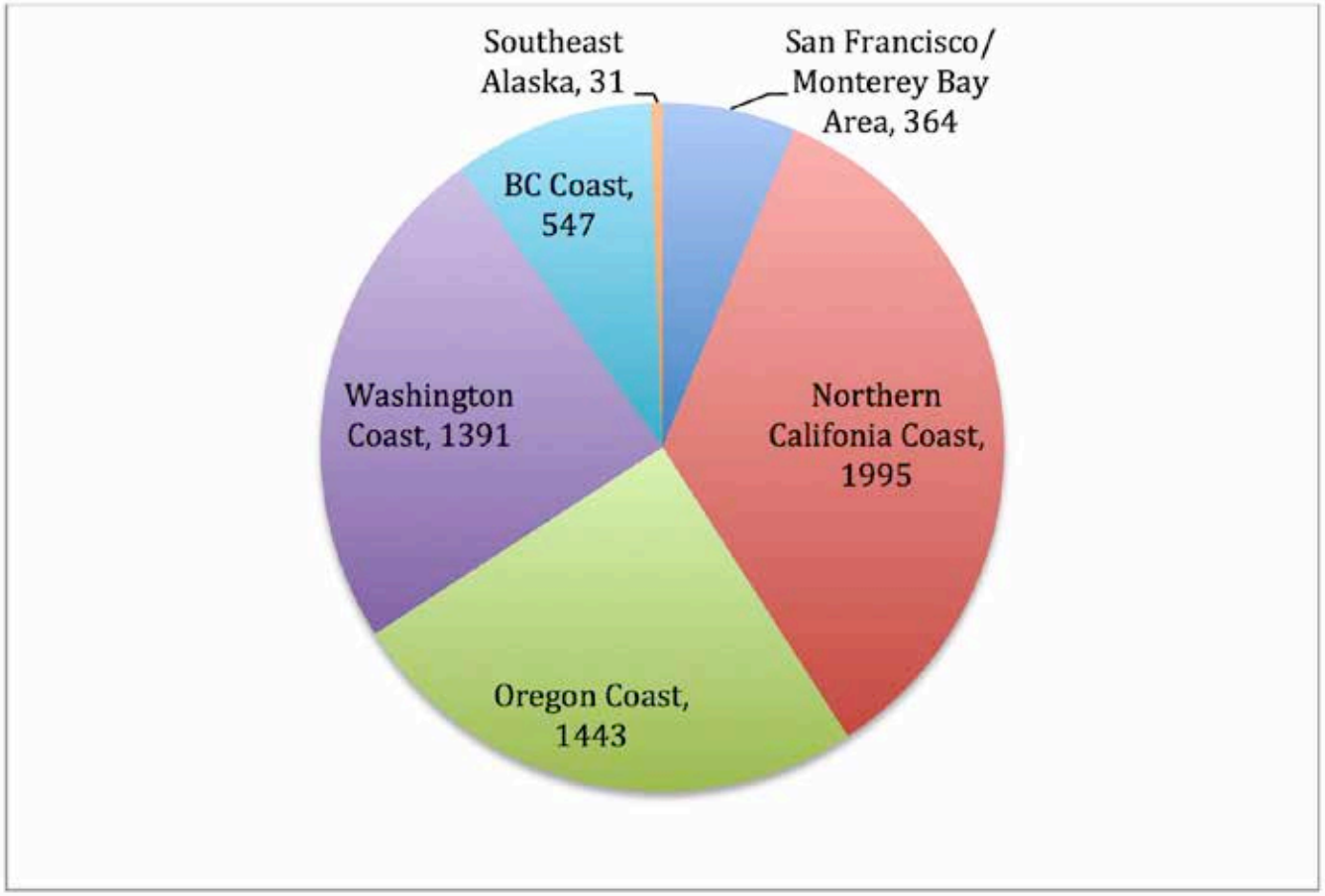
We now call the Transients “Bigg’s Killer Whales”

Transient Presence in Central Salish Sea

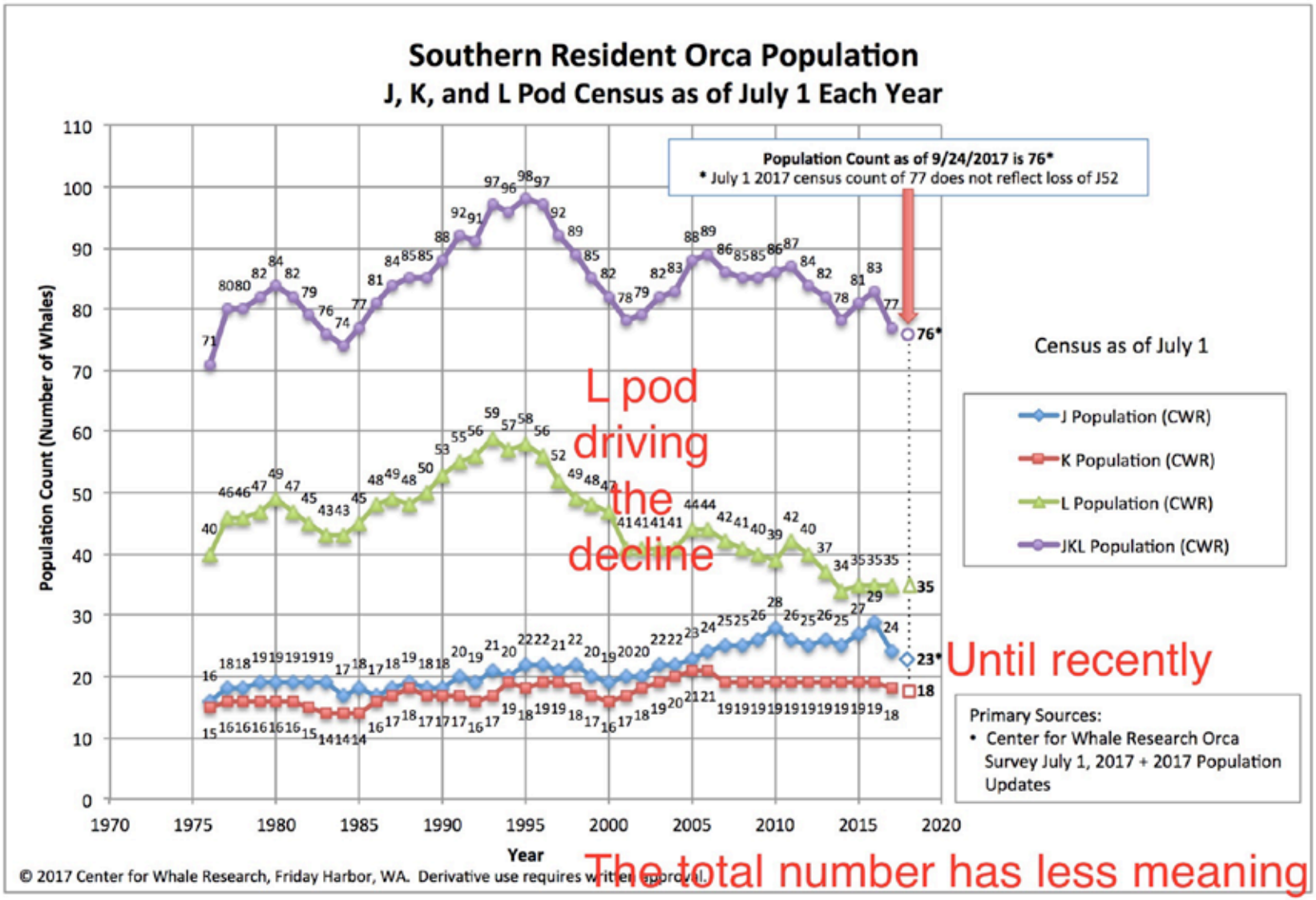
2017 as of Early October



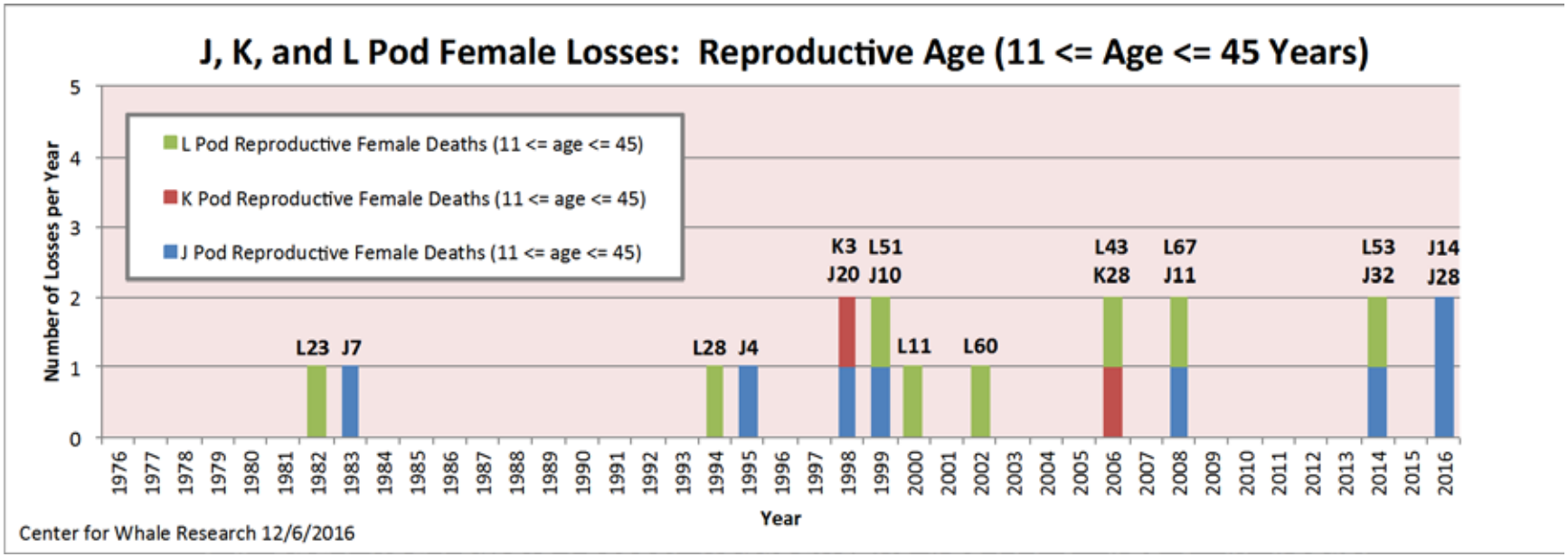
Where do the SRKW whales go when they are not in the Salish Sea?



This is the population chart that we prepare each year for NMFS, DFO, and the general public



Than who is dying!
Salmon Decline = SRKW Decline



L51 with prolapsed uterus

L51 Ovaries not found

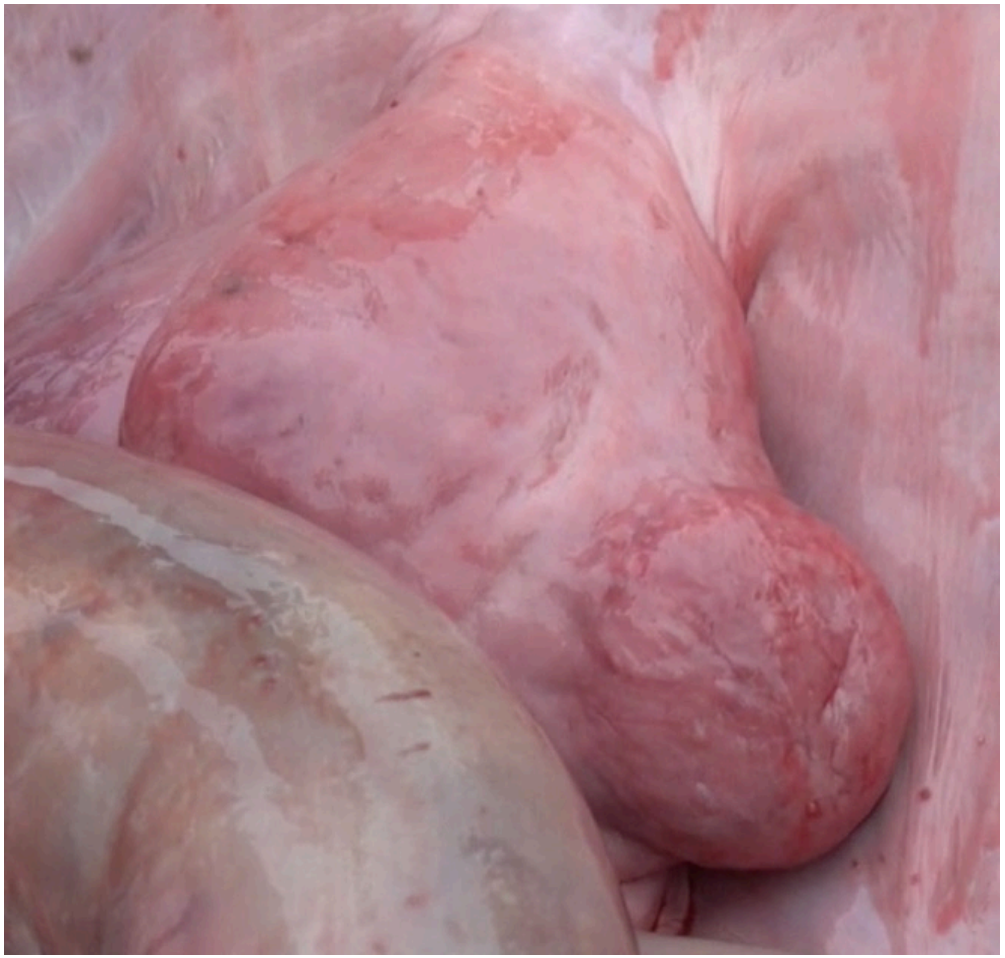
L60 prolapsed uterus

1 Corpus luteum, 7 Corpora albicantia

That is, she had eight pregnancies and two known calves = 75% fetal/neonate mortality

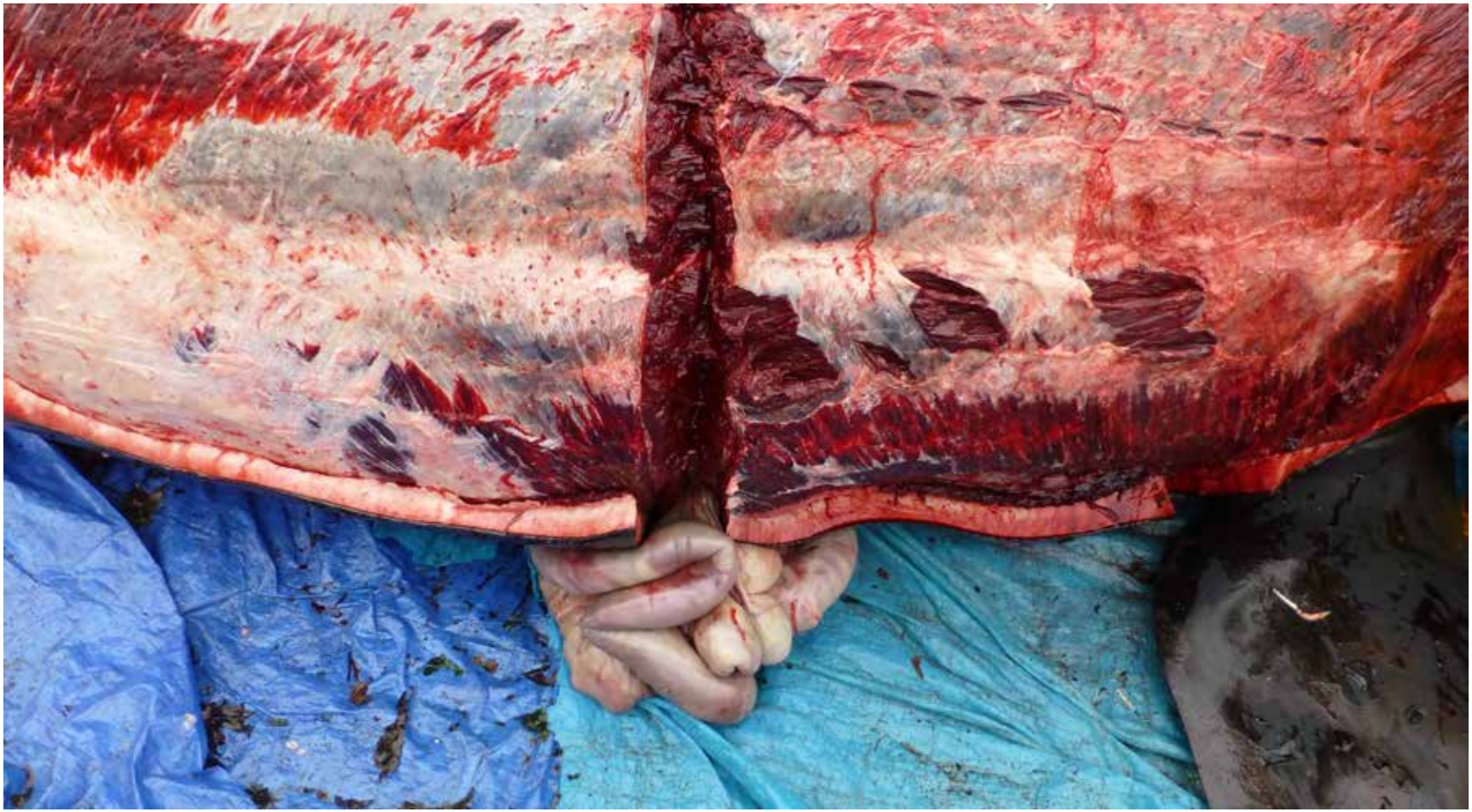
J32 died due to necrotic fetus

1 Corpus luteum, 2-3? Corpora albicantia



18 year old female with estimated two prior pregnancies surmised from girth appearance.

J32 Blubber thin and “dry”



We know:

- **Mature females are dying at greater rate now than during first two decades of this study**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- **Birth complications are on rise in this population**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- **75% of the developing fetuses are miscarried**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- **Late term miscarriages are extremely dangerous to mother survival**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- Late term miscarriages are extremely dangerous to mother survival
- **Nutritional Stress is increasing and seasonally extreme**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- Late term miscarriages are extremely dangerous to mother survival
- Nutritional Stress is increasing and seasonally extreme
- **There is a 44% mortality of SRKW young before they mature**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- Late term miscarriages are extremely dangerous to mother survival
- Nutritional Stress is increasing and seasonally extreme
- There is a 44% mortality of SRKW young before they mature
- **Less than 50% of calves born are females (male bias**)

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- Late term miscarriages are extremely dangerous to mother survival
- Nutritional Stress is increasing and seasonally extreme
- There is a 44% mortality of SRKW young before they mature
- Less than 50% of calves born are females (male bias)
- **For the last five years there is an average of only two calves born each year, none in two of the years**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- Late term miscarriages are extremely dangerous to mother survival
- Nutritional Stress is increasing and seasonally extreme
- There is a 44% mortality of SRKW young before they mature
- Less than 50% of calves born are females (male bias)
- For the last five years there is only an average of two calves born
- Two recent years of poor salmon abundance had no calves born
- **We have voiced concern about these trends for two decades**

We know:

- Mature females are dying at greater rate now than during first two decades of this study
- Birth complications are on rise in this population
- 75% of the developing fetuses are miscarried
- Late term miscarriages are extremely dangerous to mother survival
- Nutritional Stress is increasing and seasonally extreme
- There is a 44% mortality of SRKW young before they mature
- Less than 50% of calves born are females (male bias)
- For the last five years there is only an average of two calves born
- Two recent years of poor salmon abundance had no calves born
- **We have voiced concern about these trends for two decades, and only recently (perhaps too late) is the alarm being sounded**

Our 2009 paper

Journal of Applied Ecology

Journal of Applied Ecology 2009, **46**, 632–640 doi: 10.1111/j.1365-2664.2009.01647.x

Quantifying the effects of prey abundance on killer whale reproduction

Eric J. Ward[1,*], Elizabeth E. Holmes[1] and Ken C. Balcomb[2]

[1]Northwest Fisheries Science Center, 2725 Montlake Blvd E, Seattle, WA 98112, USA; and [2]Center for Whale Research, PO Box 1577, Friday Harbor, WA 98250, USA

Summary

1. Management decisions for threatened and endangered species require risks to be identified and prioritized, based on the degree to which they influence population dynamics. The potential for recovery of small populations at risk may be determined by multiple factors, including intrinsic population characteristics (inbreeding, sex ratios) and extrinsic variables (prey availability, disease, human disturbance). Using Bayesian statistical methods, the impact of each of these risk factors on demographic rates can be quantified and assigned probabilities to express uncertainty.

2. We assessed the impact of a wide range of factors on the fecundity of two threatened populations of killer whales *Orcinus orca*, specifically whether killer whale production is limited by availability of Chinook salmon *Oncorhynchus tshawytscha*. Additional variables included anthropogenic factors, climate variables, temporal effects, and population variables (population size, number of males, female age).

3. Our results indicate that killer whale fecundity is highly correlated with the abundance of Chinook salmon. For example, the probability of a female calving differed by 50% between years of low salmon abundance and high salmon abundance. Weak evidence exists for linking fecundity to other variables, such as sea surface temperature.

4. There was strong data support for reproductive senescence in female killer whales. This pattern of rapid maturity and gradual decline of fecundity with age commonly seen in terrestrial mammals has been documented in few marine mammal species. Maximum production for this species occurs between ages 20–22, and reproductive performance declines gradually to menopause over a period of 25 years.

5. *Synthesis and applications*. Our results provide strong evidence for reproductive senescence in killer whales, and more importantly, that killer whale fecundity is strongly tied to the abundance of Chinook salmon, a species that is susceptible to environmental variation and has high commercial value to fisheries. This strong predator–prey relationship highlights the importance of understanding which salmon populations overlap with killer whales seasonally and spatially, so that those salmon populations important as prey for killer whales can be identified and targeted for conservation efforts.

Key words: bayesian model selection, killer whale, management of endangered species, predator-prey interactions, resource limitation, salmon

Fecundity highly correlated with abundance of Chinook salmon

Summary

1. Management decisions for threatened and endangered species require risks to be identified and prioritized, based on the degree to which they influence population dynamics. The potential for recovery of small populations at risk may be determined by multiple factors, including intrinsic population characteristics (inbreeding, sex ratios) and extrinsic variables (prey availability, disease, human disturbance). Using Bayesian statistical methods, the impact of each of these risk factors on demographic rates can be quantified and assigned probabilities to express uncertainty.

2. We assessed the impact of a wide range of factors on the fecundity of two threatened populations of killer whales *Orcinus orca*, specifically whether killer whale production is limited by availability of Chinook salmon *Oncorhynchus tshawytscha*. Additional variables included anthropogenic factors, climate variables, temporal effects, and population variables (population size, number of

3. Our results indicate that killer whale fecundity is highly correlated with the abundance of Chinook salmon. For example, the probability of a female calving differed by 50% between years of low salmon abundance and high salmon abundance. Weak evidence exists for linking fecundity to other variables, such as sea surface temperature.

of rapid maturity and gradual decline of fecundity with age commonly seen in terrestrial mammals has been documented in few marine mammal species. Maximum production for this species occurs

Scientific publication is not enough

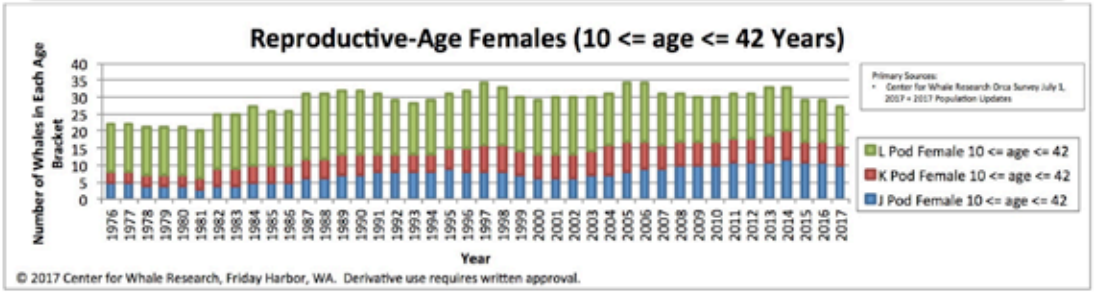
Action Required: We MUST restore abundant natural and wild stocks of Chinook salmon ASAP

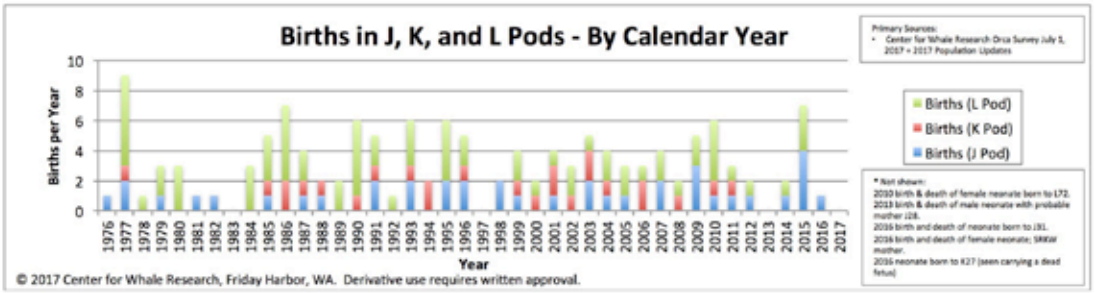
The way it is:

These are the important details of effective population size and fecundity

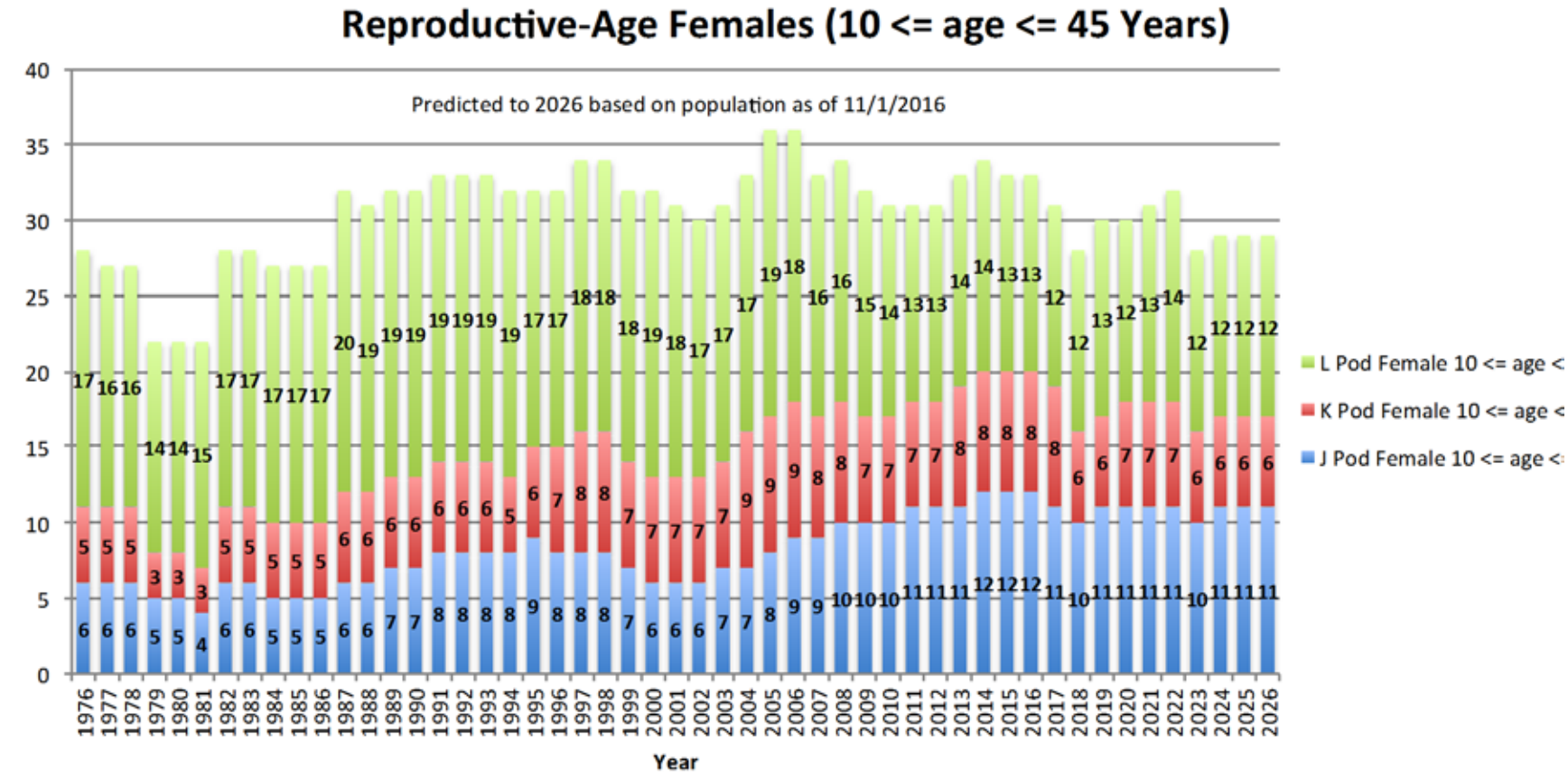
Reproductive-Age Females and Births

J, K, and L Pods



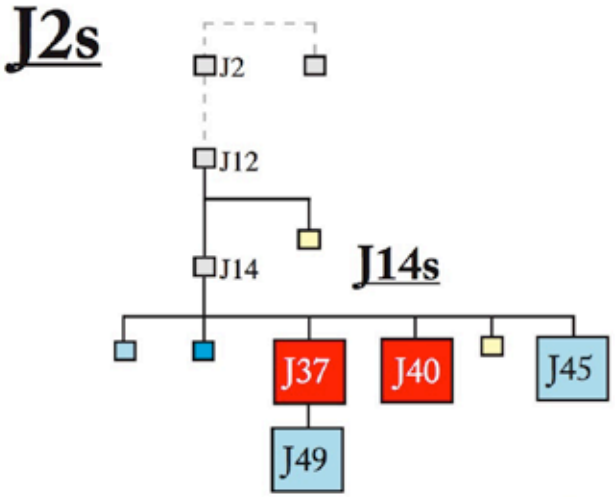


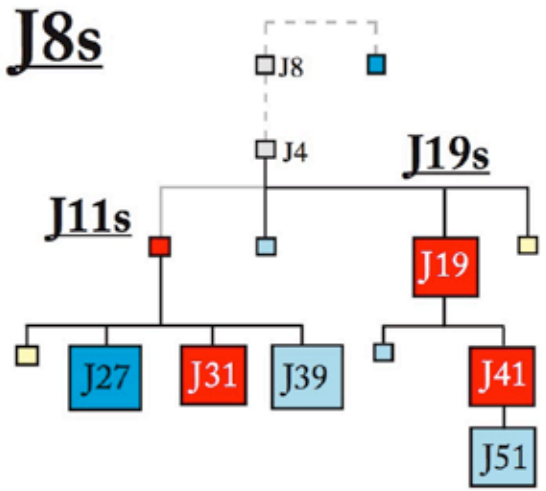
Most optimistic predicted future

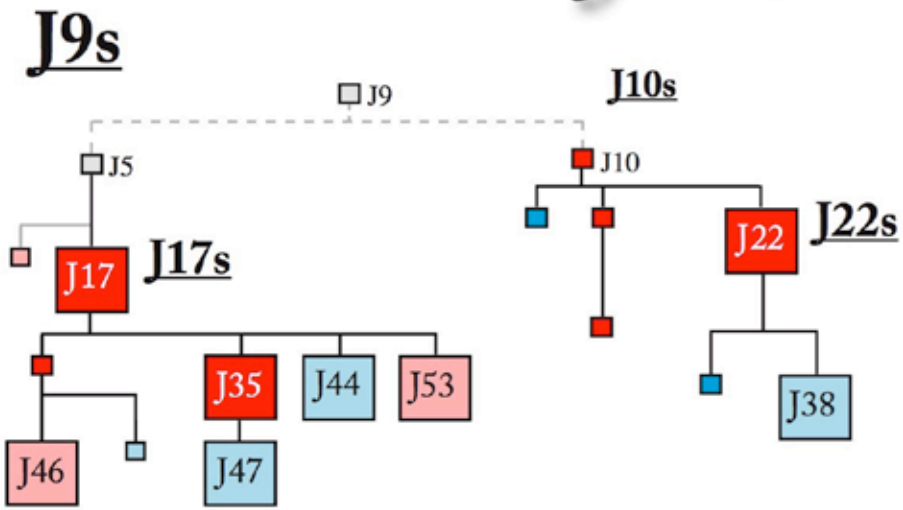


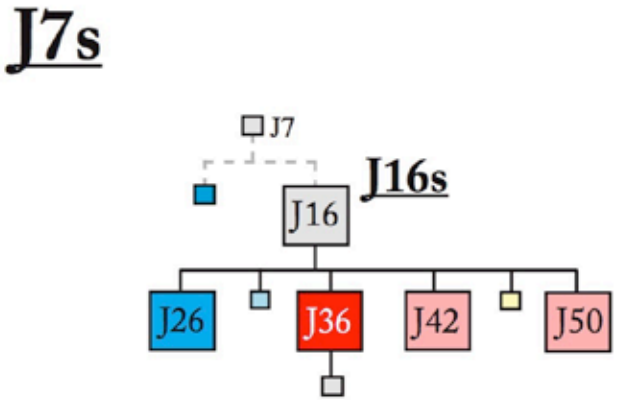
er for Whale Research 20161101

J POD

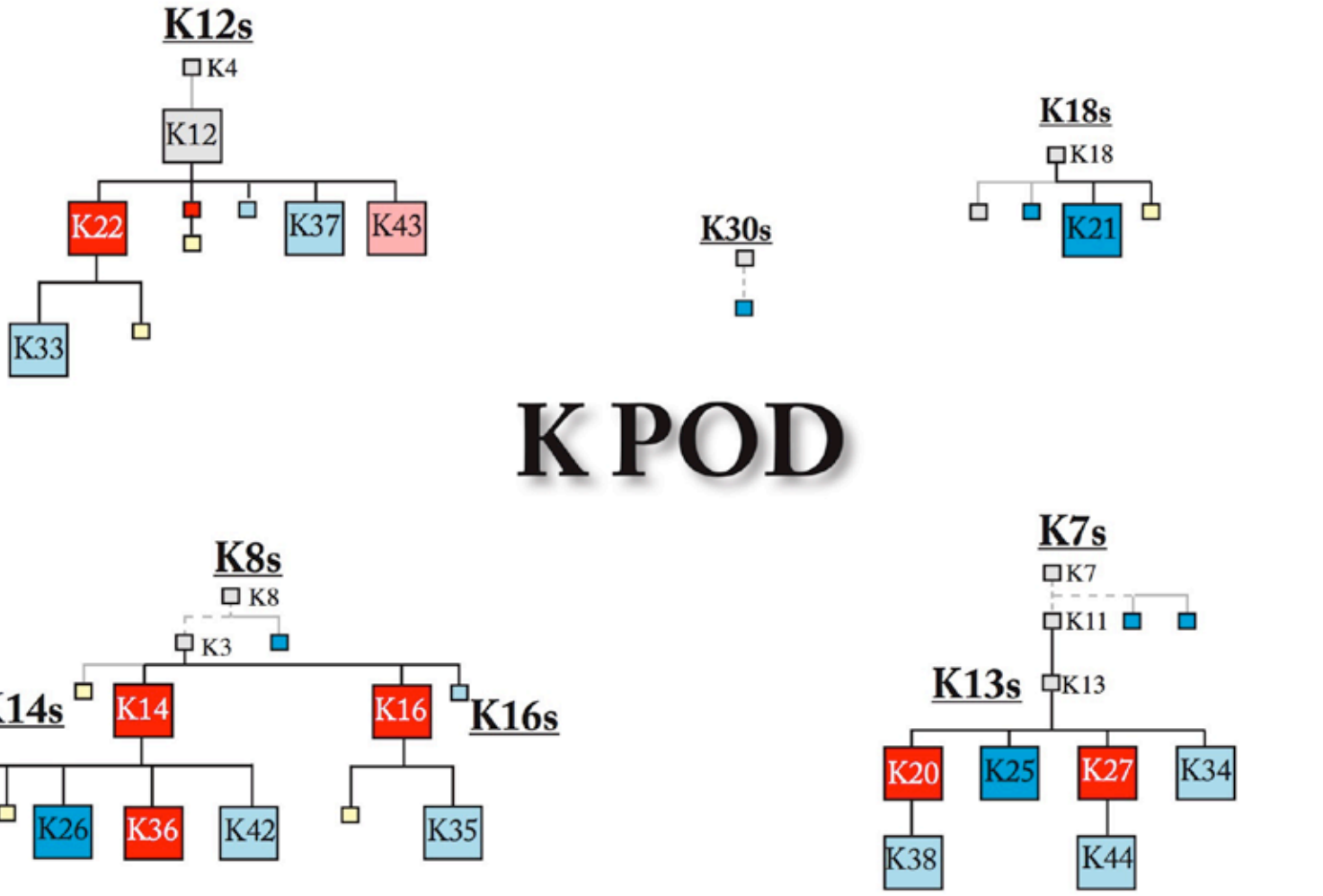




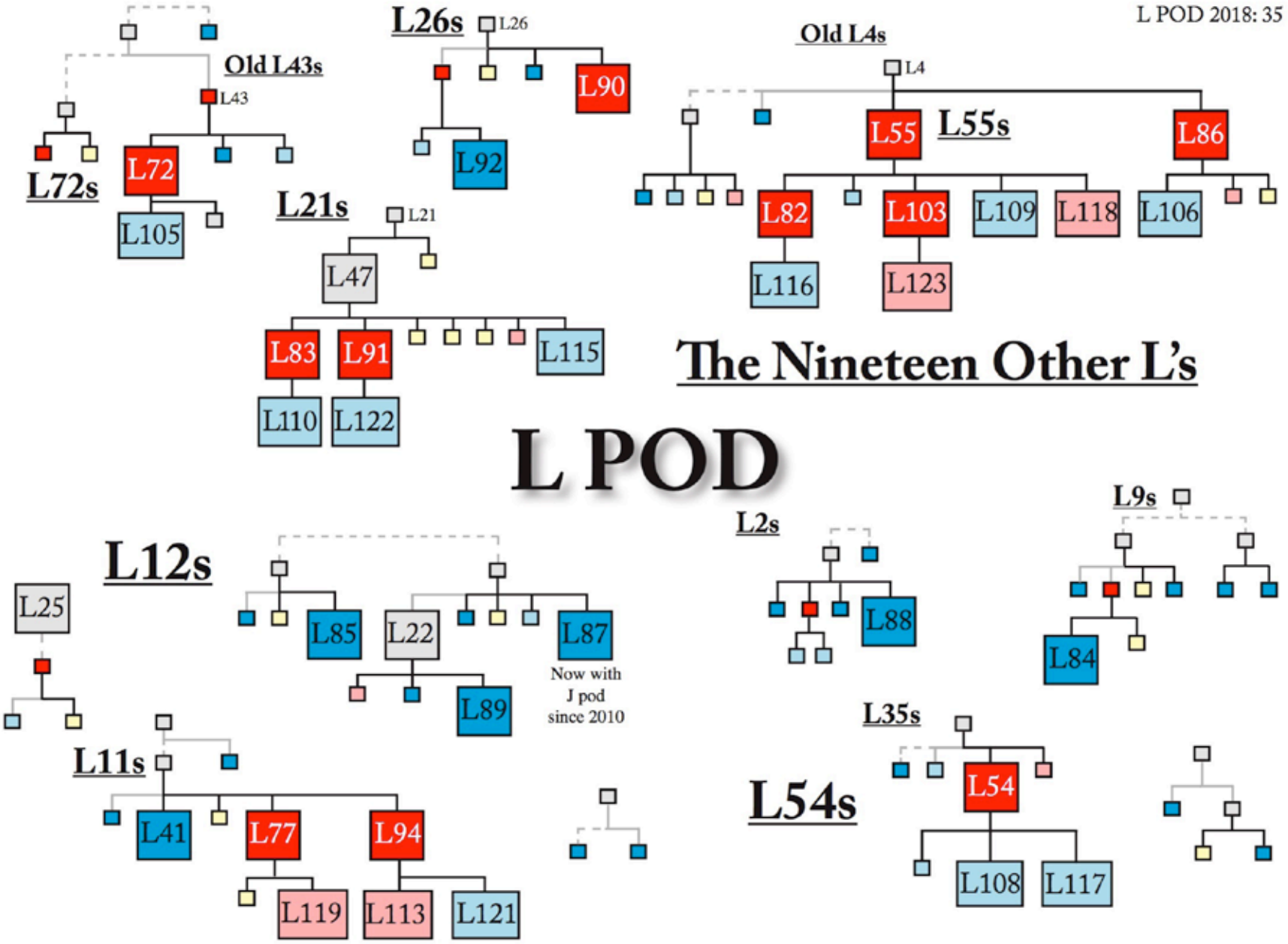




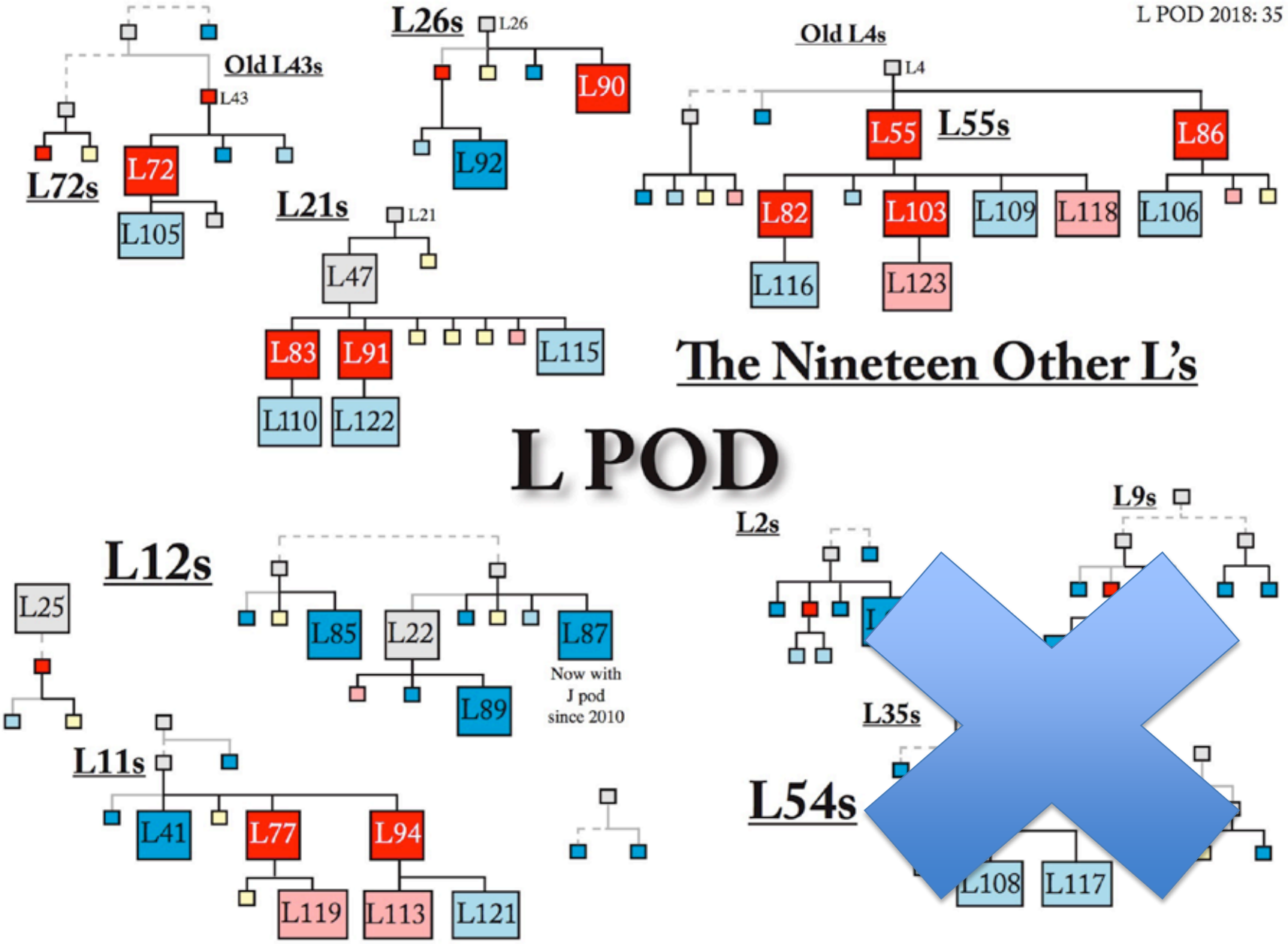
9 Adult females with 4 producing; 4 young females; 7 young males



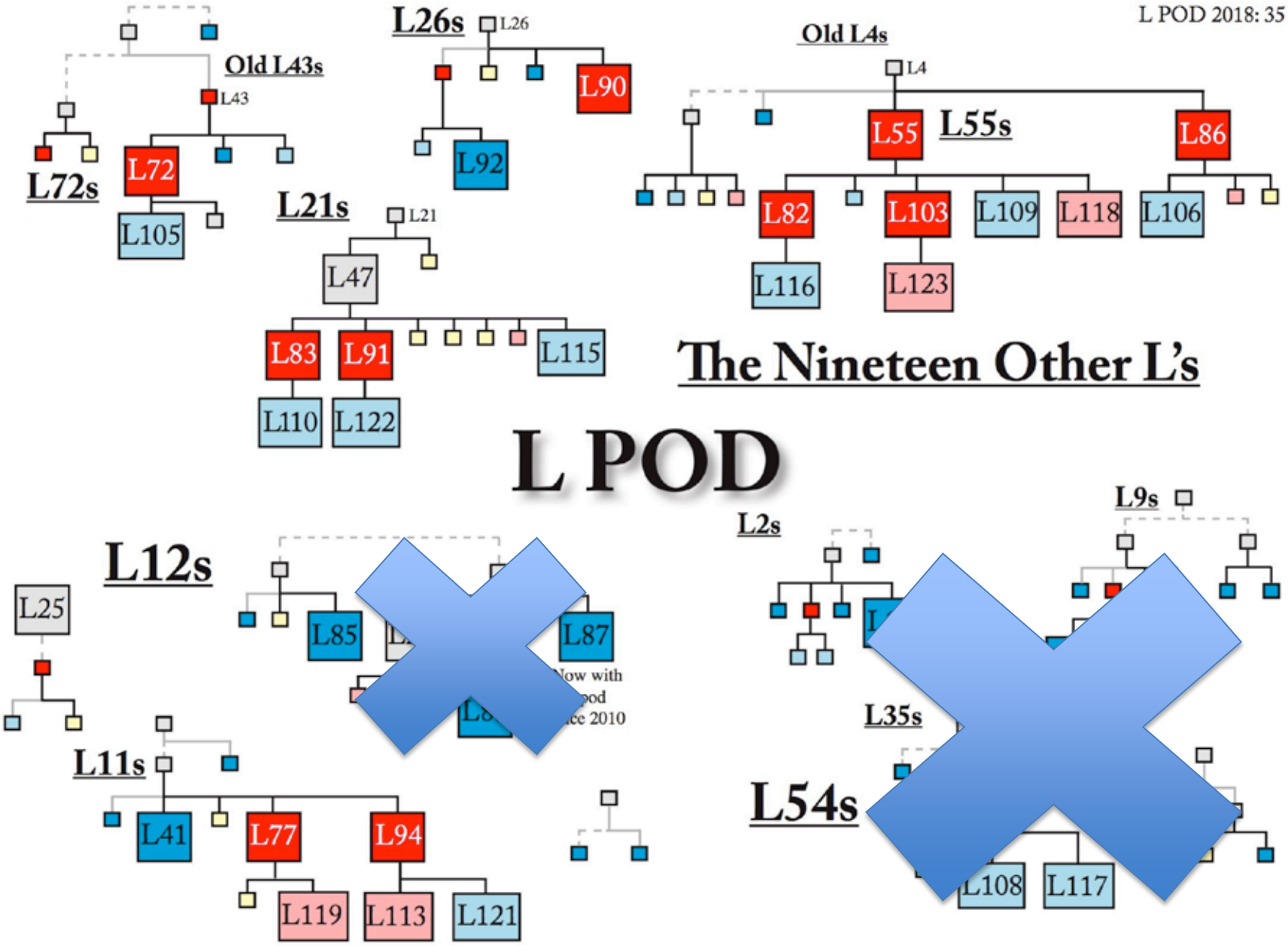
6 Adult females all non-producing except K27; 1 young female; 7 young males



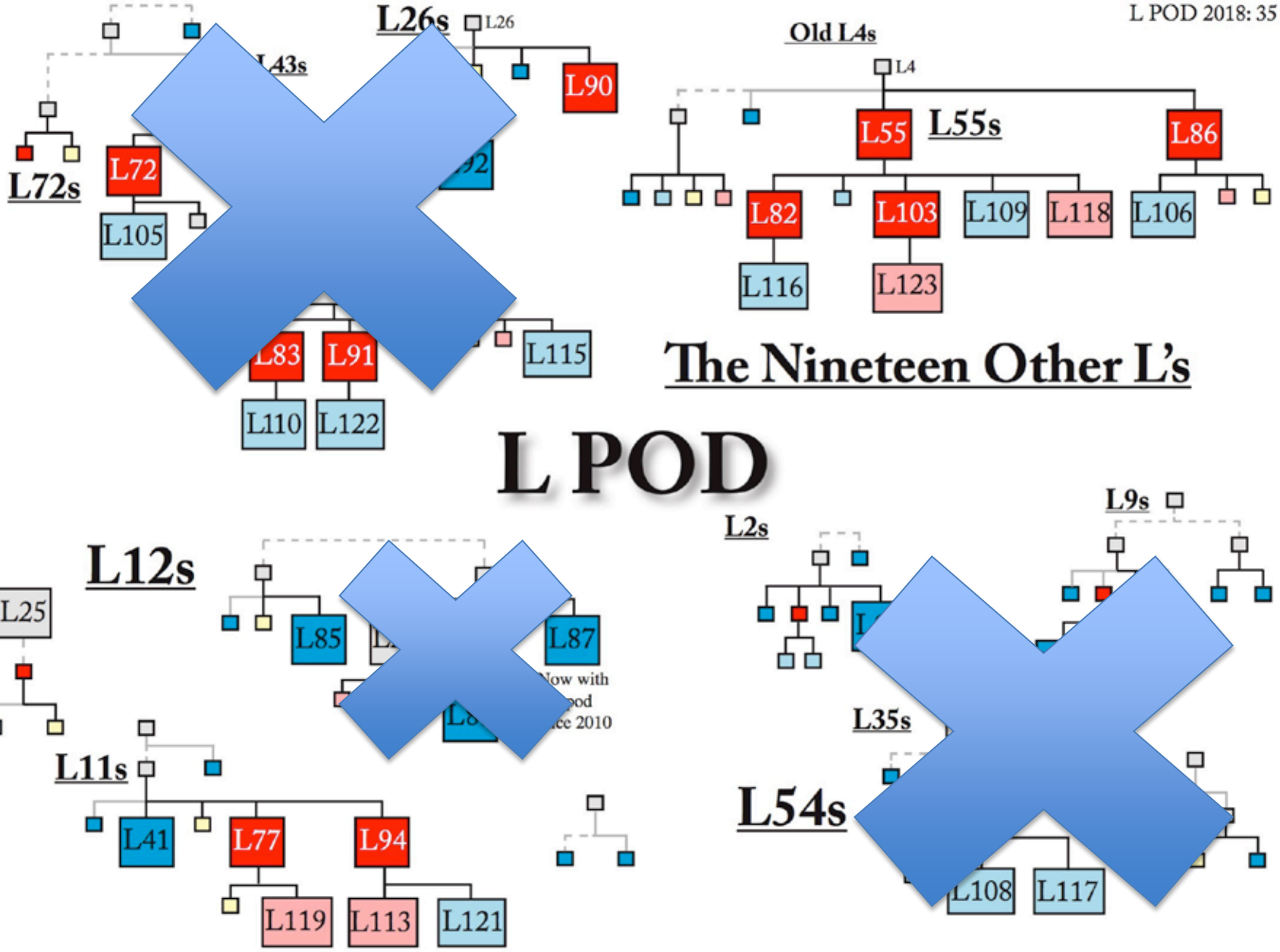
6 of 11 Adult females non-producing; 4 young females; 10 young males = no growth



6 of 11 Adult females non-producing; 4 young females; 10 young males = no growth

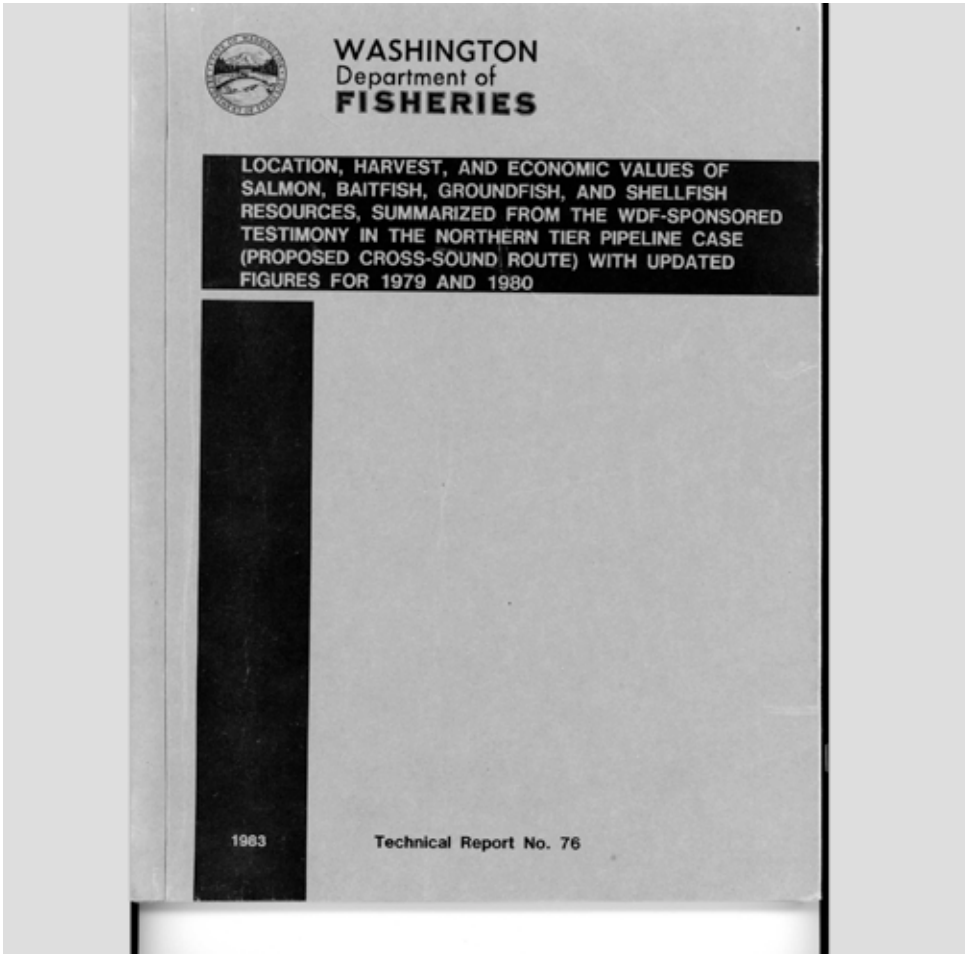


6 of 11 Adult females non-producing; 4 young females; 10 young males = no growth



6 of 11 Adult females non-producing; 4 young females; 10 young males = no growth

This demonstrates the Tragedy of the Commons



1974 to 1978 WDFW data

Appendix C Table 2. Summary of magnitude and value of salmon runs utilizing Strait of Juan de Fuca for migration (rounded to nearest thousand).

Species	Escapement		Catch		Value	
	Average	High	Average	High	Average	High
Chinook	192,000	245,000	1,498,000	1,918,000	74,400,000	95,200,000
Coho	610,000	1,025,000	3,000,000	5,100,000	51,700,000	86,900,000
Chum	941,000	1,459,000	1,500,000	2,300,000	11,900,000	18,400,000
Pink	2,433,000	3,271,000	3,433,000	6,562,000	8,579,000	17,017,000
Sockeye	1,444,000	2,949,000	4,982,000	7,062,000	47,840,000	68,500,000
Total	5,620,000	8,949,000	14,414,000	22,942,000	194,419,000	286,017,000

1974 to 1978 WDFW data

Appendix C Table 2. Summary of magnitude and value of salmon runs utilizing Strait of Juan de Fuca for migration (rounded to nearest thousand).

Species	Escapement		Catch		Value	
	Average	High	Average	High	Average	High
Chinook	192,000	245,000	1,498,000	1,918,000	74,400,000	95,200,000
Coho	818,000	1,025,000	3,000,000	5,100,000	51,700,000	86,900,000
Chum	941,000	1,459,000	1,500,000	2,300,000	11,900,000	18,400,000
Pink	2,433,000	3,271,000	3,433,000	6,562,000	8,579,000	17,017,000
Sockeye	1,444,000	2,949,000	4,982,000	7,062,000	47,840,000	68,500,000
Total	5,620,000	8,949,000	14,414,000	22,942,000	194,419,000	286,017,000

-42-

The human harvest of **1.5 to 1.9 Million Chinook salmon** in inland Washington State waters during these years was roughly **two** to **four** times that of the maximum potential harvest by the SRKW population at that time, and it only allowed about **13% salmon escapement** for spawning!

DFO data for Canada

Appendix C Table 7. Canadian Georgia Strait sport catch statistics (X1000 rounded to nearest thousand).

	Chinook	Coho	Pink[1/]	Total[2/]
1972	287	335	9	632
1973	272	373	50	696
1974	269	772	9	1,050
1975	398	454	27	878
1976	490	415	4	909
Average	343	470	20	833
High	490	772	50	1,312
Value				
Average	33,589	19,060	147	52,796
High	47,918	31,373	374	79,664

1/ Includes minor catches of sockeye and chum salmon.

2/ The Canadian Fisheries Service (Fisheries and Oceans) recently determined that their 1972-1976 salmon sport catch was actually about twice as high as reported in their original estimates. This table shows the original estimates.

DFO data for Canada

Appendix C Table 7. Canadian Georgia Strait sport catch statistics (X1000 rounded to nearest thousand).

	Chinook	Coho	Pink 1/	Total 2/
1972	287	335	9	632
1973	272	373	50	696
1974	269	772	9	1,050
1975	398	454	27	878
1976	490	415	4	909
Average		470	20	833
High	490	772	50	1,312
Value				
Average	33,589	19,060	147	52,796
High	47,918	31,373	374	79,664

1/ Includes minor catches of sockeye and chum salmon.

2/ The Canadian Fisheries Service (Fisheries and Oceans) recently determined that their 1972-1976 salmon sport catch was actually about twice as high as reported in their original estimates. This table shows the original estimates.

DFO data for Canada

Appendix C Table 7. Canadian Georgia Strait sport catch statistics (X1000 rounded to nearest thousand).

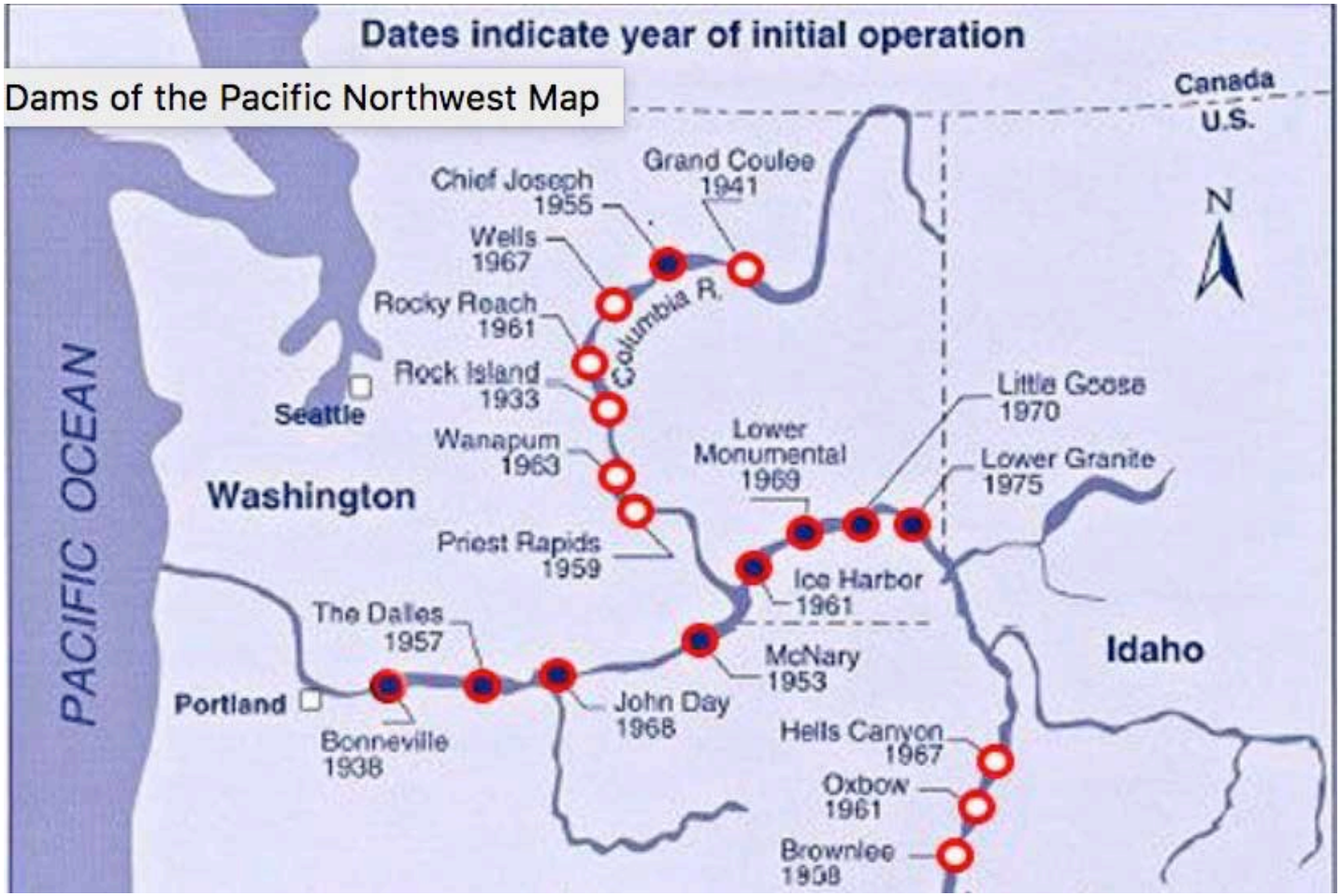
	Chinook	Coho	Pink 1/	Total 2/
1972	287	335	9	632
1973	272	373	50	696
1974	269	772	9	1,050
1975	398	454	27	878
1976	490	415	4	909
Average		470	20	833
High	490	772	50	1,312
Value				
Average	33,589	19,060	147	52,796
High	47,918	31,373	374	

/ ...includes minor catches of sockeye and chum salmon.

The Canadian Fisheries Service (Fisheries and Oceans) recently determined that their 1972-1976 salmon sport catch was actually about twice as high as reported in their original estimates. This table shows the original estimates.

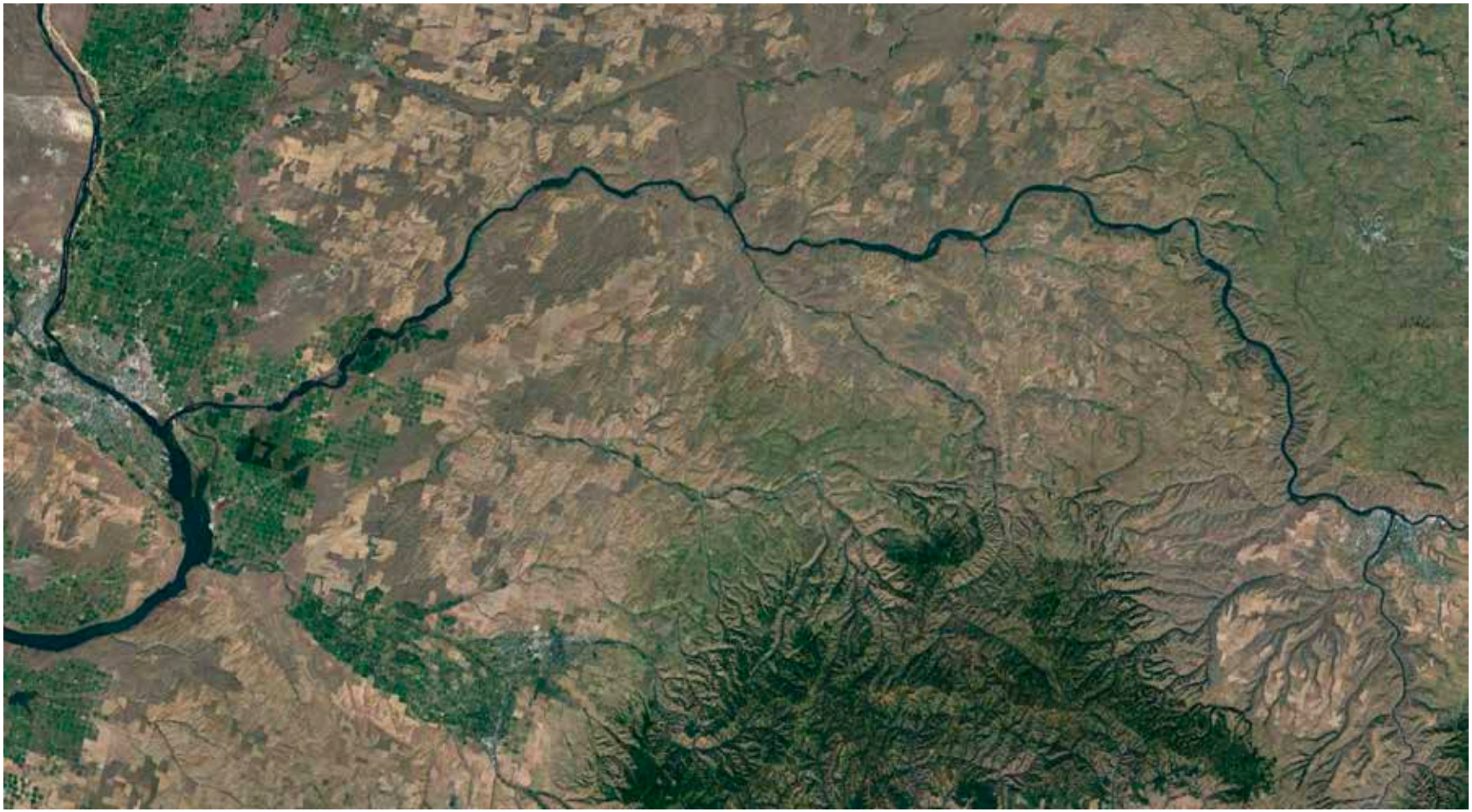
The Canadian Sport Harvest of up to one million Chinook salmon was also roughly **twice** that of what was even possible by the SRKW at the time.

Overfishing is just one of the Tragedies



Dams, Mining, Forestry Practices, Ranching, Agriculture, Industrialization, Commerce, all have tragic stories of environmental abuse toward salmon.

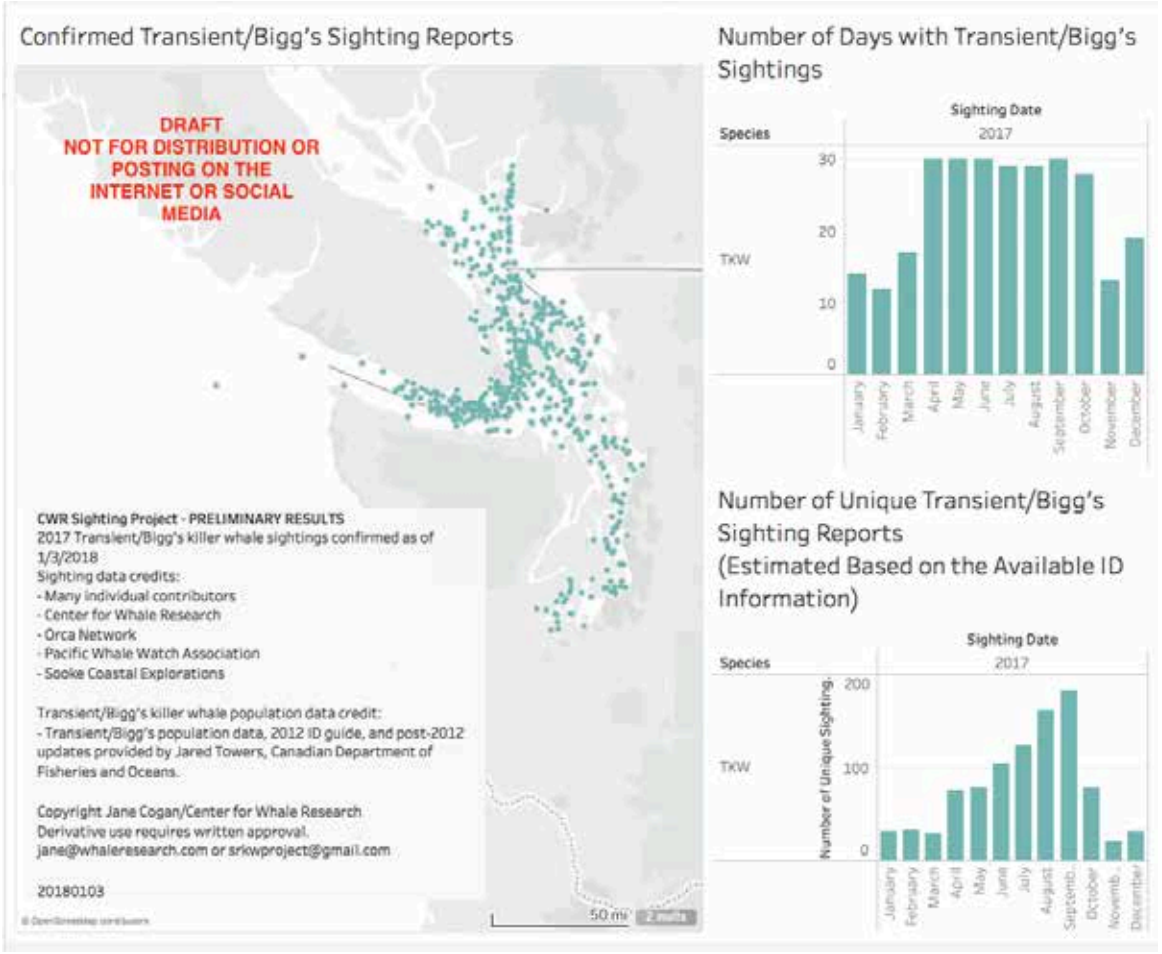
The Salish Sea needs Recovery - Yes



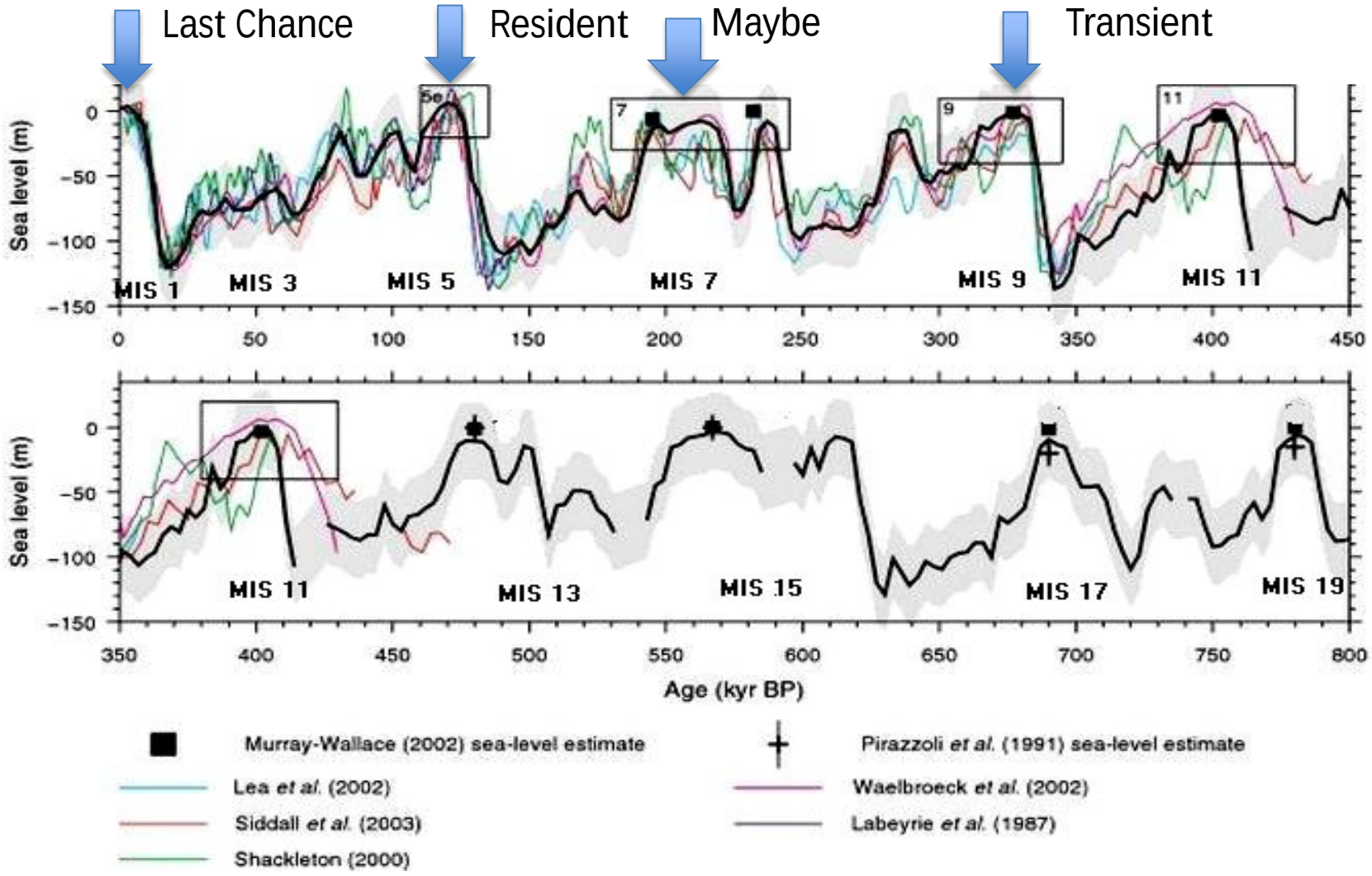
But, the whales urgently need hundreds of thousands of non-toxic Chinook to survive, and that is why I have been advocating immediate recovery of the Snake River.

Questions?

But they are not always here, whereas the "Transients" are now almost always are:



Sea Level in the Pleistocene



Killer Whale Ecotypes MRCA

Most recent common ancestor

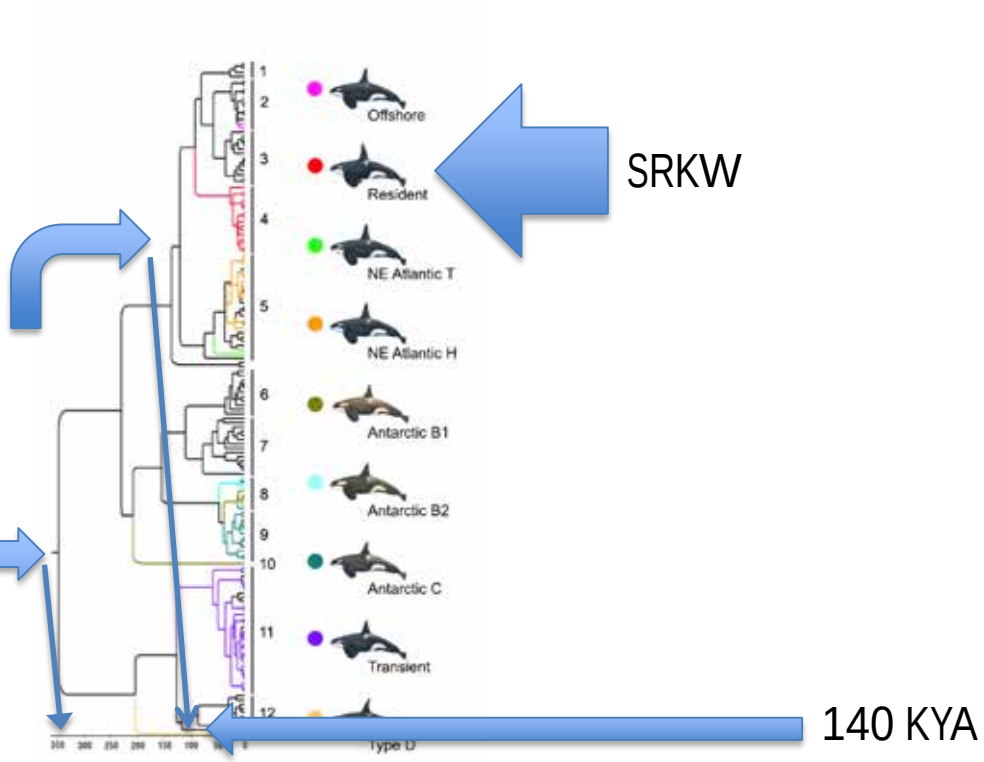
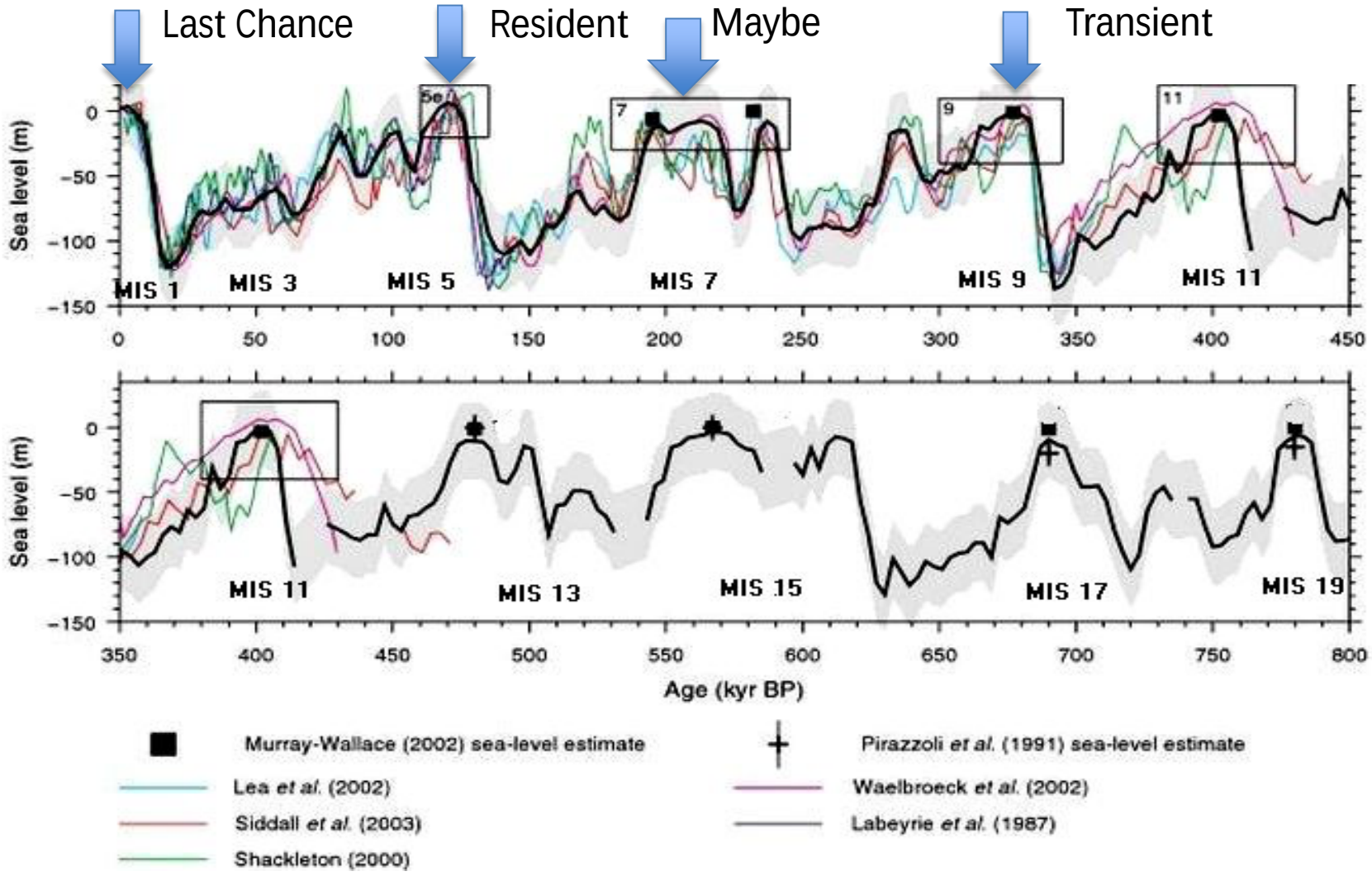


Fig. 2 Bayesian phylogenetic tree of 158 unique mitogenome sequences. Coloured branches identify haplotypes found in individuals identified ecologically or morphologically based on well-characterized types or populations. 'NE Atlantic T' and 'NE Atlantic H' represent the herring- and tuna-eating populations, respectively. Solid lines to the right indicate numbered clades referred to in the text. Sample information for haplotypes is provided in Fig. S2 and Table S1 (Supporting information).

Sea Level in the Pleistocene



These Fish-eaters earned the name “Resident”, but they were still predators

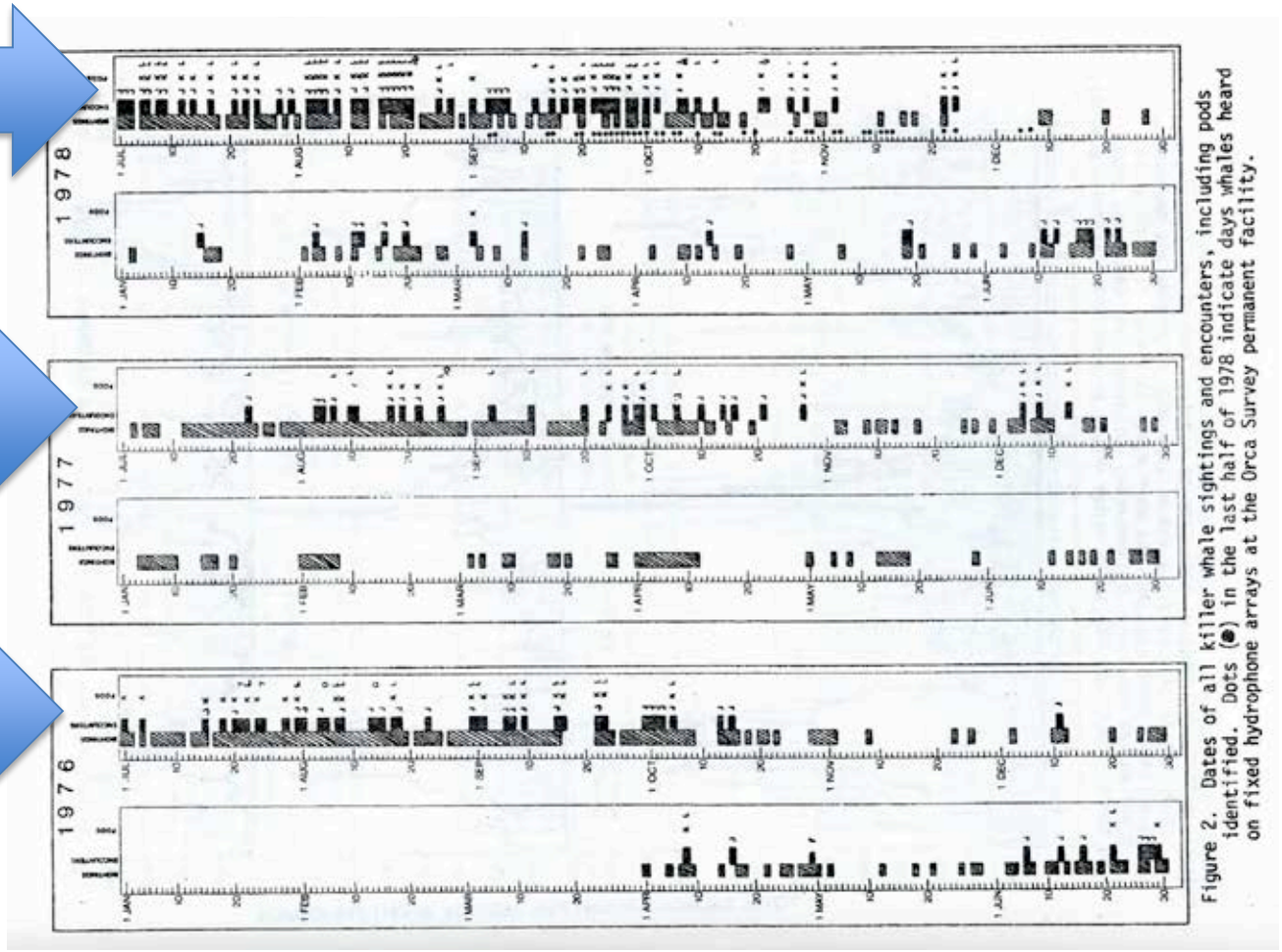


Figure 2. Dates of all killer whale sightings and encounters, including pods identified. Dots (●) in the last half of 1978 indicate days whales heard on fixed hydrophone arrays at the Orca Survey permanent facility.

We will stick with the “Resident” Story

We will stick with the “Resident” Story

Sometime around 140 KYA,…

“Fish-eating” ecotype spread out in coastal waters in the North Pacific