Western Steller Sea Lions:
Population Trends and Vital Rates

Alaska Ecosystem Program
NOAA Fisheries
National Marine Mammal Laboratory
Alaska Fisheries Science Center
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Outline

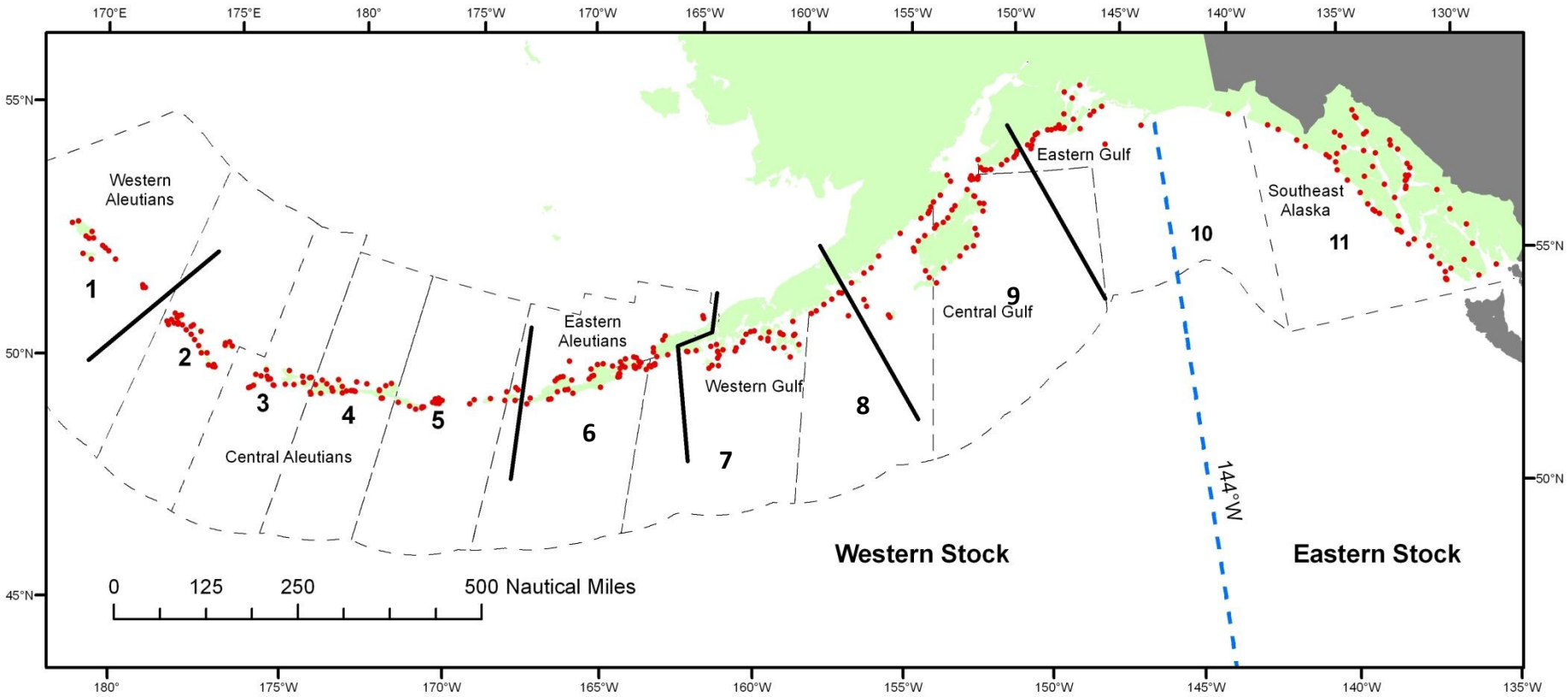
Abundance and Trends

- Western Stock (DPS) in Alaska
- Eastern DPS in SE Alaska
- Russia

Survival

- Western DPS: E Aleutians – E Gulf of Alaska
- Comparisons with SE Alaska (eastern DPS)
- Changes in western DPS survival 1970s-2000s
- Possible relationships between survival, natality, population trends and differences in life history between E & W DPSs

Steller Sea Lion Stocks and Regions in AK



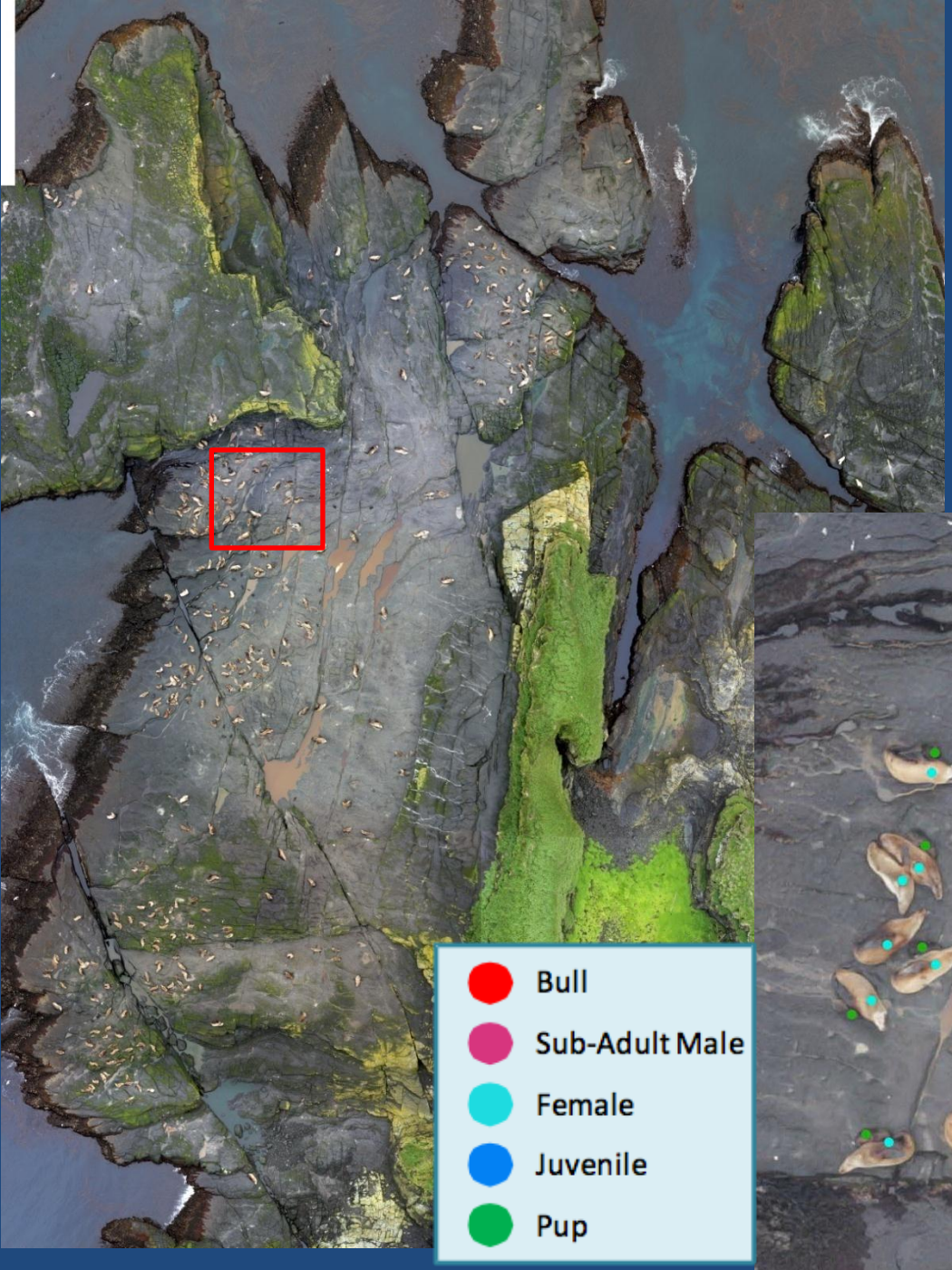
- Eastern and Western Distinct Population Segments (DPS)
- Eastern, Central, Western Aleutians & Gulf of Alaska; SE AK
- Rookery Cluster Areas 1-11

Western Stock

Ulak/Hasgox Point – Central Aleutians

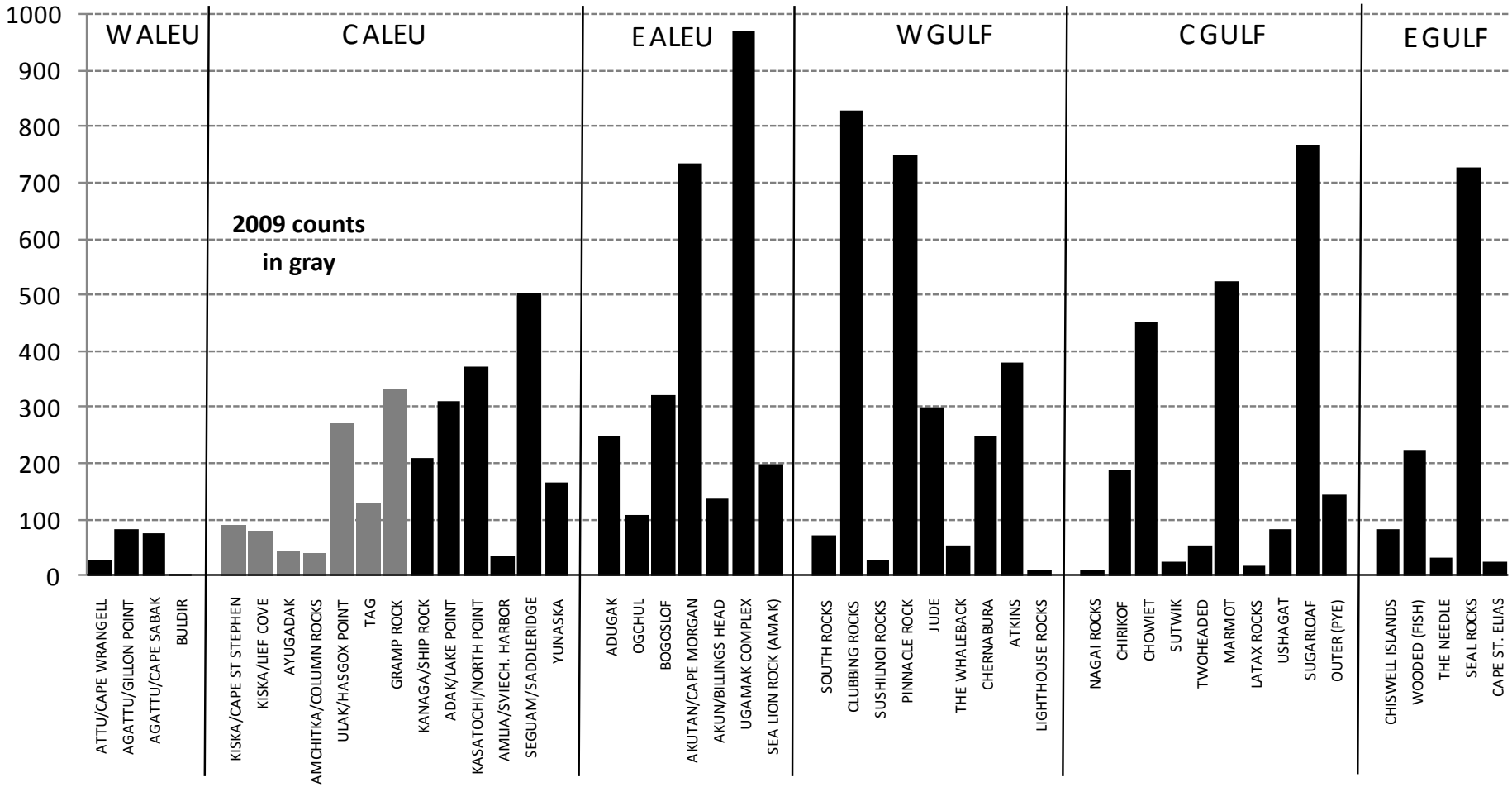
Decreasing: 272 Pups

515 Adults and Juveniles



SSL Pup Counts 2009 & 2011

- All rookeries
- Major haulouts
- Western DPS in AK



Change in SSL Pup Counts 2009 to 2011

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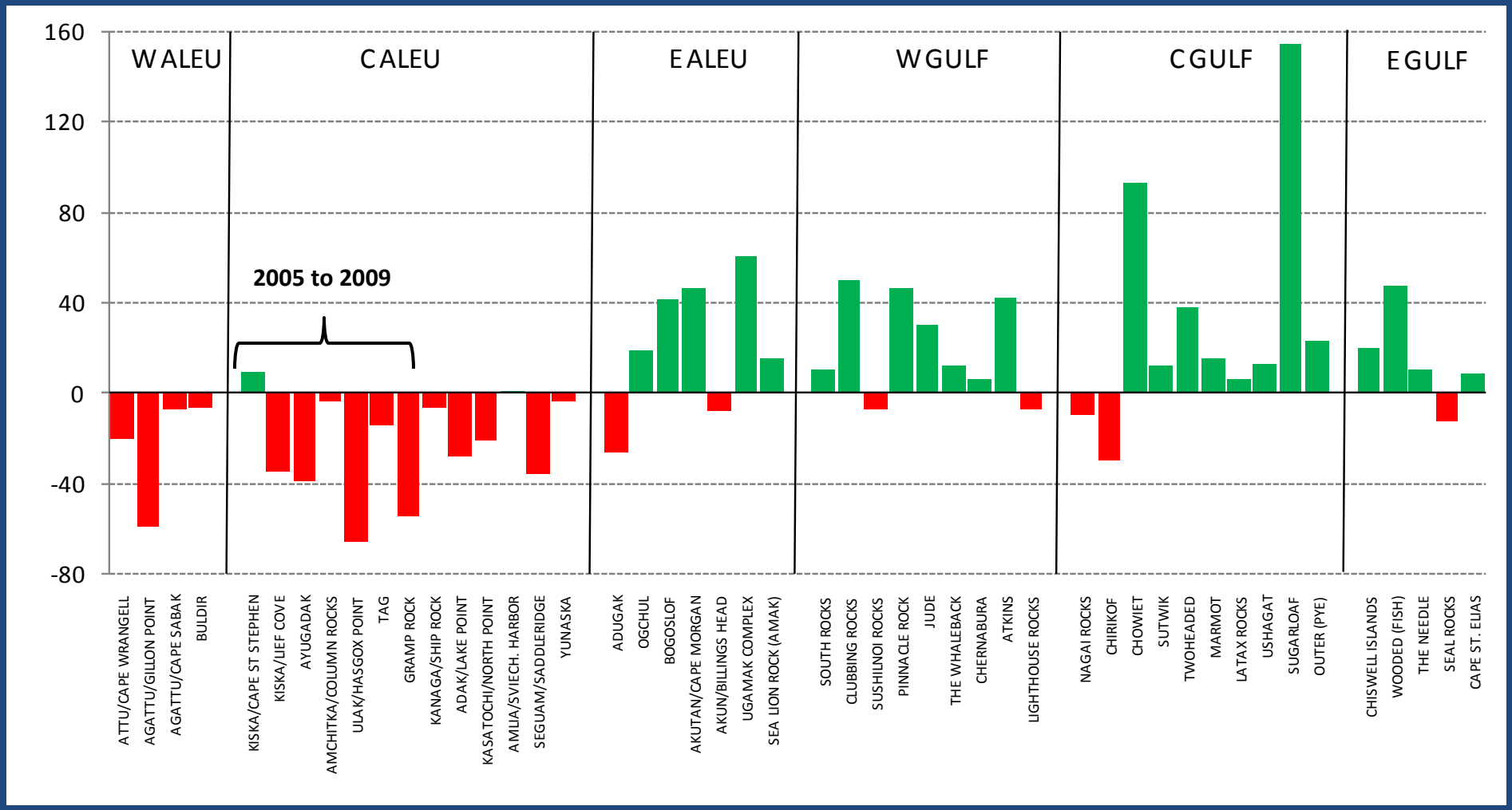
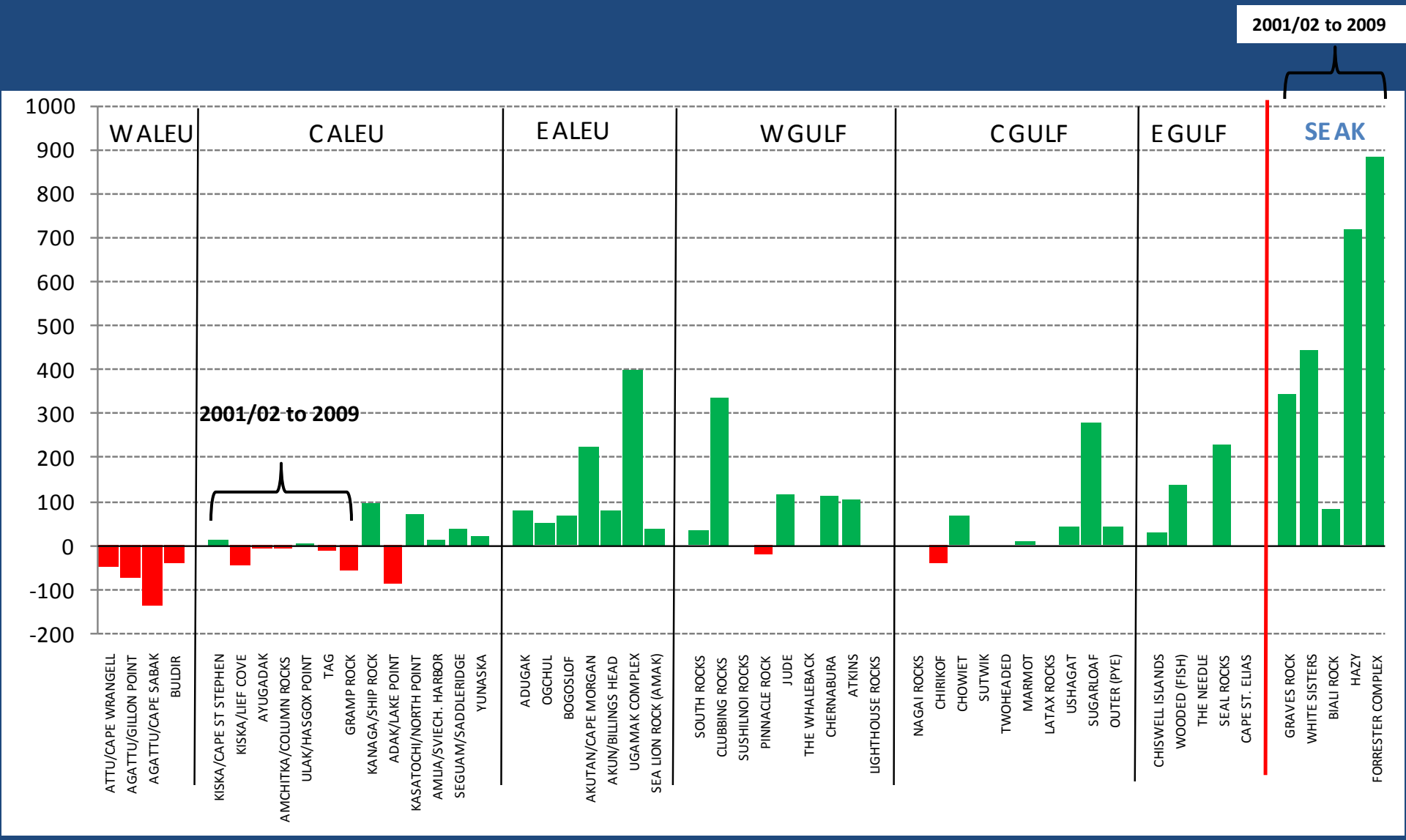
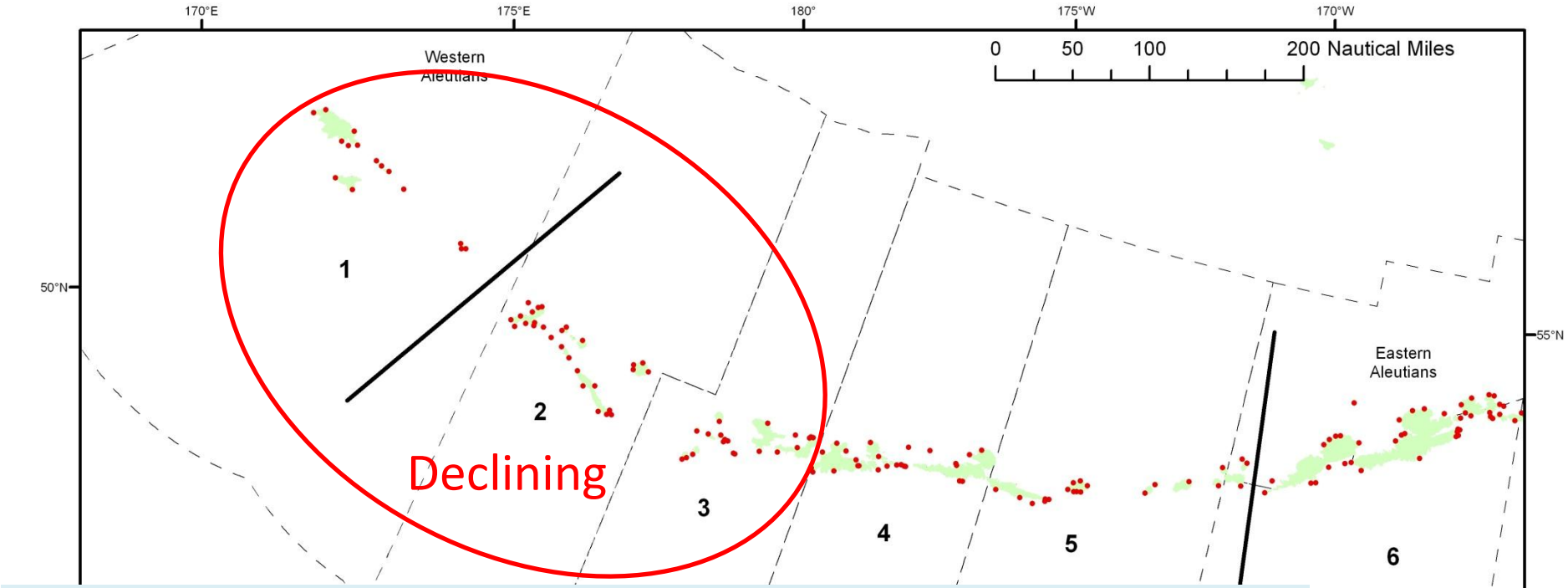
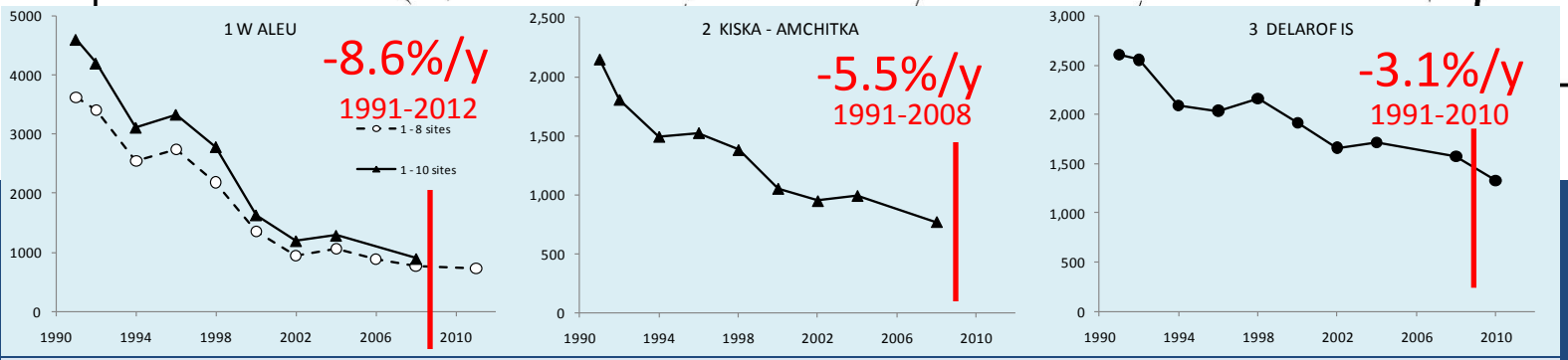


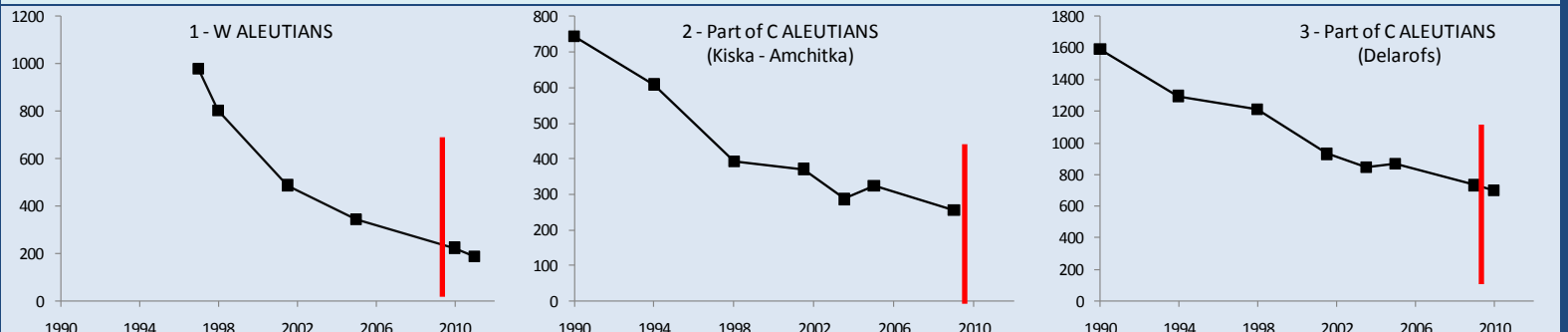
Change in SSL Pup Counts 2001/02 to 2009 or 2011

- All rookeries
- Major haulouts
- Eastern & Western DPS in AK



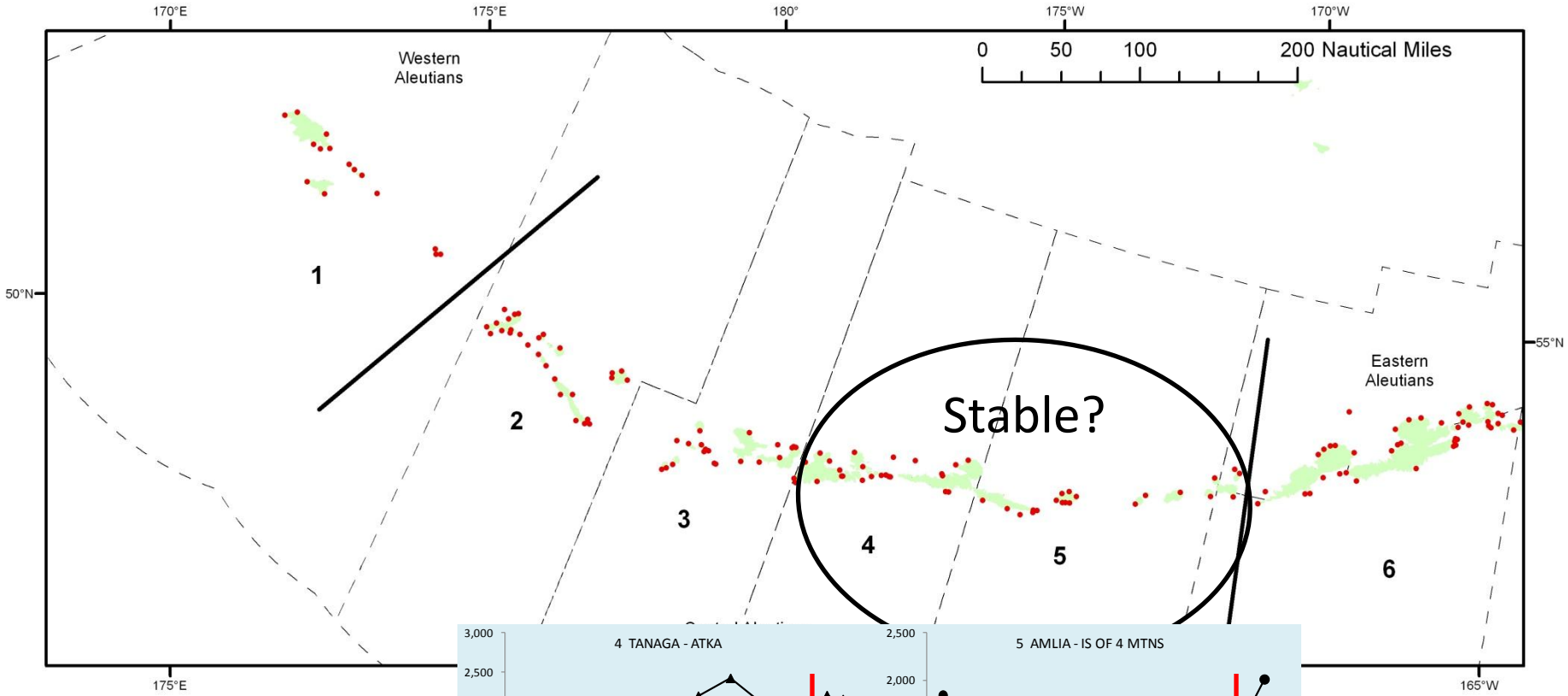


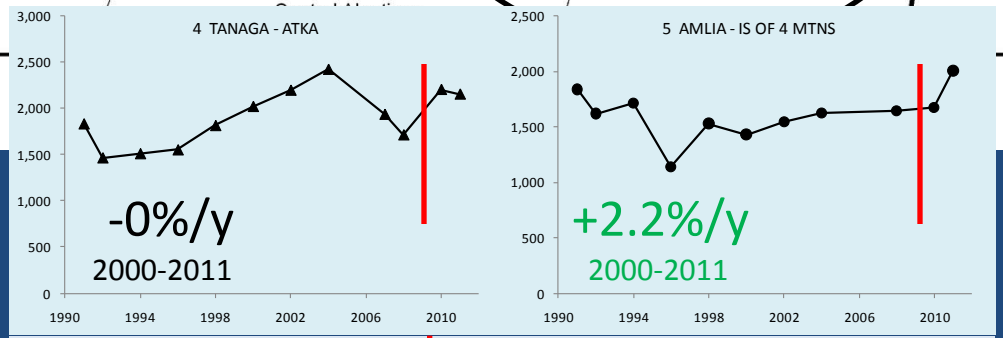




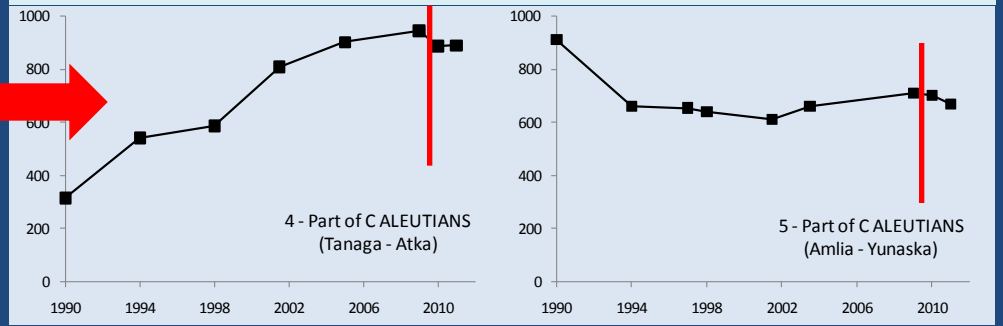
Non-Pups

Pups



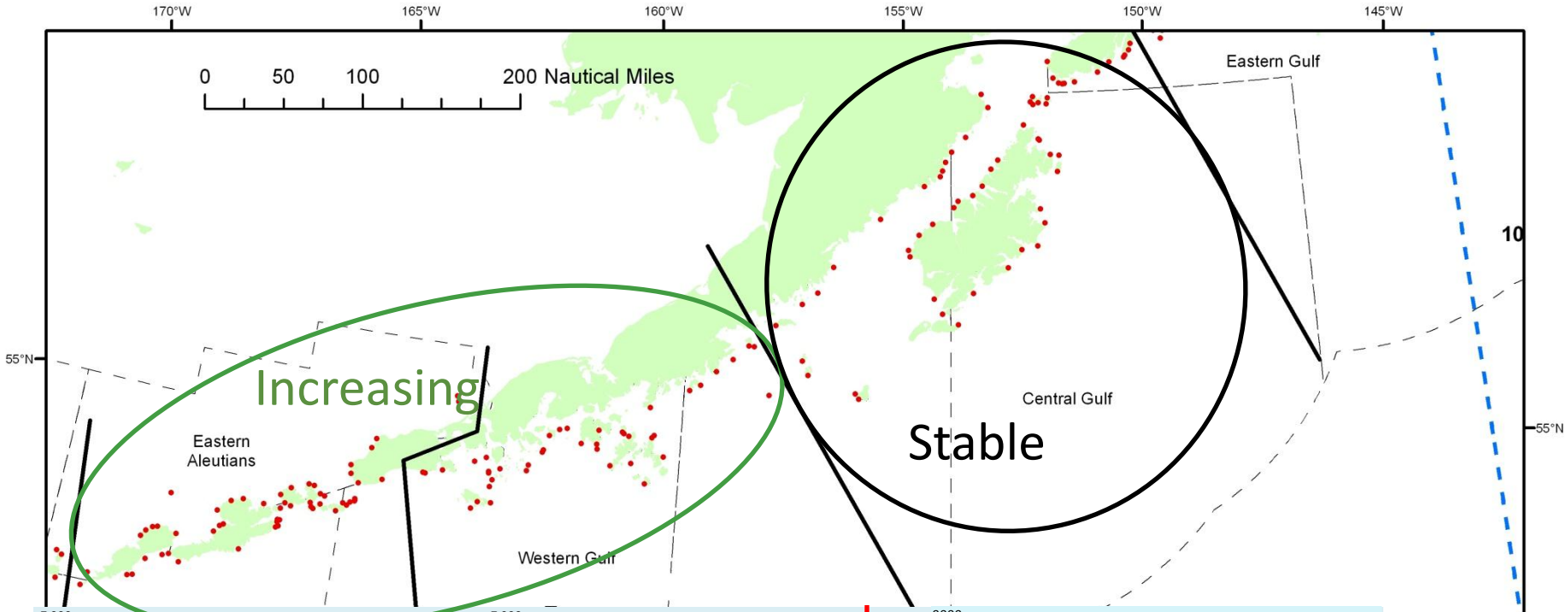


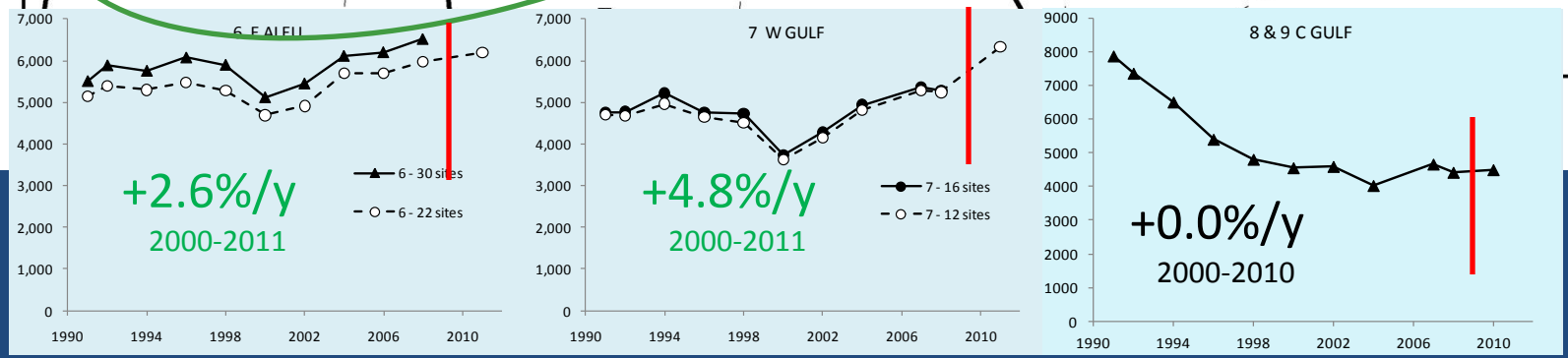
Non-Pups



Pups

AREA 4 – ONLY PART OF CENTRAL/WESTERN ALEUTIANS THAT HAD AN INCREASING PUP TREND 1990-2011





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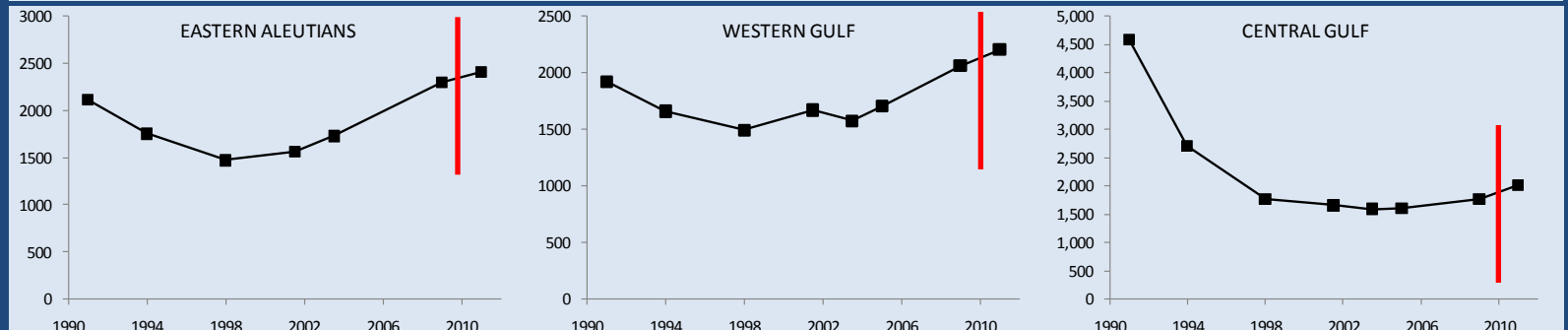

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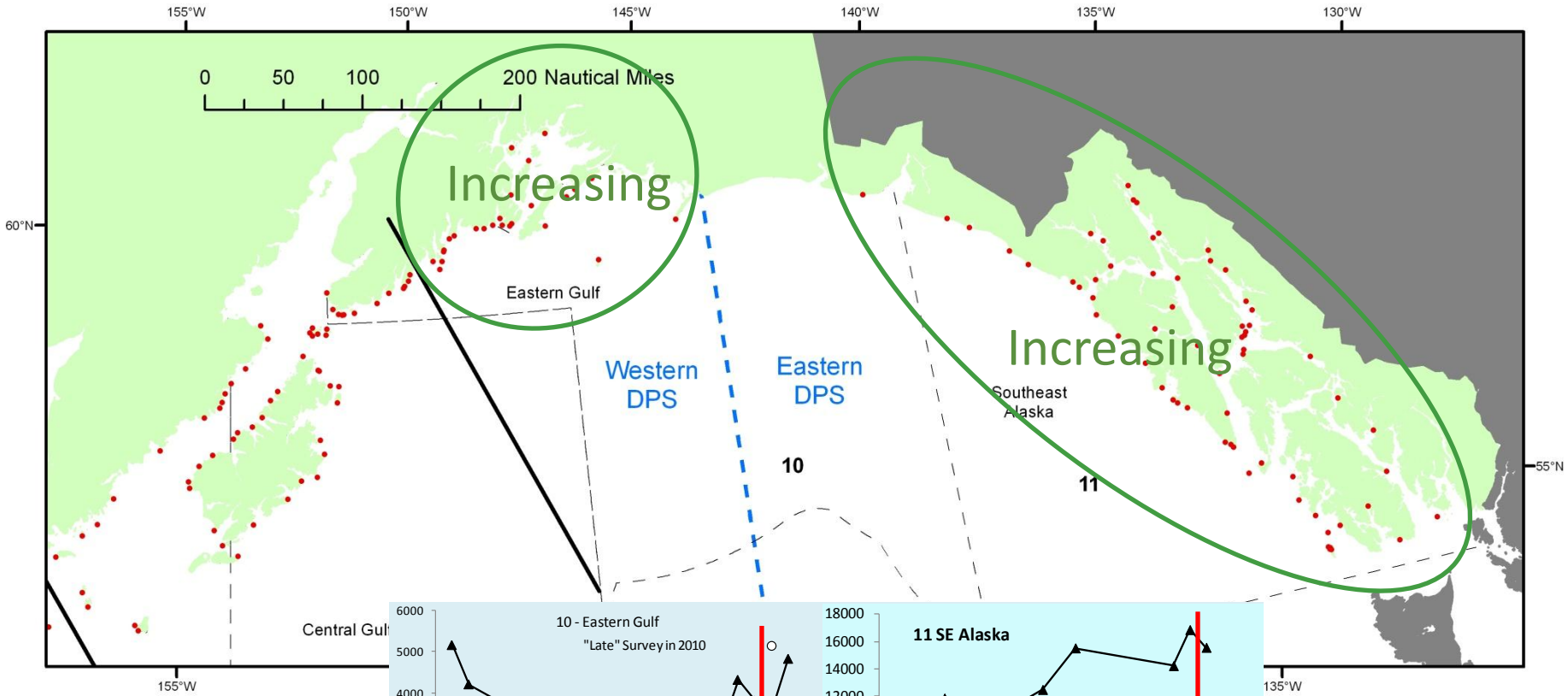
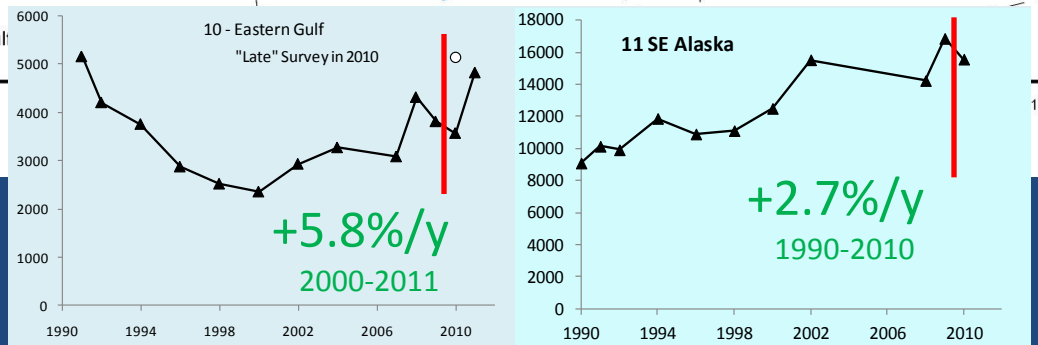
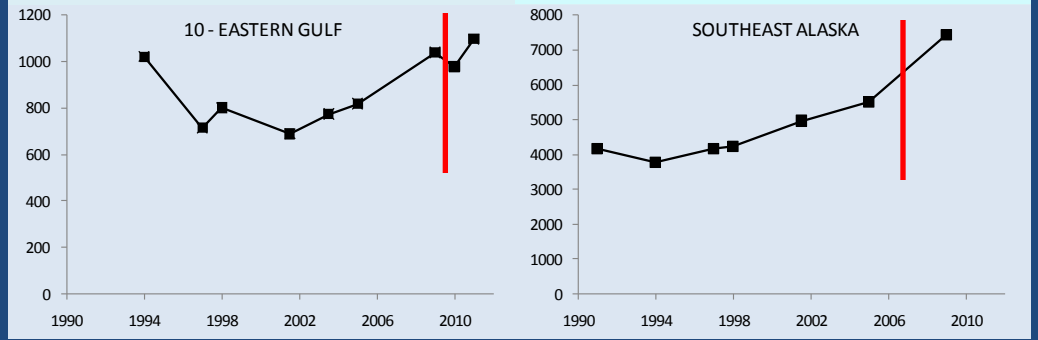


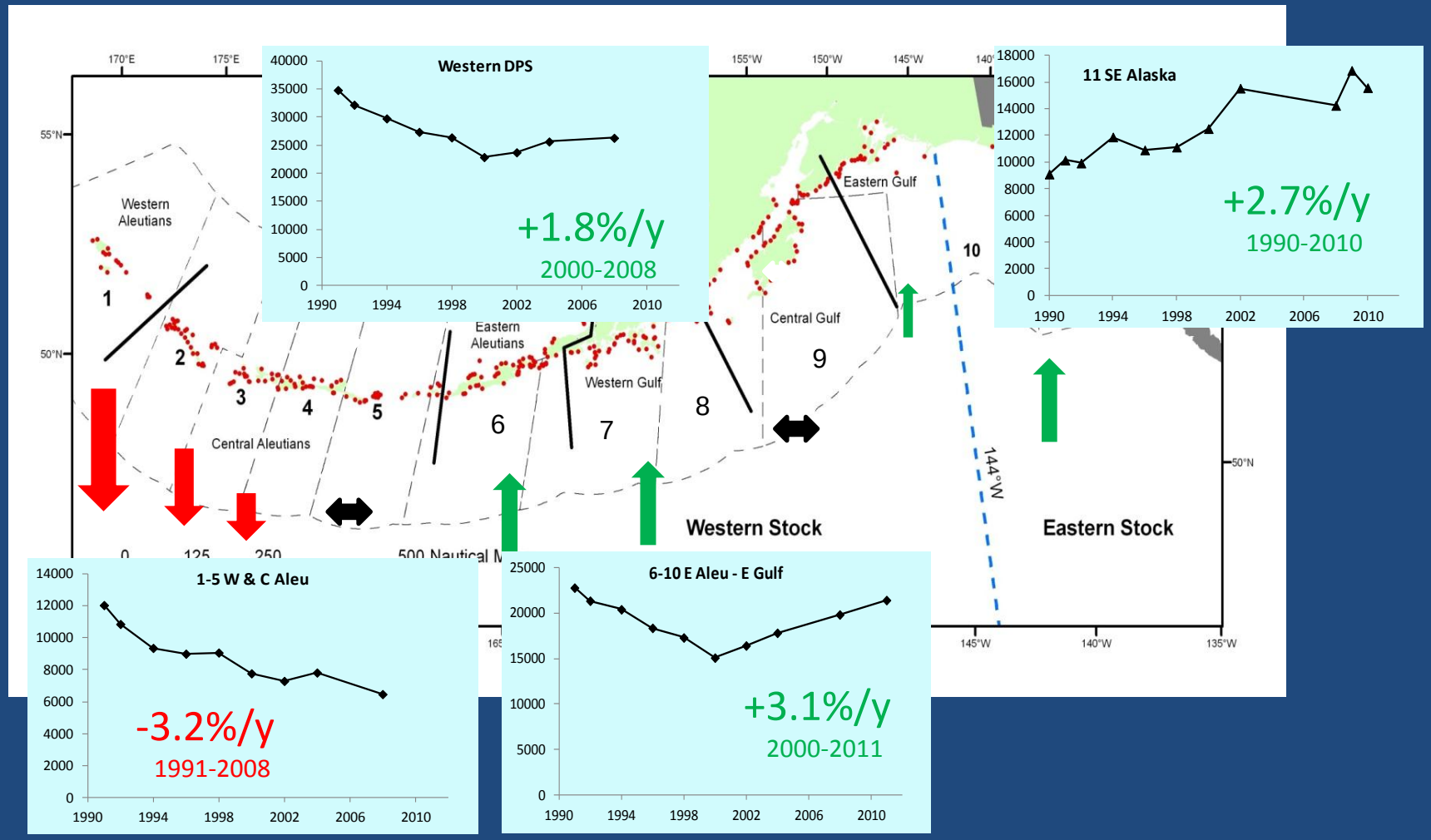




Non-Pups

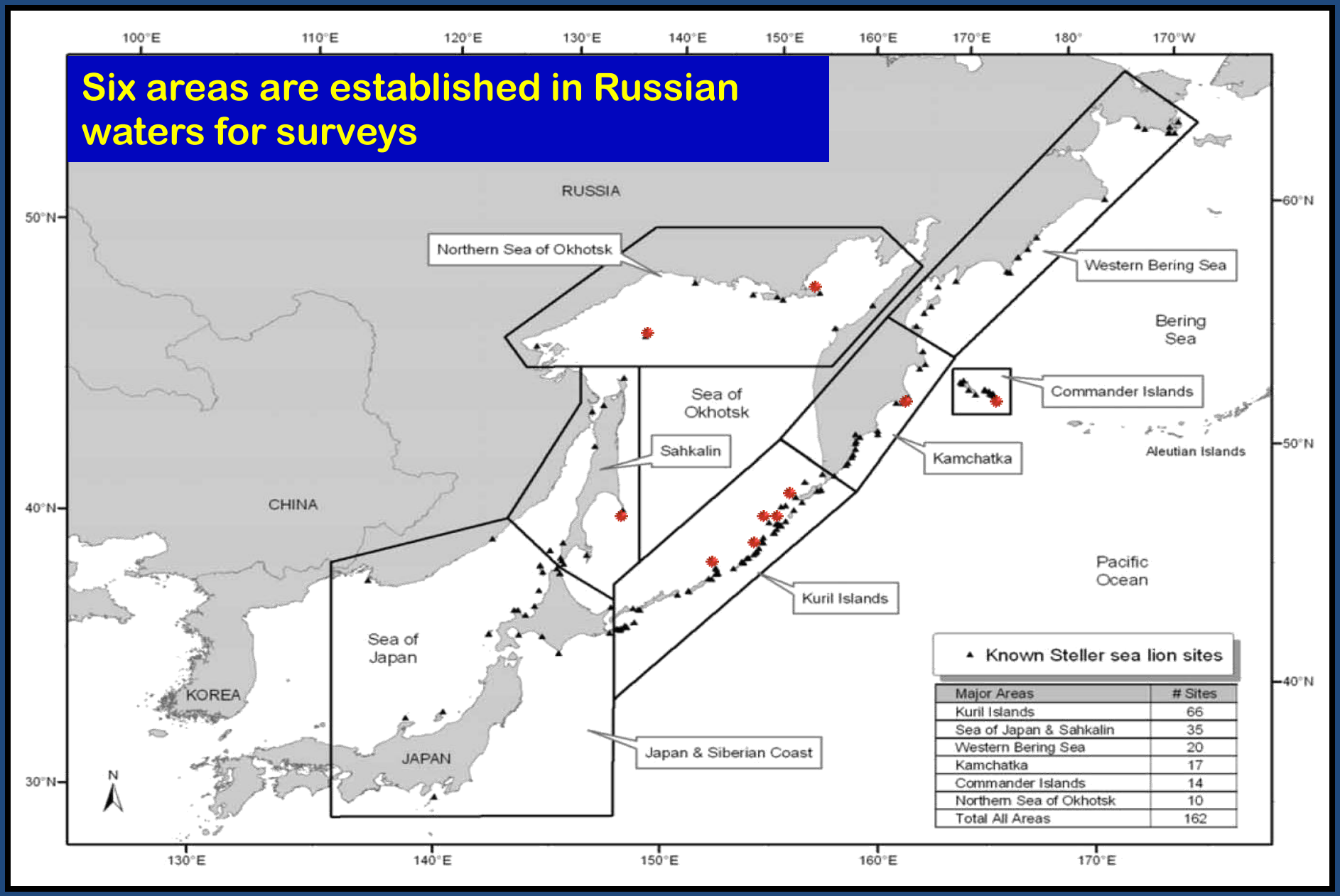
Pups

Steller Sea Lion Non-Pup Population Trends in AK

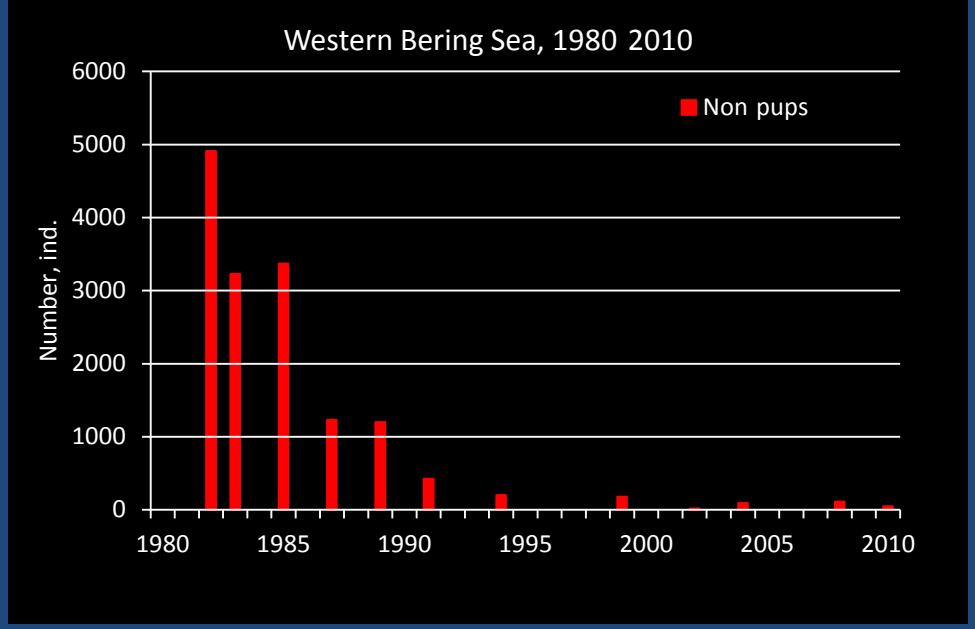


- Similar increasing trends in EAI-EGOA and SE AK (~+3%/y)
- Decreasing trend in W&C Aleutians (~-3%/y)
- Increasing trend in western DPS (~2%/y)

SSL survey areas in Russian waters



Major Areas	# Sites
Kuril Islands	66
Sea of Japan & Sahkalin	35
Western Bering Sea	20
Kamchatka	17
Commander Islands	14
Northern Sea of Okhotsk	10
Total All Areas	162



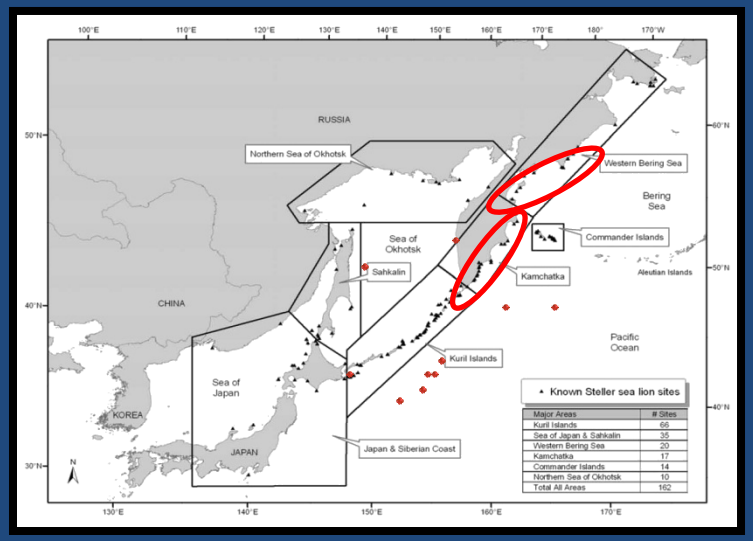
Western Bering Sea Non-Pups

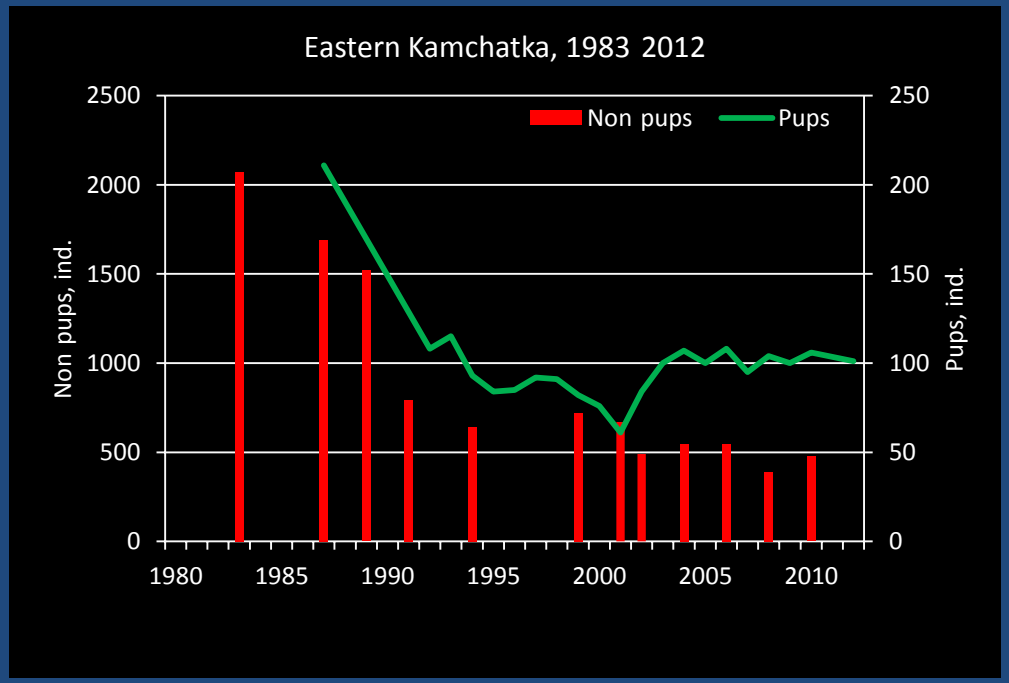
*** 98% decline since 1982**

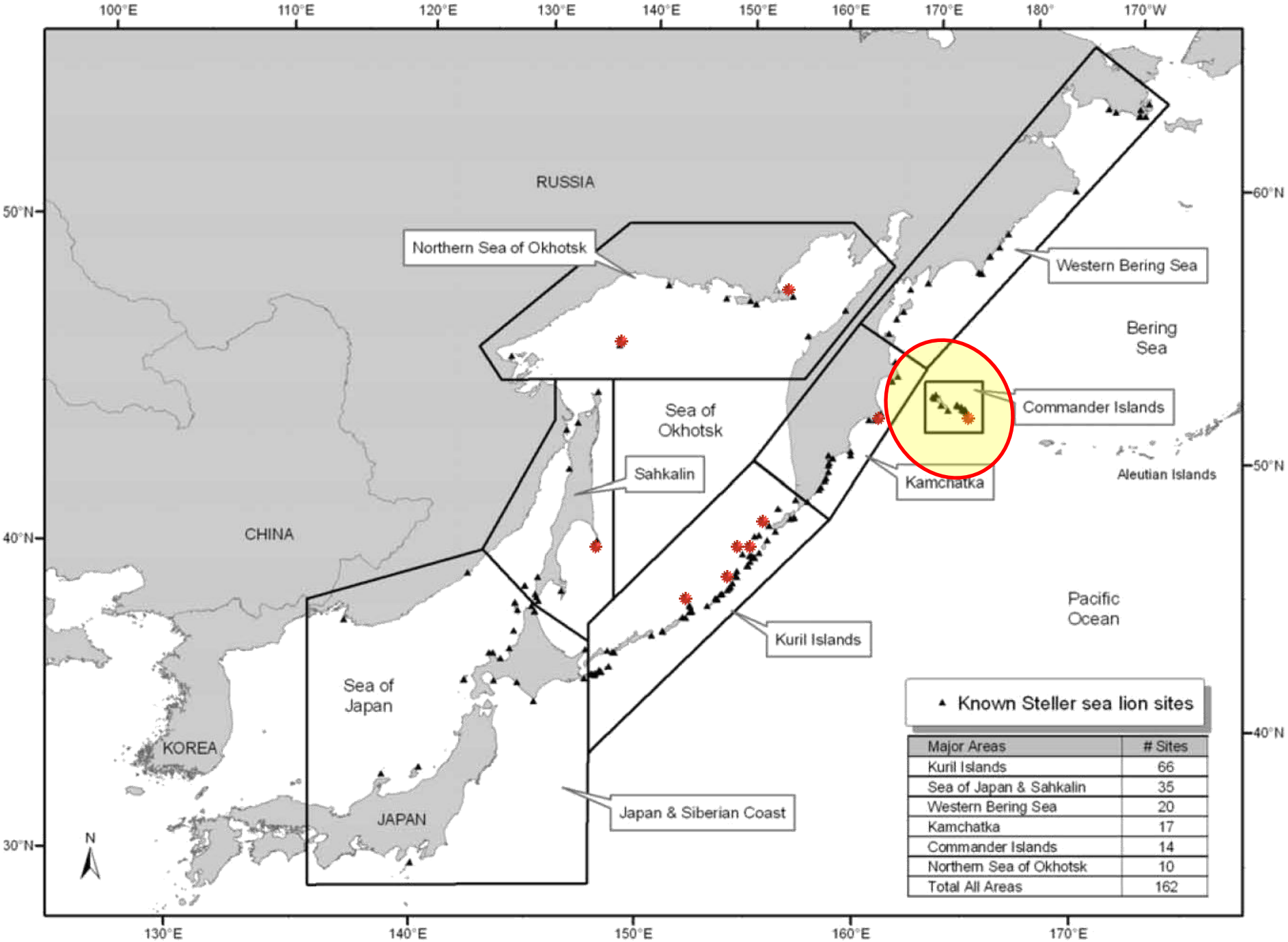
Eastern Kamchatka:

*** non-pups 81% decline since 1983**

*** pups 50% decline since 1986**







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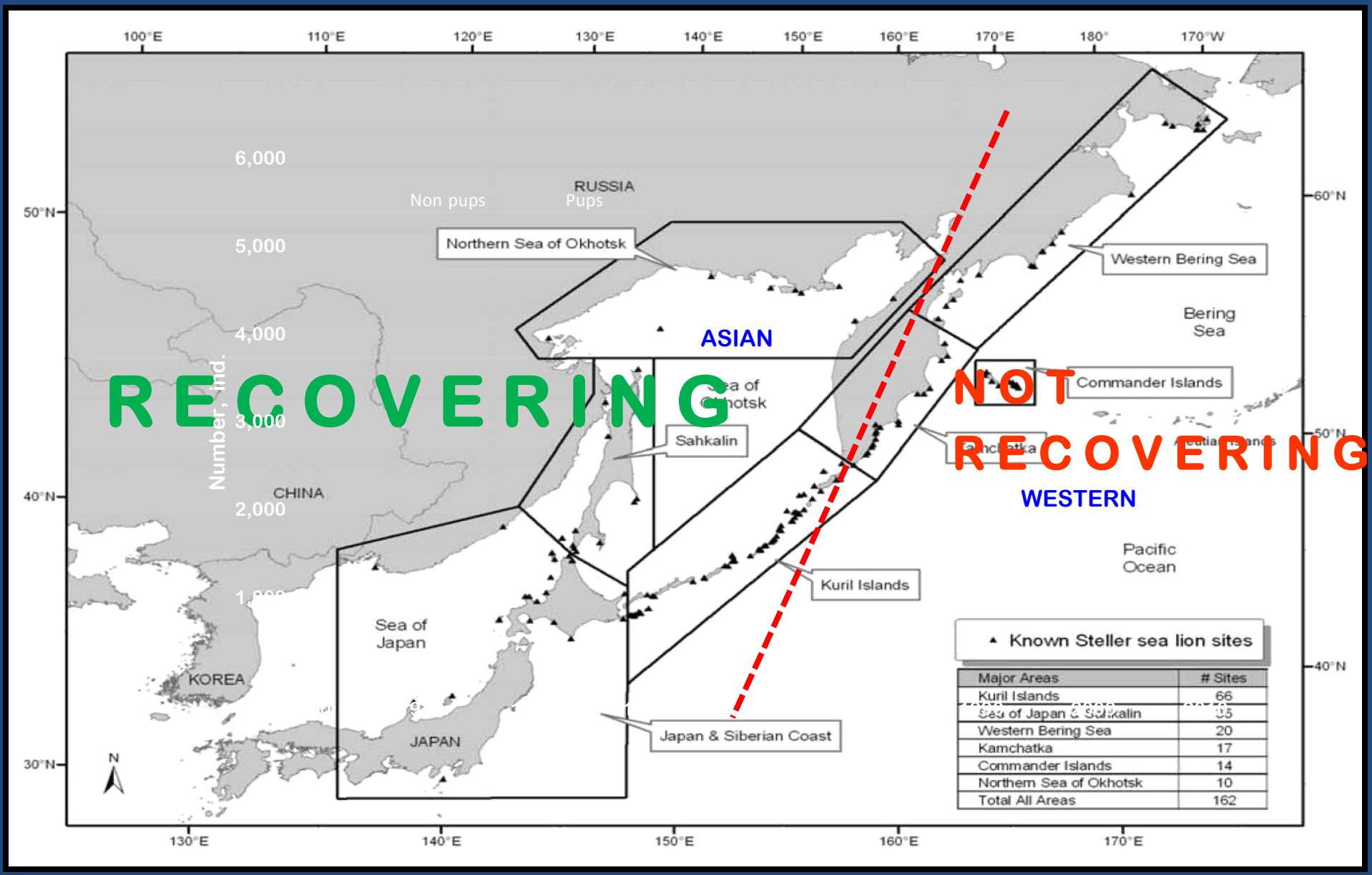
SSL survey areas along coast of Asia



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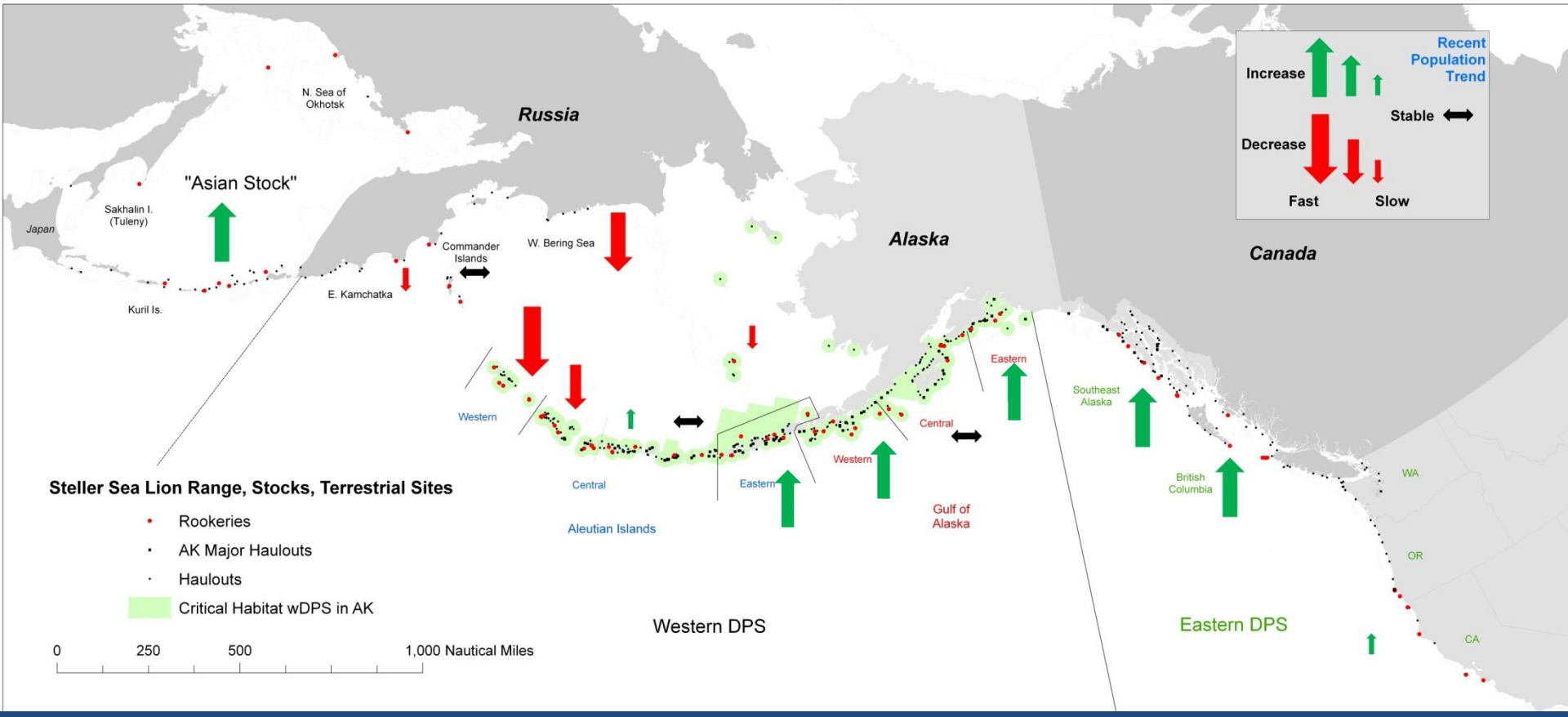
SSL Range-wide Non-pup Trends



Questions on Abundance and Trend?

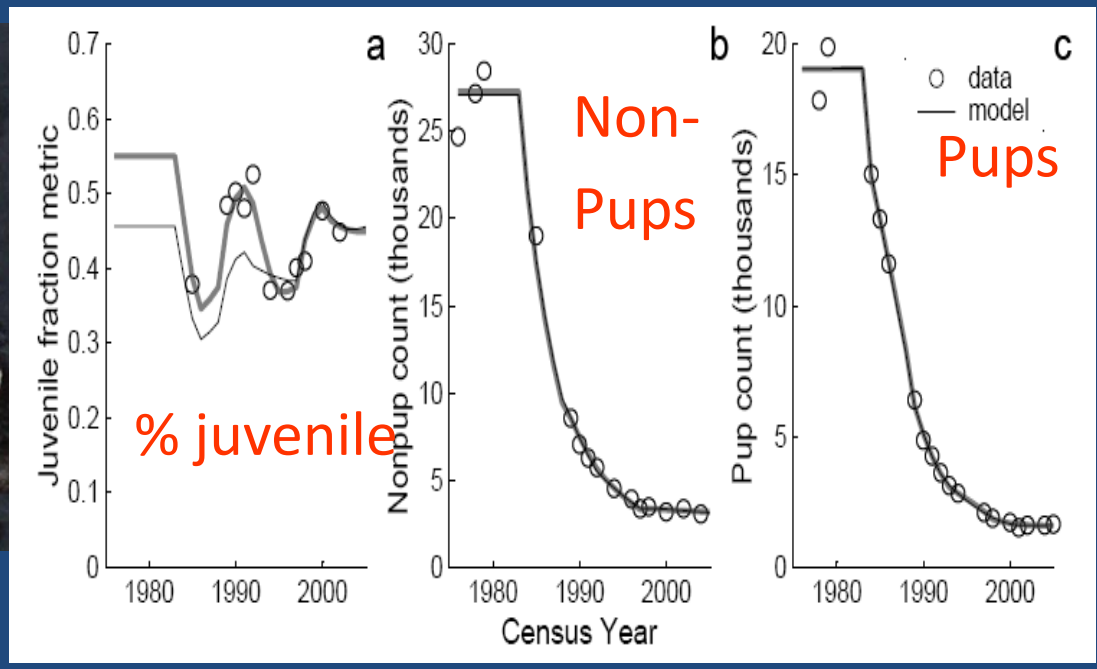
Next: Survival – Model and Branding Results

Estimation of changes in vital rates

Modeling - time-varying Leslie matrix (Holmes & York 2003; Holmes et al. 2007)

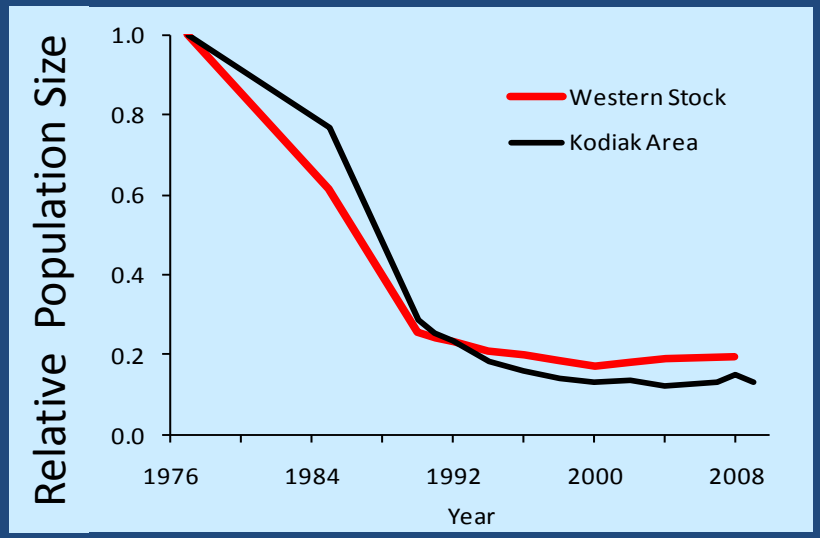
- Used data from Central Gulf aerial surveys – pup and non-pup counts
- Developed a recruitment index (% juvenile based on size)
- Changed survival and reproductive rates to fit observed counts and % juvenile
- Start with estimates from the mid-1970s based on lethal sample

Steller sea lion length measurements from aerial photograph taken over Kodiak's Cape Ugat on 12 June 2008

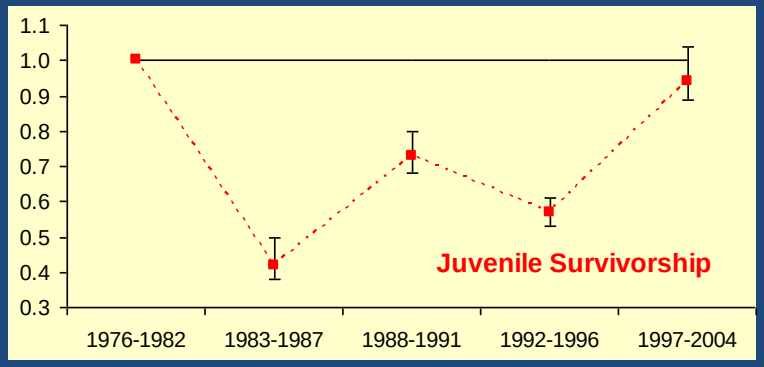


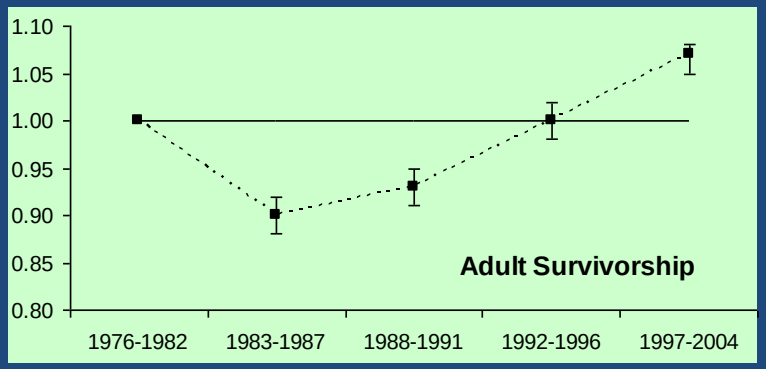
CGOA Female Vital Rate Changes over Time

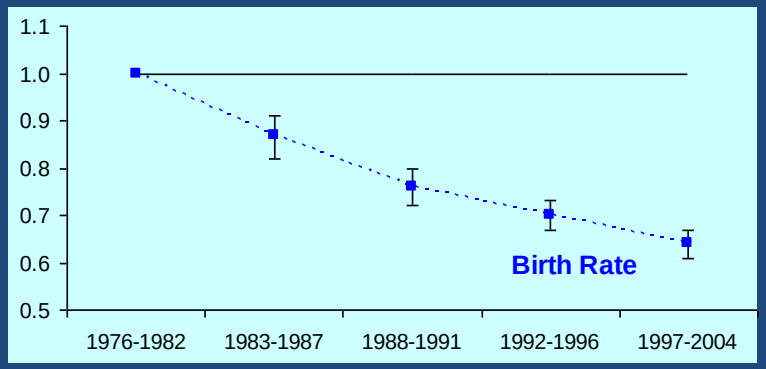
- Vital Rates of 1970s are baseline (=1)
- ‘Low’ survival in late 80s-early 90s
- ‘High’ survival in 2000s
  - Similar or greater than 1970s
- Decline in birth rate
- Pattern suggests change in magnitude of factors affecting population
  - Decline in direct mortality
  - Increase in indirect effects



Changes in Vital Rates to Fit Counts and Age Structure







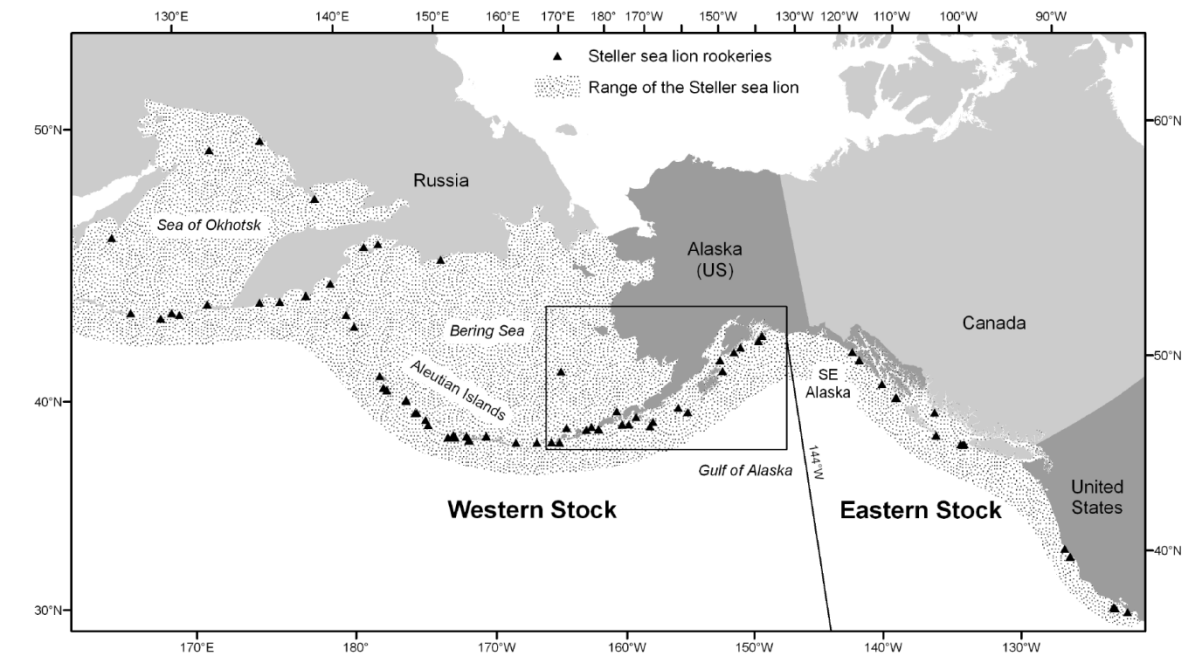
Steller Sea Lion Survival: Branding and LHX

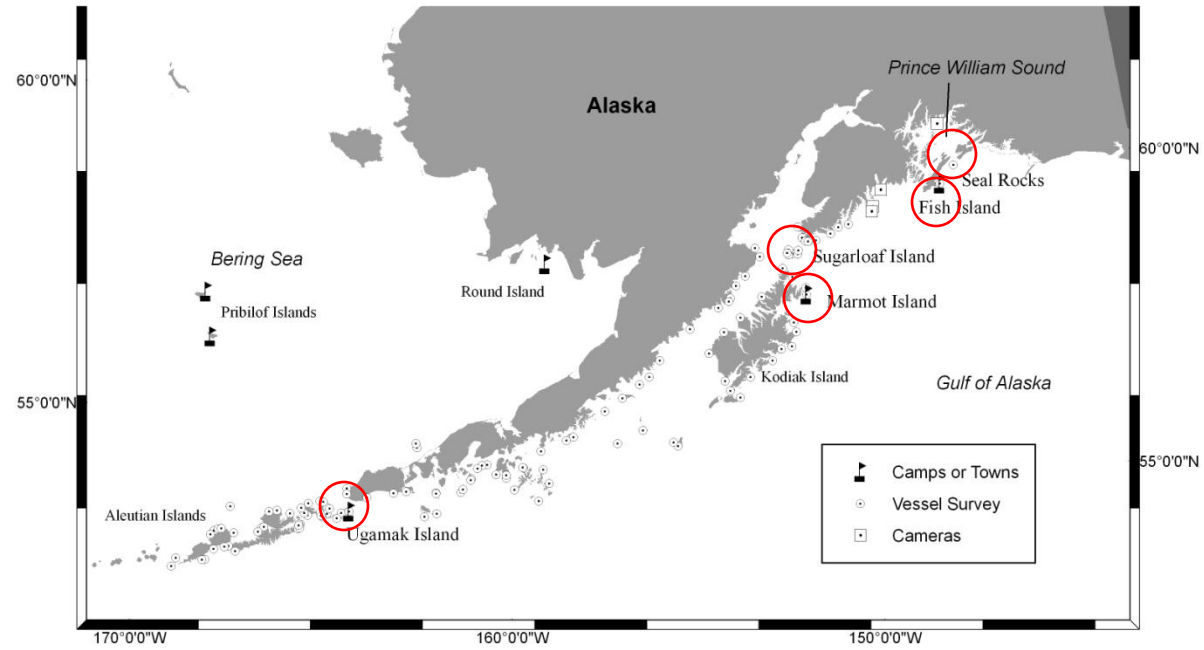
Populations, Time Periods and Methods

- Eastern DPS
  - Pups branded 2001-2005 SEAK N=1995; sightings through 2009 (Hastings et al. 2011)
- Western DPS
  - Pups branded 2000-05 EAI-EGOA N=1449; sightings through 2011 (NMML)
  - Life History Transmitter (LHX) 2005-11 EGOA N=36; (Horning and Mellish 2012)
  - Pups branded 1987-88 CGOA N=751; sightings through 2003 (Pendleton et al. 2006)

T128 branded 4 July 2002 on Marmot

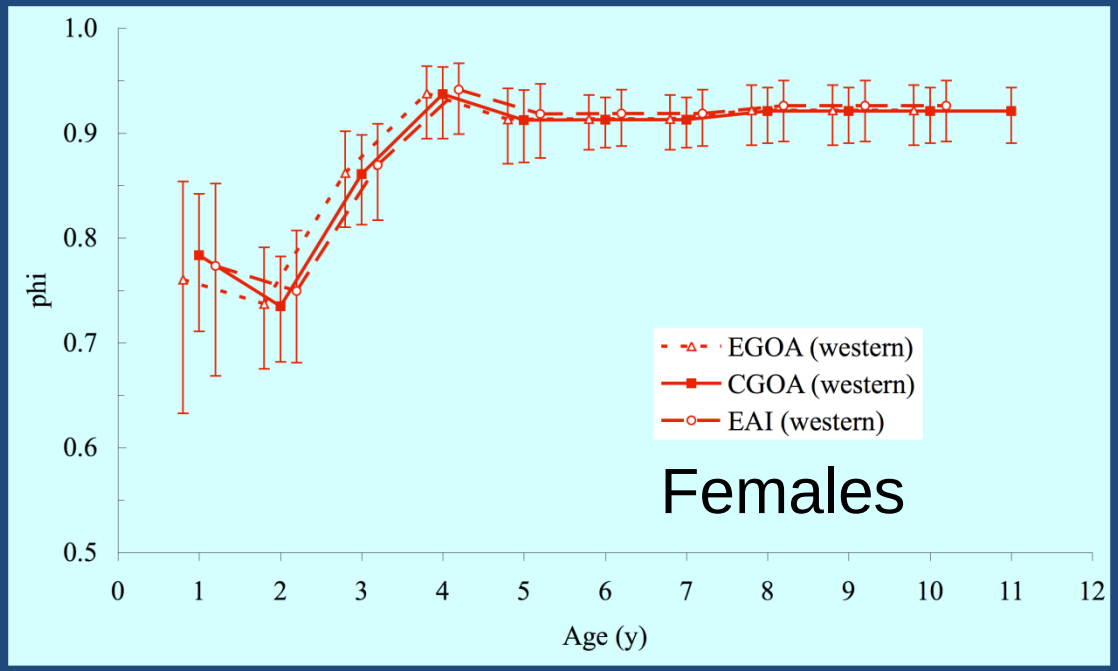
T128 observed 20 June 2007 Latax Rocks

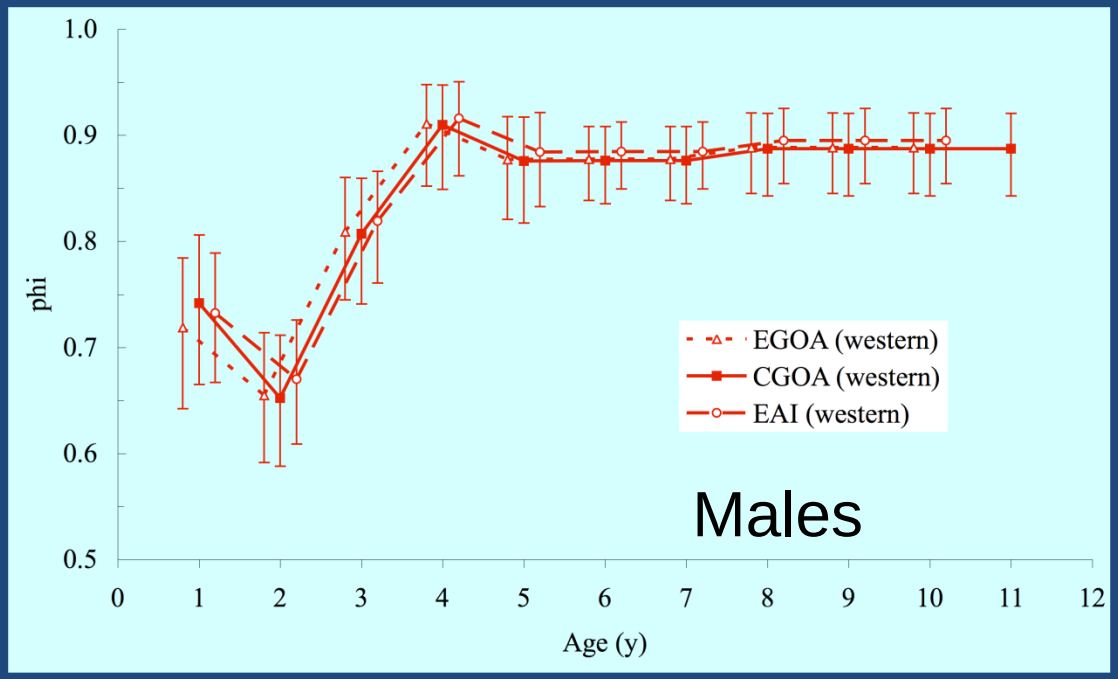




NMML Steller Sea Lion Branding Western DPS

- 1,449 pups
- 5 rookeries in the E Aleu through EGOA
- 6 cohorts: 2000-2005
- Sightings thru 2011

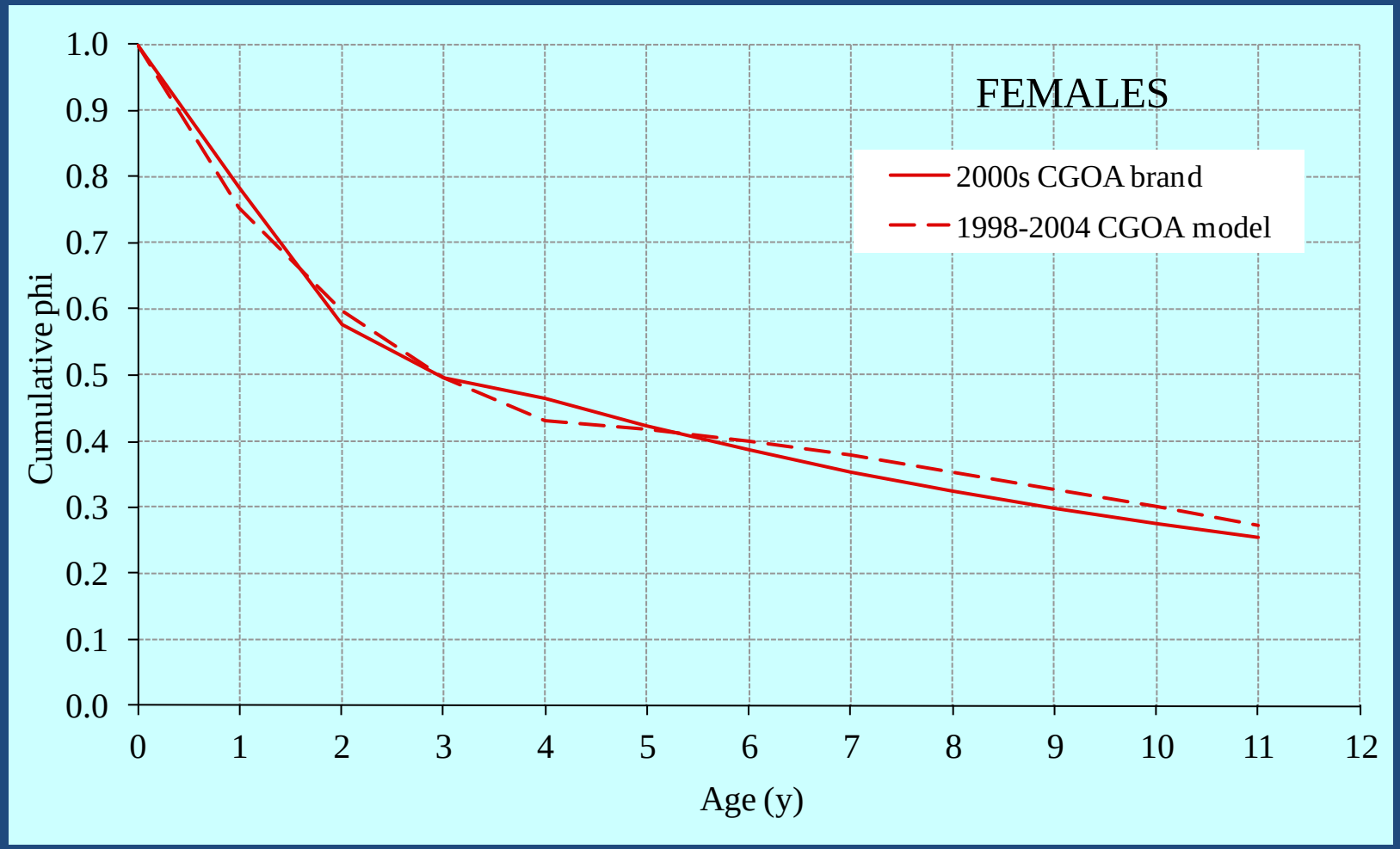




Western DPS Survival at Age

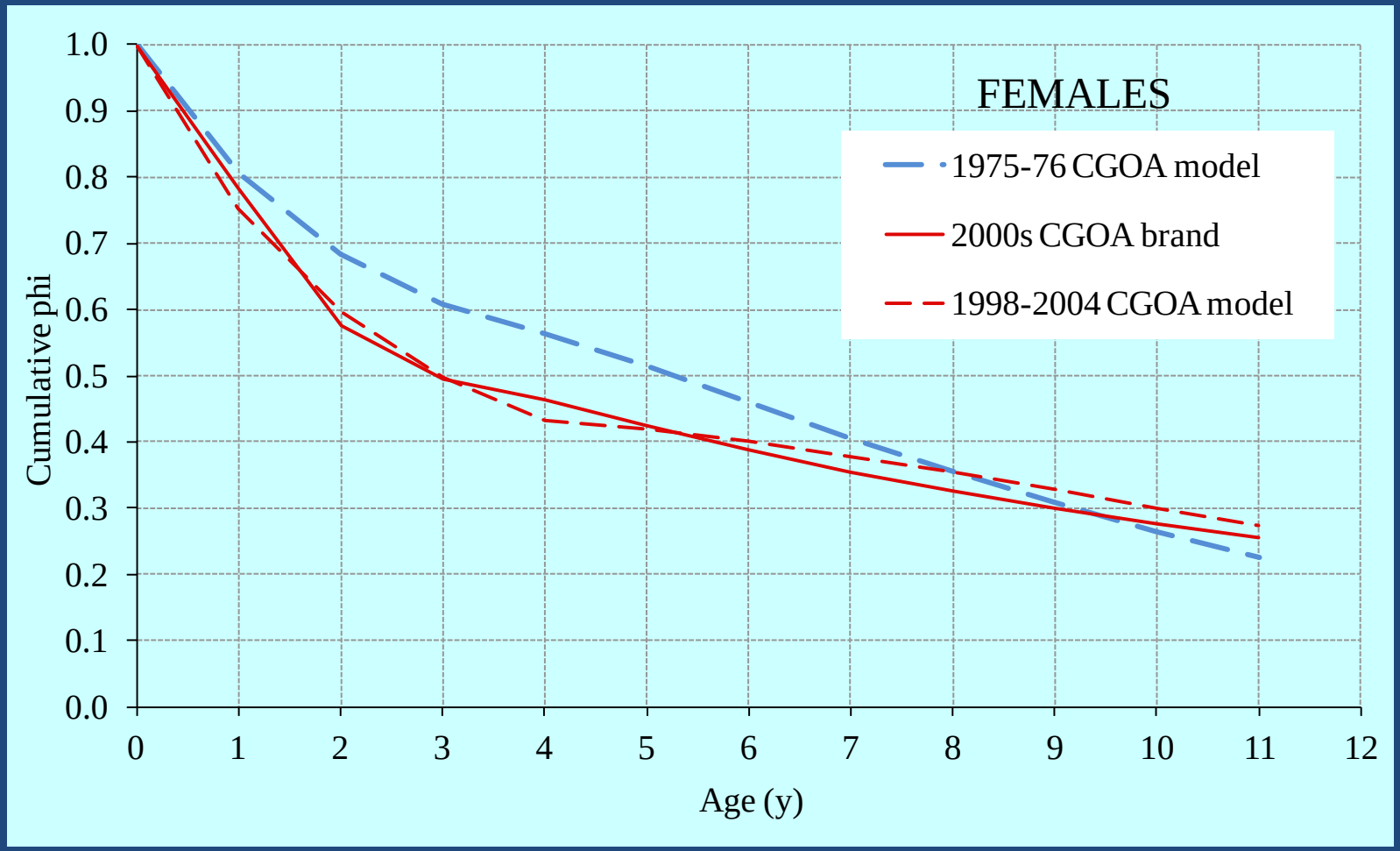
- No regional differences
- Females > Males
- 1st year > 2nd year
- More pronounced in males
- No cohort differences

Cumulative Female Survival to Age



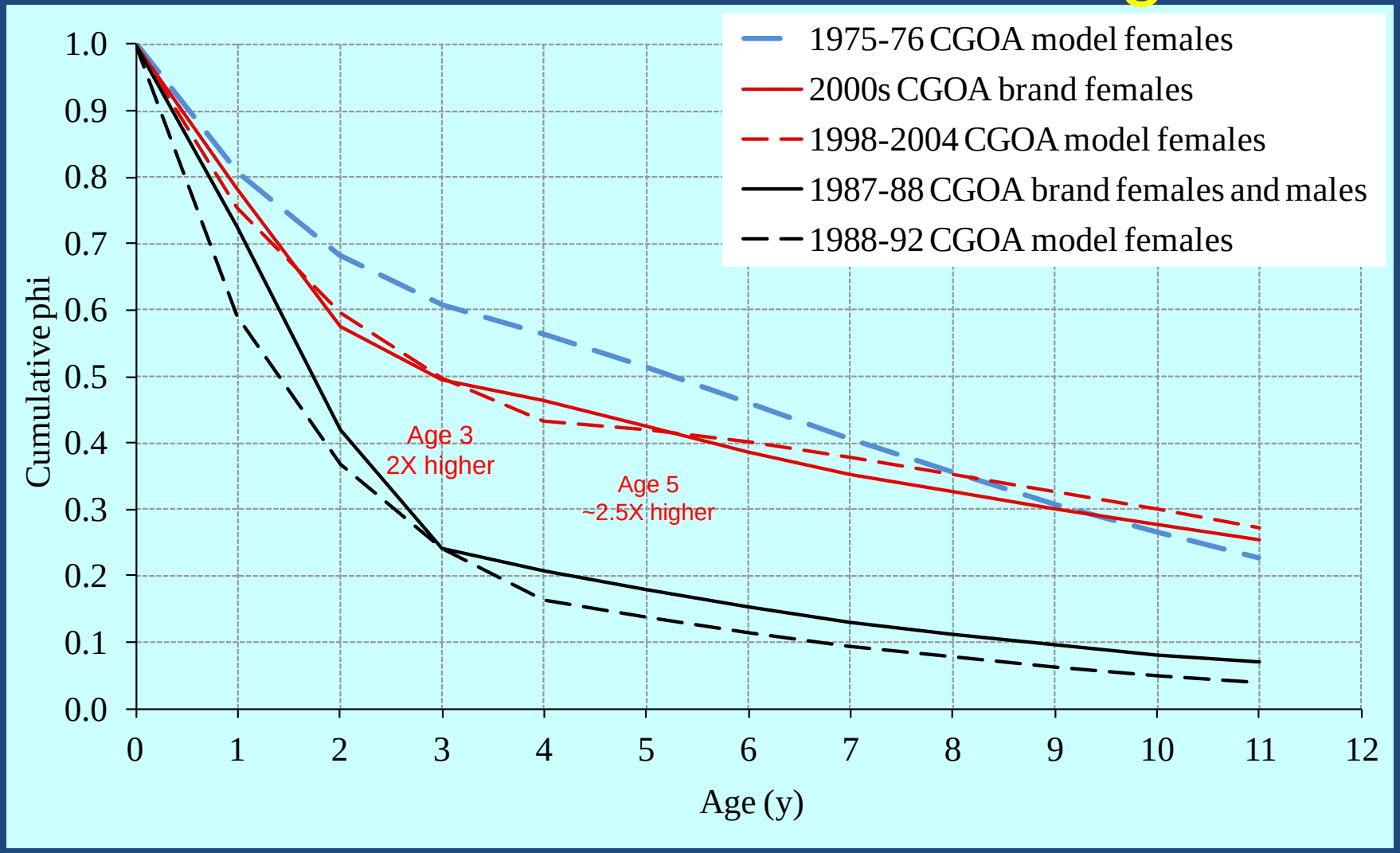
2000s branding and model results nearly identical

Cumulative Female Survival to Age



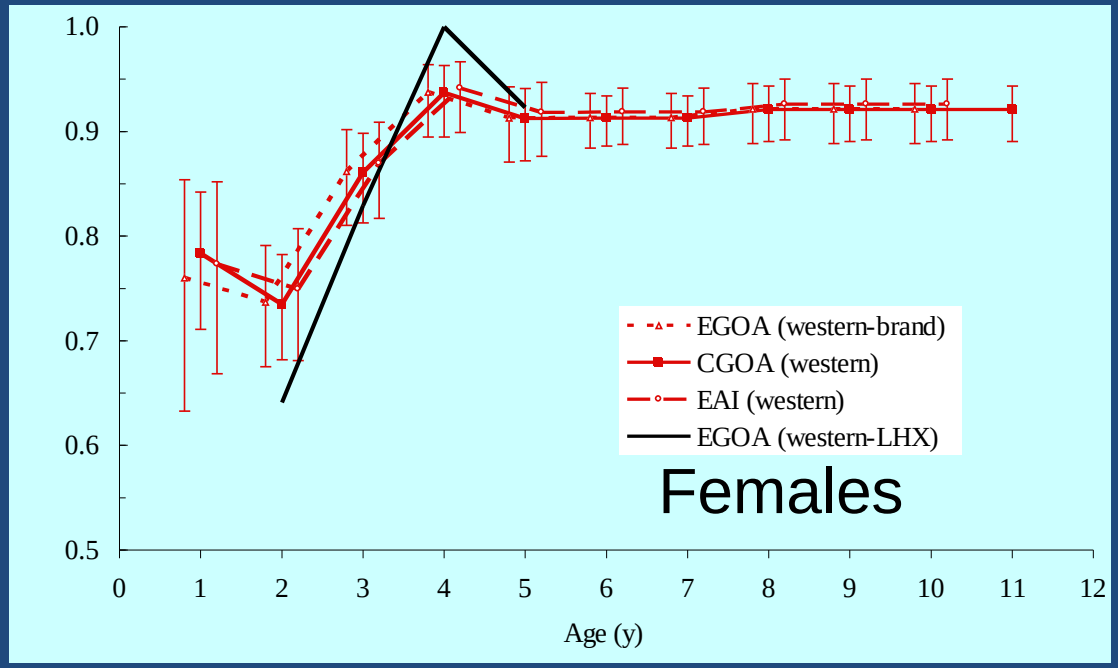
- Survival to ages 3-5 10-20% lower in 2000s than 1970s
- Survival to ages 7-11 similar in 2000s than 1970s

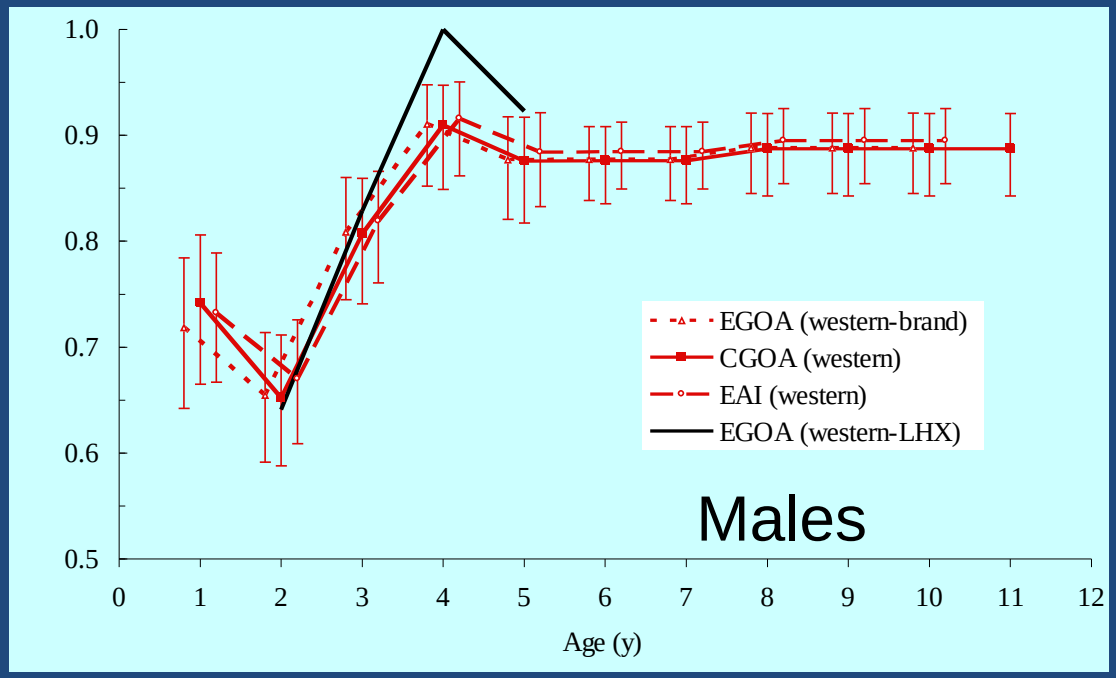
Cumulative Survival to Age



CGOA Survival in 2000s much greater than in late 80s-early 90s

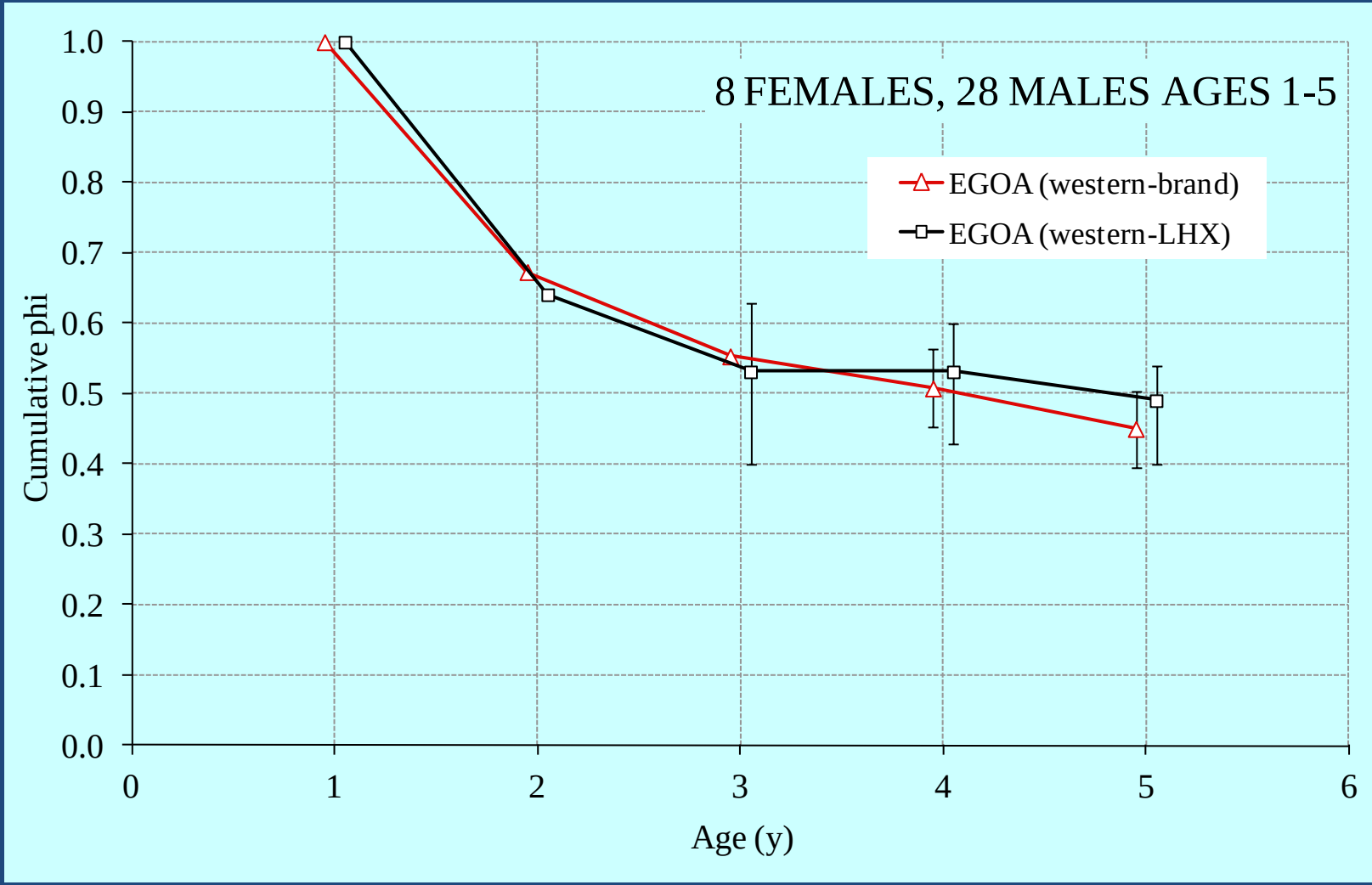
Brand & LHX





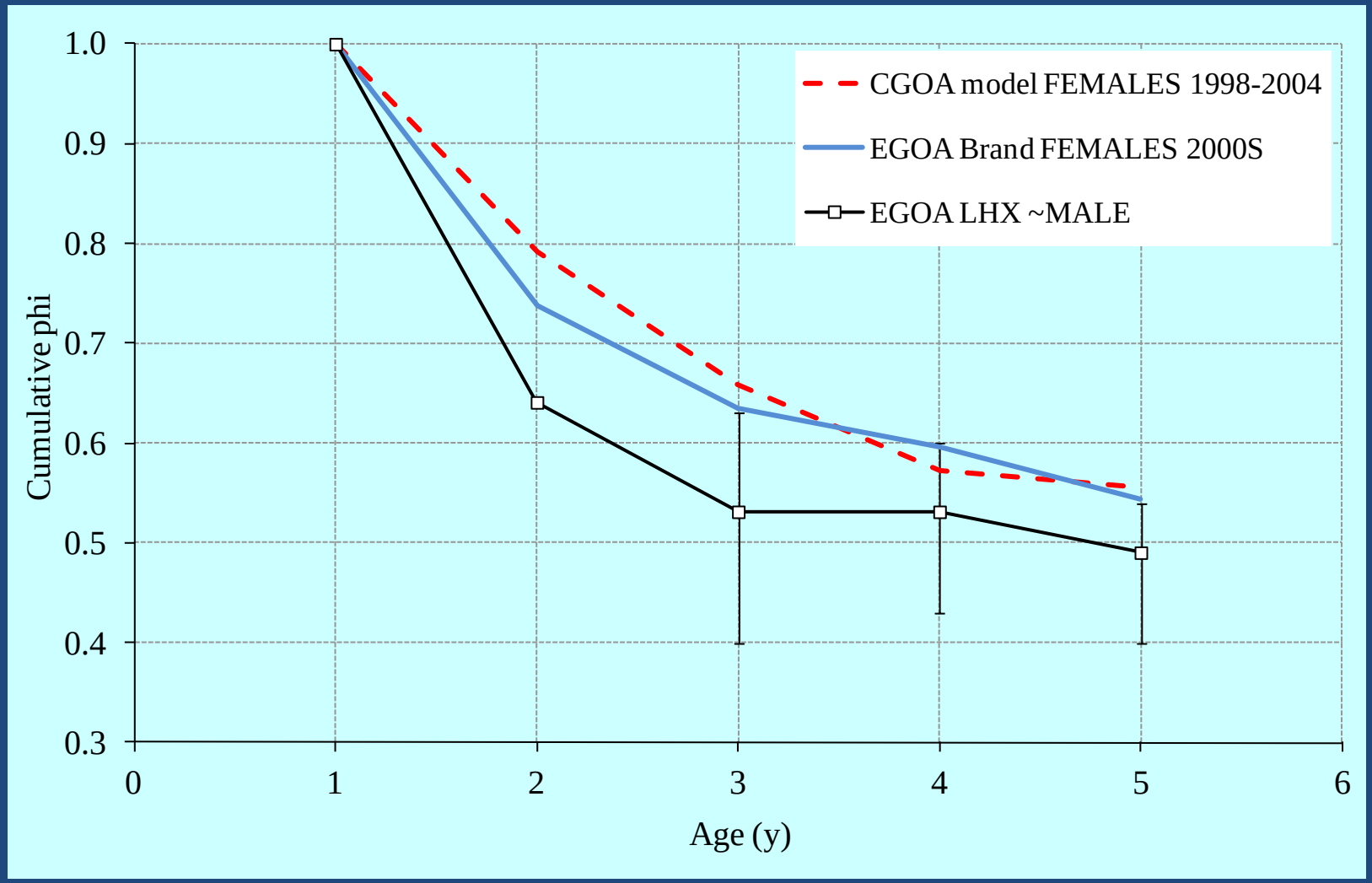
- LHX data ages 2-5 only
- LHX 8 females, 28 males
- LHX ~ Branded males @ 2-3 y
- LHX > Brand @ 4-5 y

Cumulative Survival to Age: Brand & LHX



Brand and LHX survival nearly identical ages 1-5 in the 2000s

Cumulative Survival to Age: Brand, LHX & Model



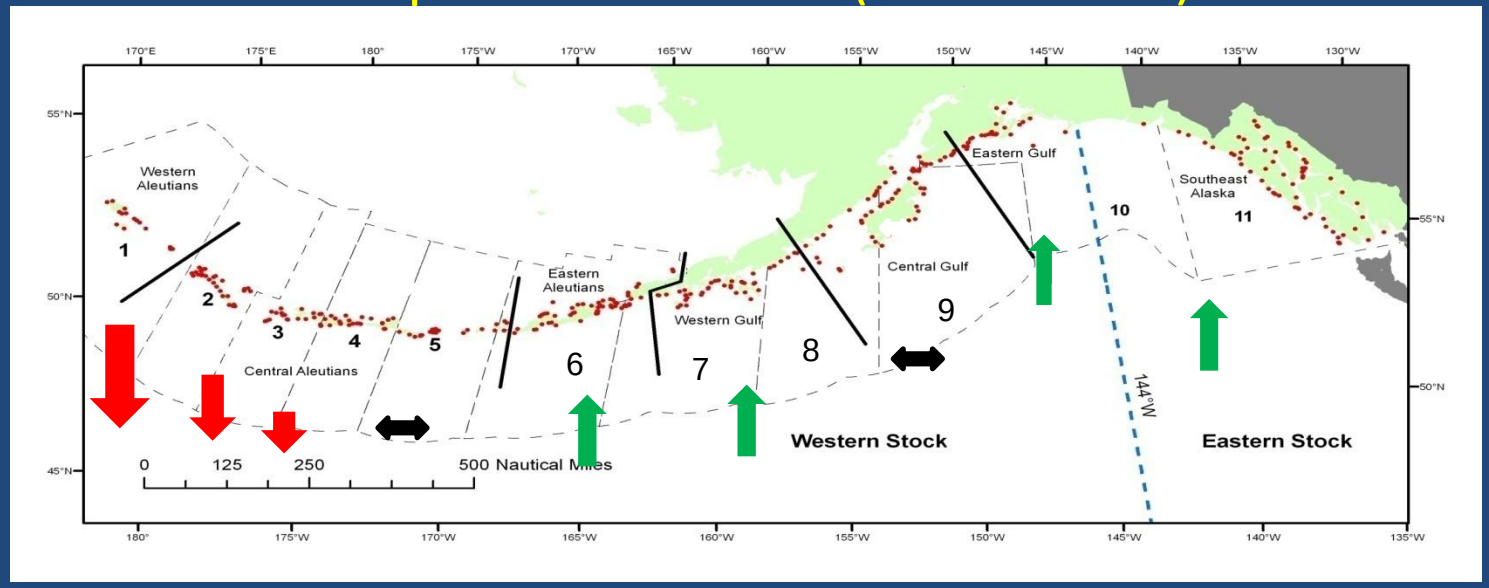
Brand and Model FEMALE Survival to Ages 3-5 > LHX ~MALE

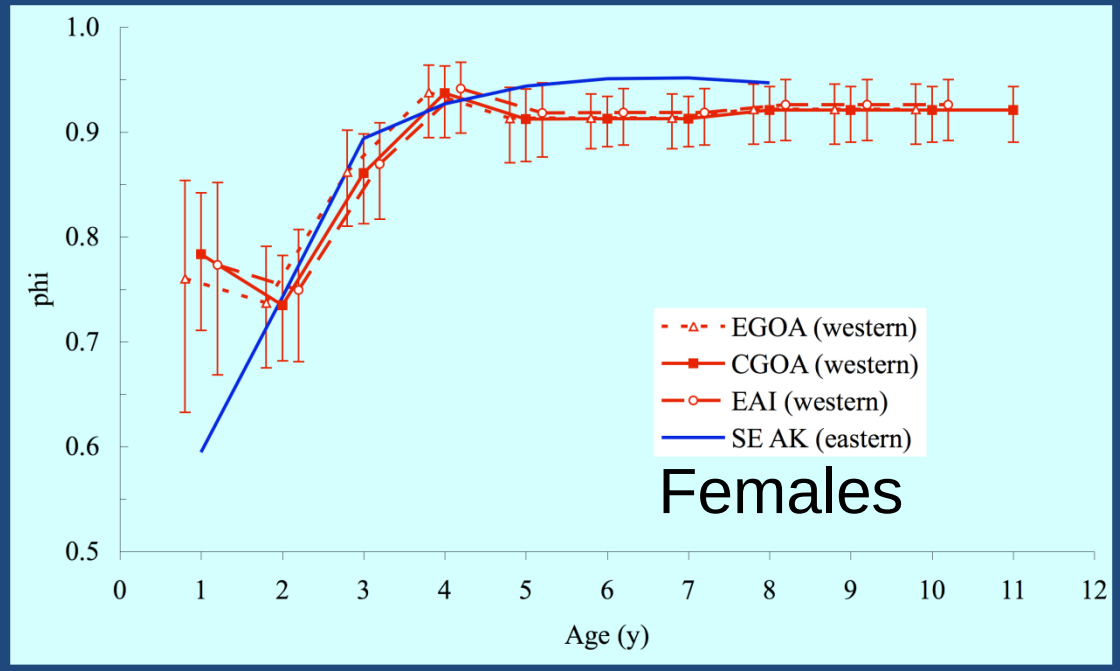
Are our conclusions different from Horning and Mellish's?

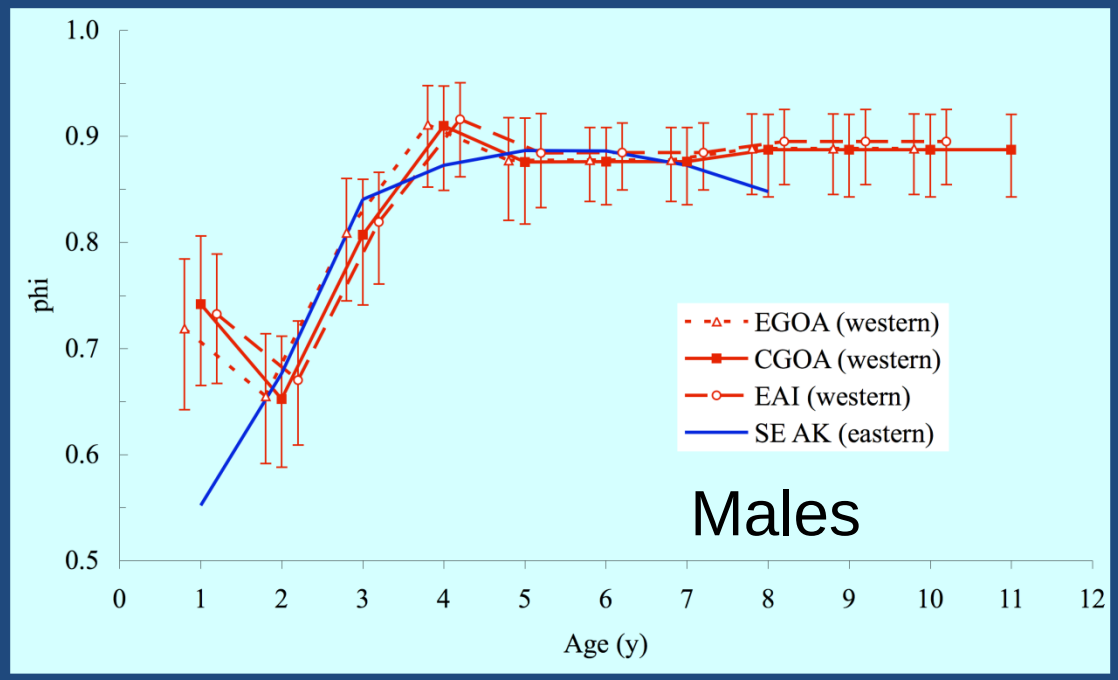
- Yes and No
- H&M: "…our data demonstrate continued low juvenile survival in the Prince William Sound/Kenai Fjords region of the Gulf of Alaska…"
- Juvenile survival in 2000s 2X higher than 80s and slightly lower than in 1970s
  - 1970s > 2000s >> 1980s
  - Not continued low juvenile survival
- In 2000s, LHX results = Branding results for sample with same sex composition
  - 28 males, 8 females
- Survival of Females > Males
- H&M compared mostly male (LHX) with female (Holmes et al. 2007) survival
- Survival in 2000s is NOT lower than estimated by Holmes et al.
  - We found that LHX=Brand=Model for 2000s
- Survival in 2000s is NOT stalling recovery
  - Survival to maturity is not currently low
  - E Gulf population (Prince William Sound/Kenai Fjords) is increasing
- Killer whale predation is likely a major component of total juvenile sea lion mortality but it is not likely a threat to recovery in the EGOA-EAI region

Western DPS 2000s Survival Summary

- Females > Males
- No cohort differences 2000-2005
- No regional differences in survival EAI through EGOA
- 1st year > 2nd year
  - Consistent with older weaning age
- Brand = LHX in EGOA ages 2-5
- Population Trend:
  - EAI and EGOA are INCREASING
  - CGOA is STABLE
- Consistent with Reproductive Rate: (EAI & EGOA) > CGOA



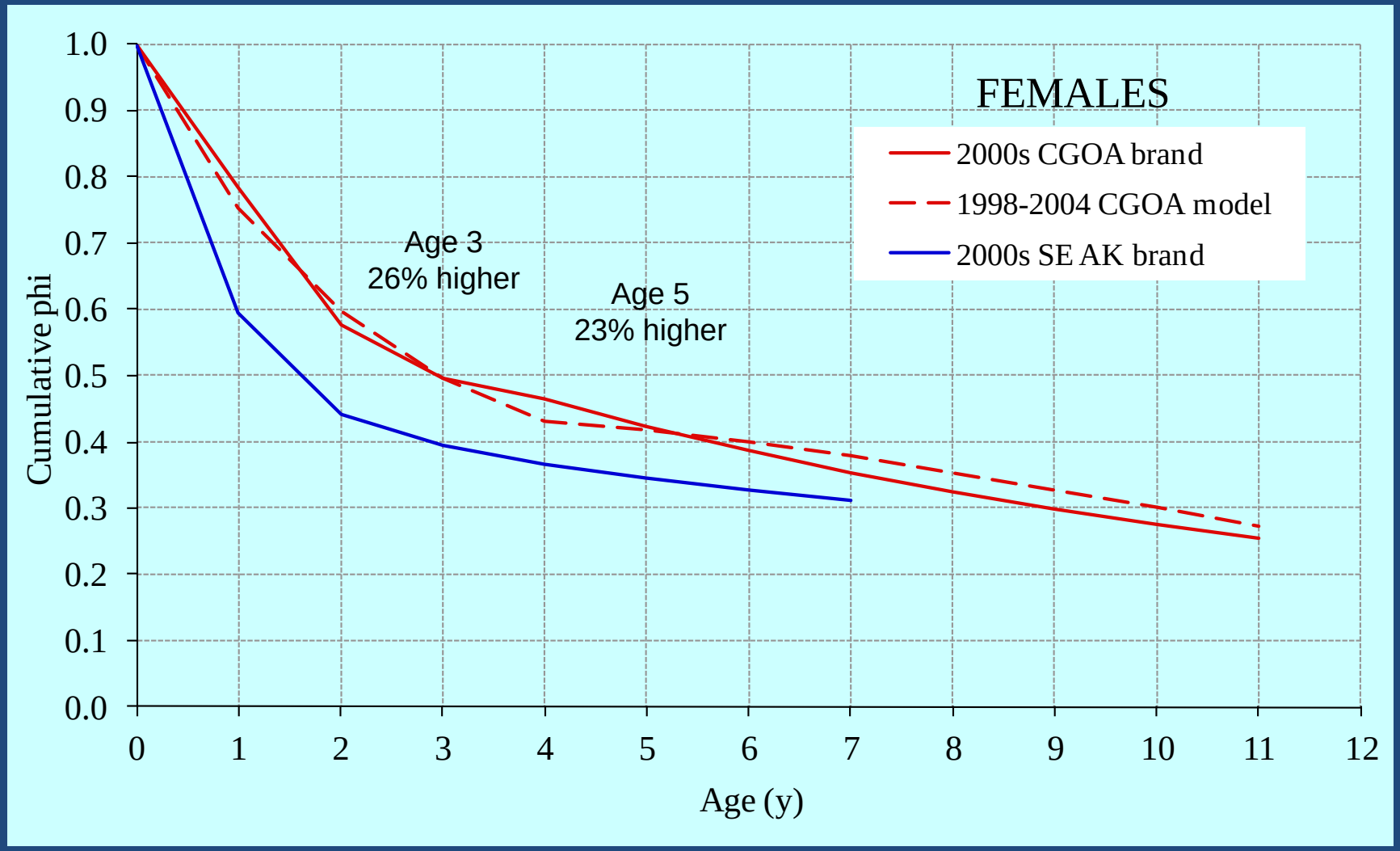




Western DPS vs Eastern DPS

- East: 1st year < 2nd year
- West: 1st year > 2nd year
- Ages 2-8 Similar

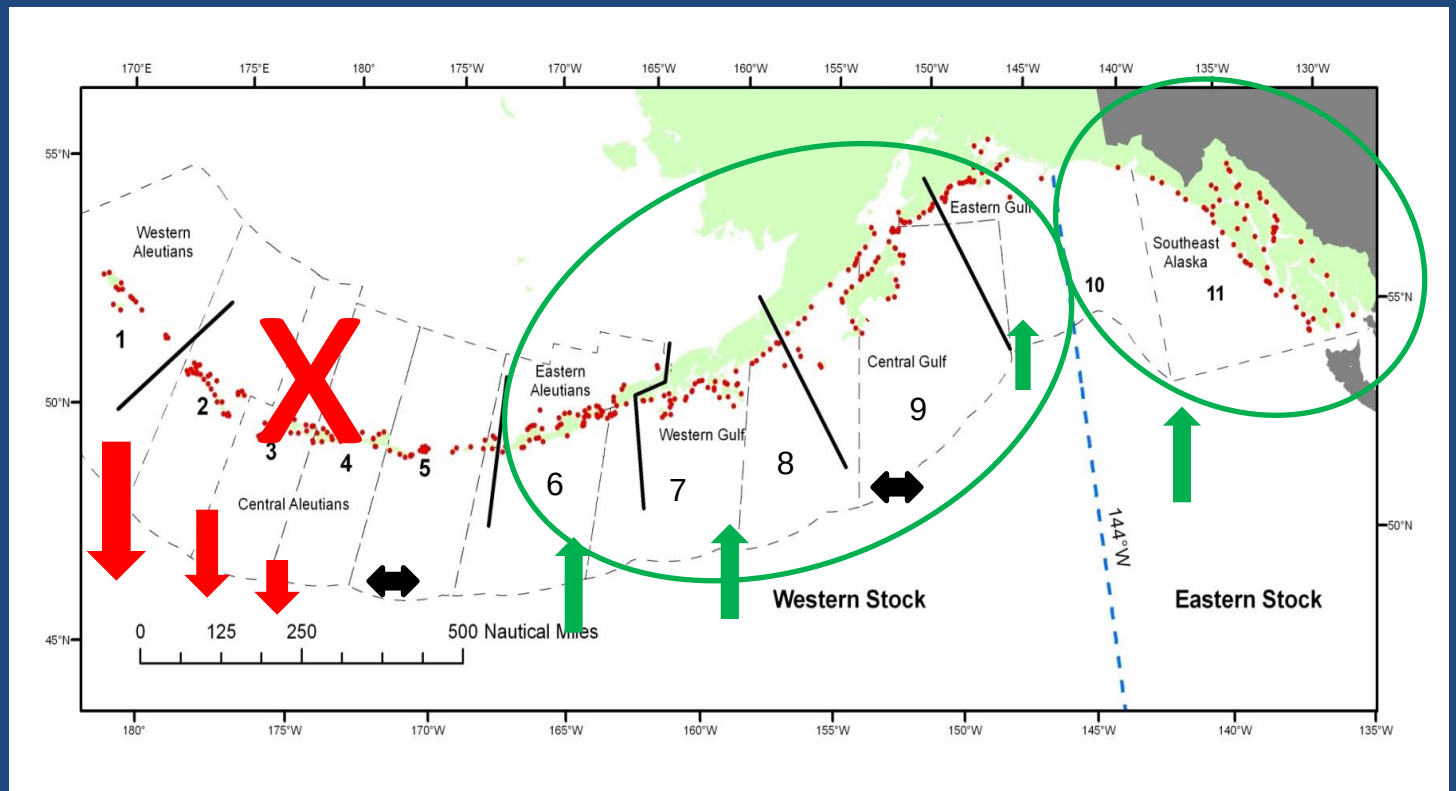
Cumulative Female Survival to Age



CGOA (west) higher survival than SE AK (east)

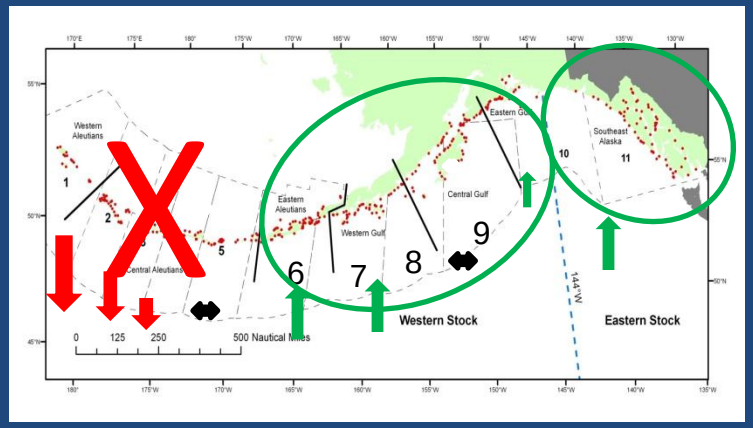
Western DPS vs Eastern DPS

- Survival to adulthood: West (EGOA-EAI) > East (SE AK)
- Survival in 1st year: West > East
- Population trend: East ≈ West
- Consistent with Reproductive Rate: East > West



Western DPS vs Eastern DPS (2)

- Consistent with West more ‘K’ and East more ‘r’ selected
- ‘K’ selection - West
  - Higher survival rate (shown here)
  - Longer maternal care (1st yr higher survival?)
  - Lower reproductive rate (hypothesized)
  - Larger body size
- ‘r’ selection - East
  - Lower survival rate (shown here)
  - Shorter maternal care (1st yr lower survival?)
  - Higher reproductive rate (hypothesized)
  - Smaller body size
- If true, West would take longer to recover than East once direct mortality threats removed since it has lower reproductive rate



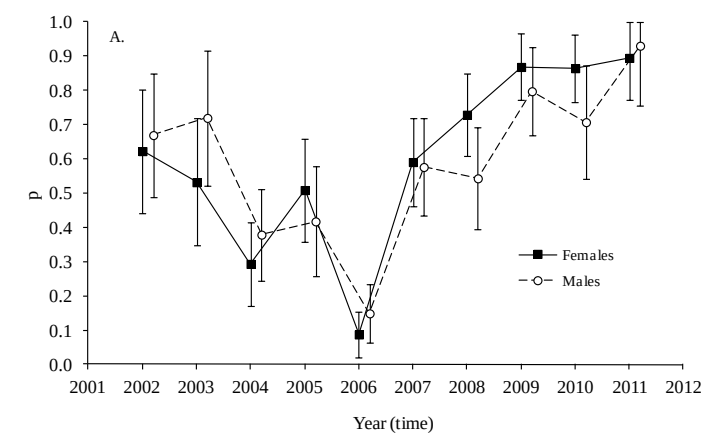
Future Research

- Publish wDPS survival paper (brand) in 2012
- Initiate natality estimation (brand)
- Continue development of size distribution methods
  - Juvenile recruitment in areas with no marked animals
- Development of age-structured model
  - All areas using counts, survival, size, natality
- Field Work 2012-13
  - Aerial surveys to count pups and non-pups
    - SE AK EAI: manned; part of post de listing monitoring for eDPS
    - CAI WAI: possible use of unmanned aircraft (UAS)
  - Brand sighting camps and cruises

Questions on Survival and Vital Rates?

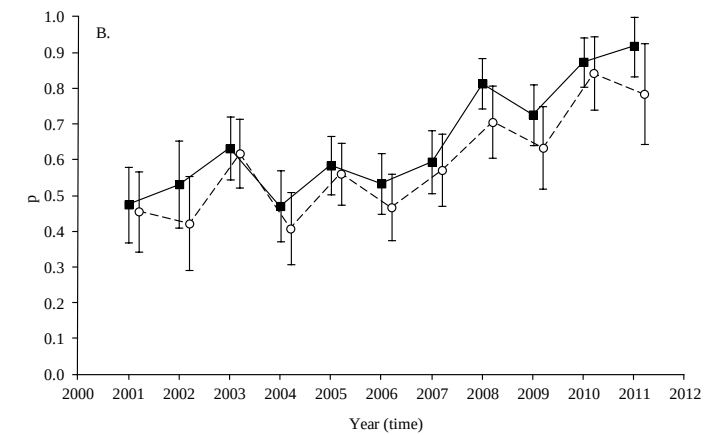
Next: Composition – Age, Sex, Length

Sighting Probability



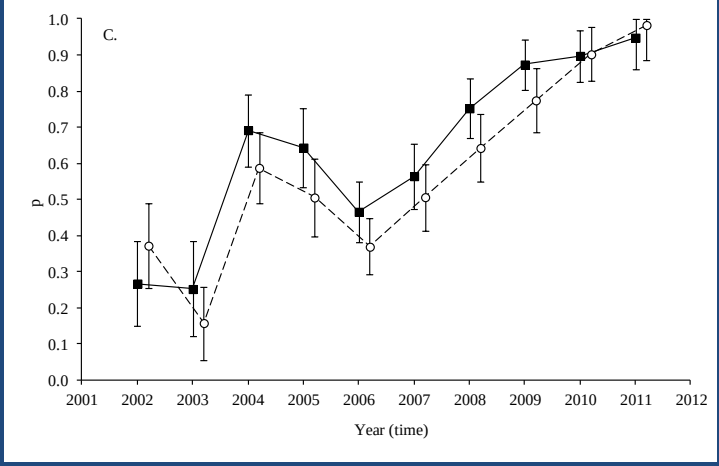
Eastern Gulf of Alaska

- Seal Rocks & Fish Island



Central Gulf of Alaska

- Sugarloaf & Marmot



Eastern Aleutian Islands

- Ugamak

Composition and Length

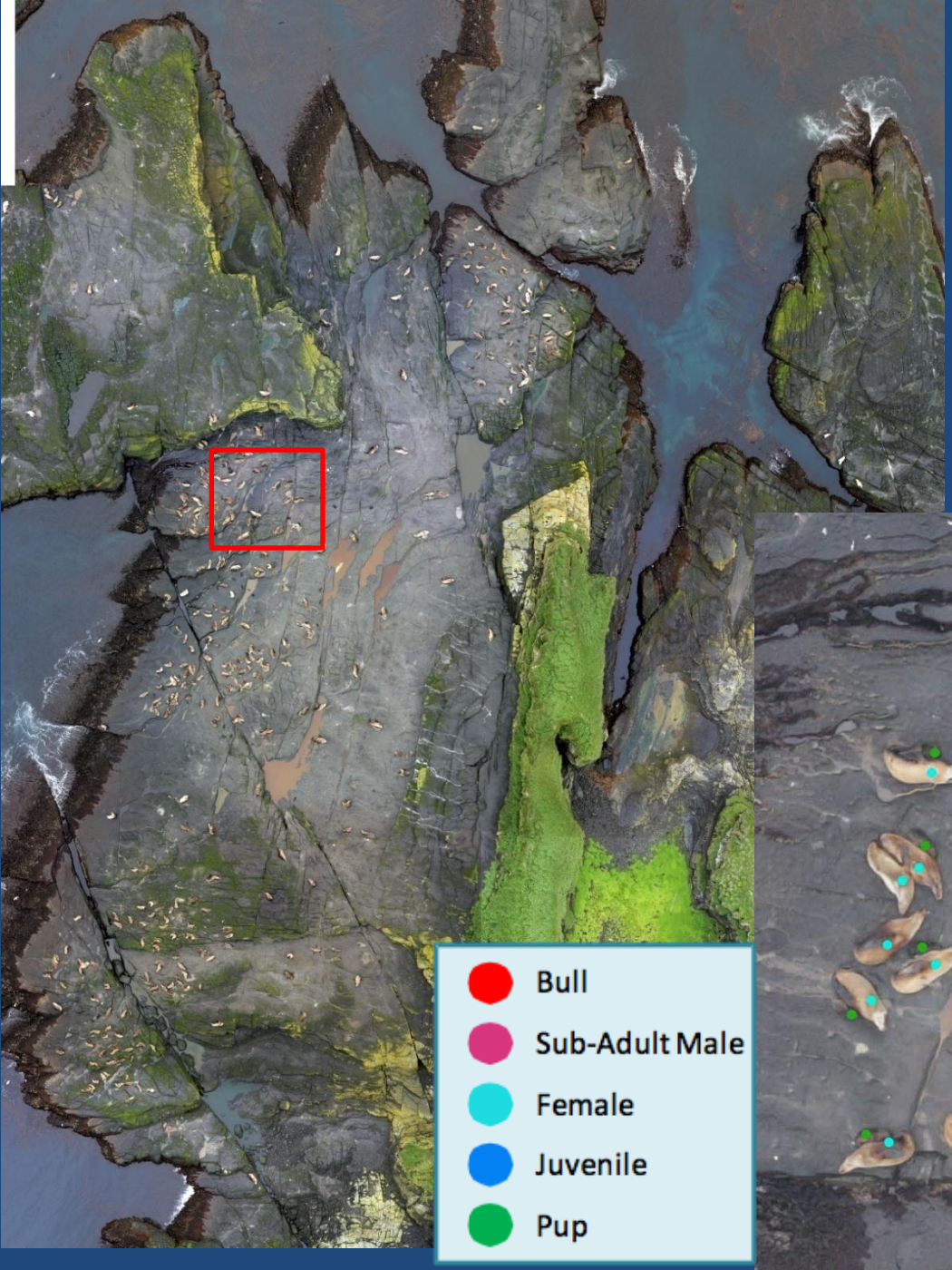
- Aerial survey data
- Across all of Alaska, not just where we branded
- Pup-Female Ratios
  - Relative ‘natality’
- Length distribution and Modeling
  - Regional Variation in Adult Female length
    - Identified with Pups or Juveniles
    - Eastern vs. Western DPS
    - Within Western DPS
  - Finite Mixture Distribution Modeling
    - Juvenile proportion within Western DPS
    - Compare Increasing vs. Decreasing Areas
    - EGOA-EAI (brand data) vs. CAI-WAI (no brand data yet)

Western Stock

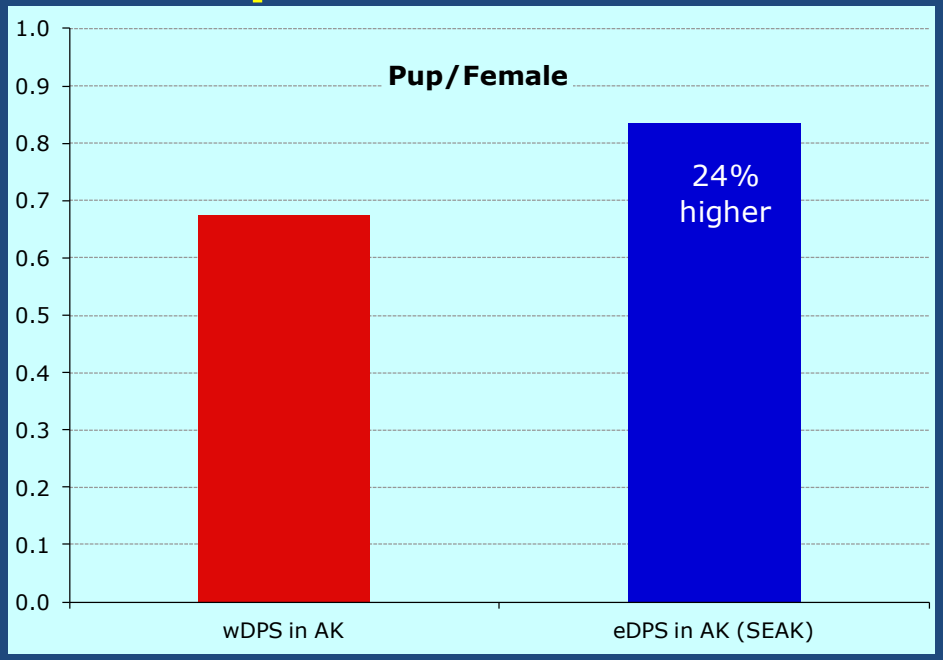
Ulak/Hasgox Point – Central Aleutians

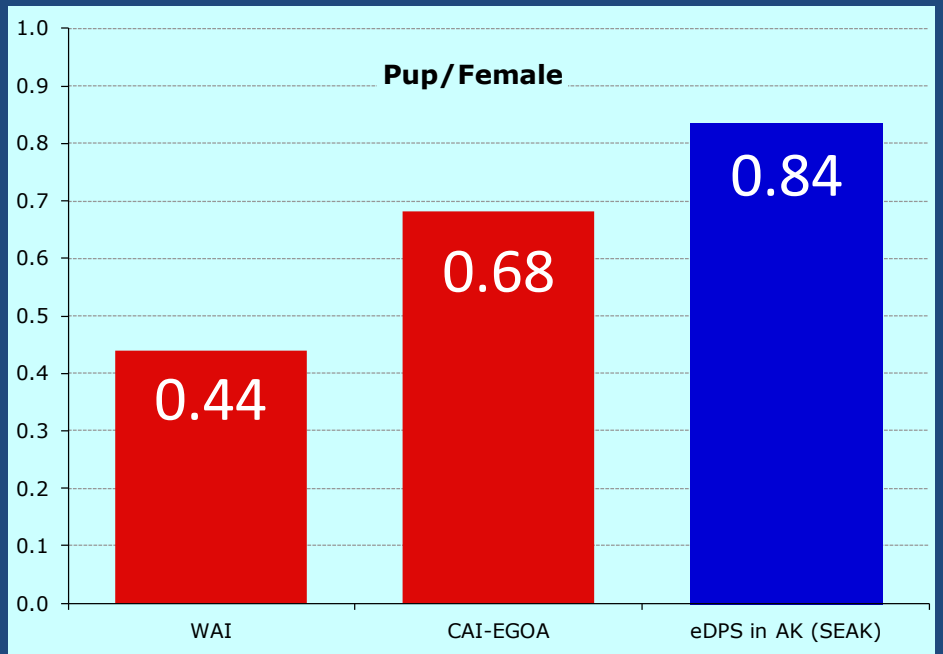
Decreasing: 272 Pups

515 Adults and Juveniles



Pup:Adult Female Ratios (2008-11)



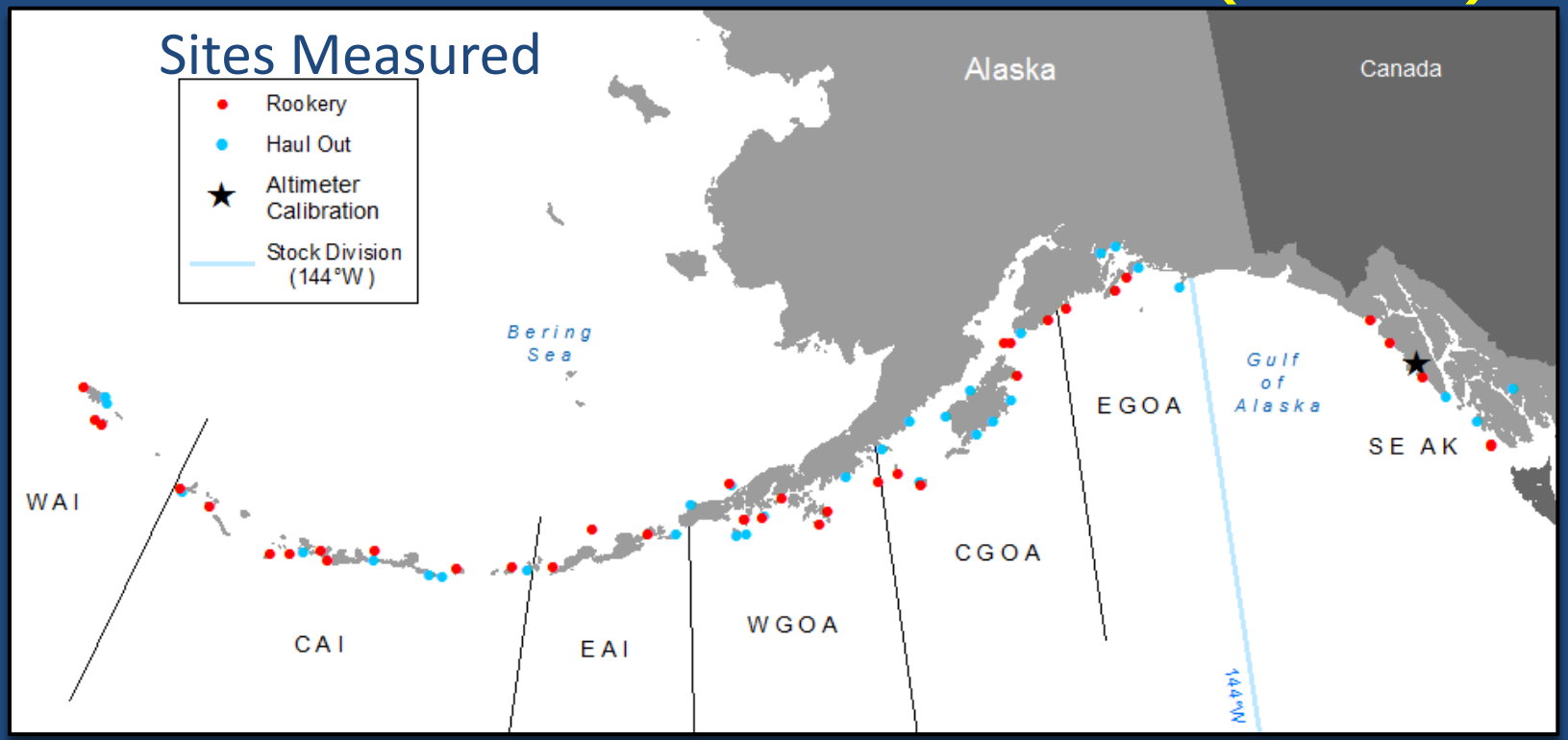


- eDPS > wDPS
- WAI < rest of wDPS
- Consistent with:
  - Natality higher in eDPS than wDPS
  - Natality low in WAI

Length Data and Population Demographics

- Photogrammetric methods and marine mammals
  - Steller Sea Lions (Holmes & York 2003; Holmes et al. 2007)
  - Cetaceans (SWFSC 1998, 2008)
- Fisheries: Length frequency data and **Finite Mixture Distribution Model**
  - Size composition for age-sex classes (Everitt & Hand 1981; Wolfe 1970)
  - Identify individual fish stocks in mixed-stock distribution of length data (Millar 1987; Wood et al. 1987)
- **Steller sea lion length data & Finite Mixture Distribution Model**
  - Estimate mean length and population proportion of three age-sex classes: Juvenile, adult female, and adult male (Bull and sub-adult male)
  - Use photogrammetry to measure lengths from 2008 aerial survey images (Alaskan range-wide survey)
    - "**observed known adult female**"

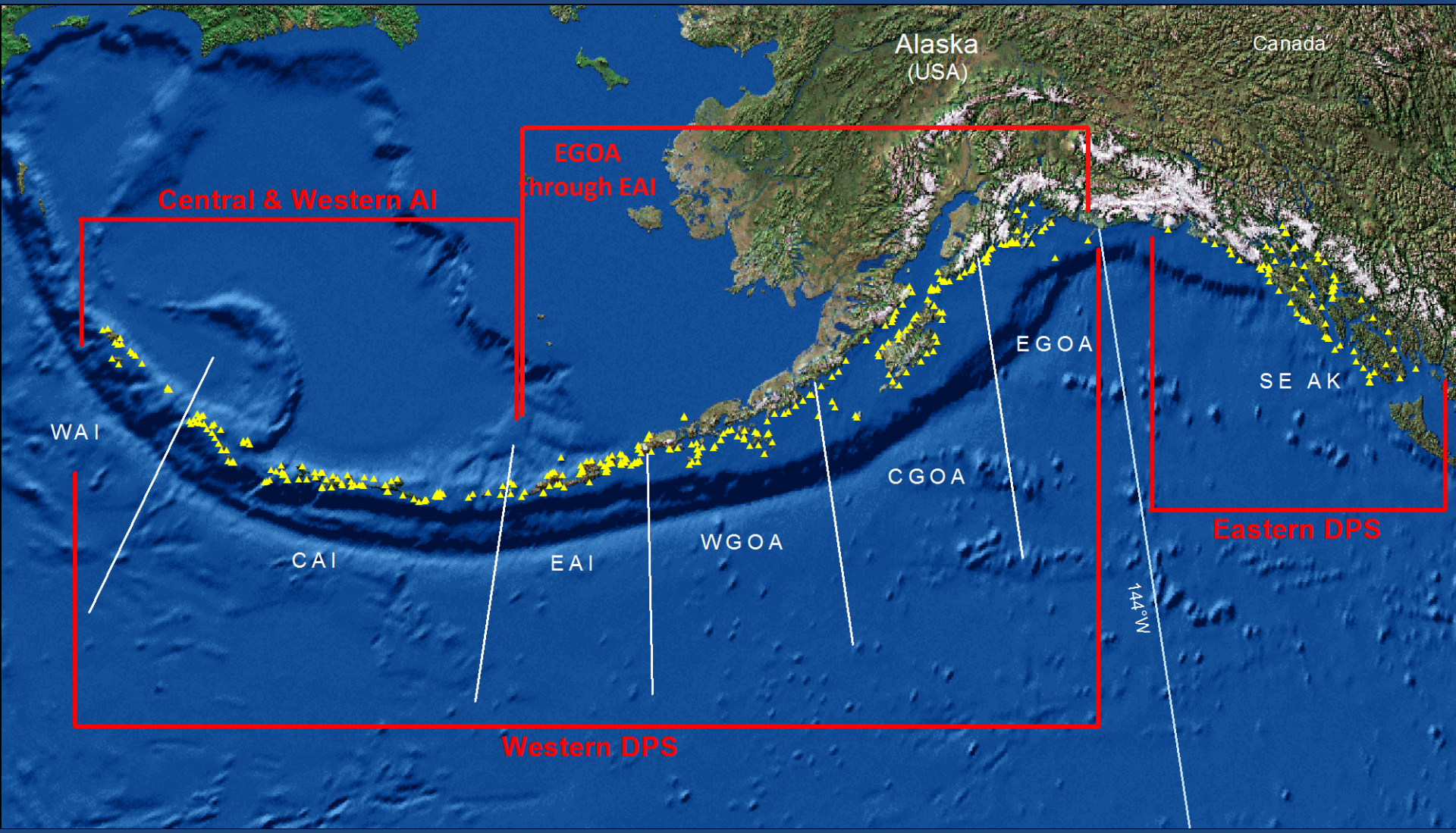
Measurement Collection (SC 3)



- Sites with:
  - Highest relative abundance
  - At least one rook/HO site selected from each RCA
  - Associated altitude data

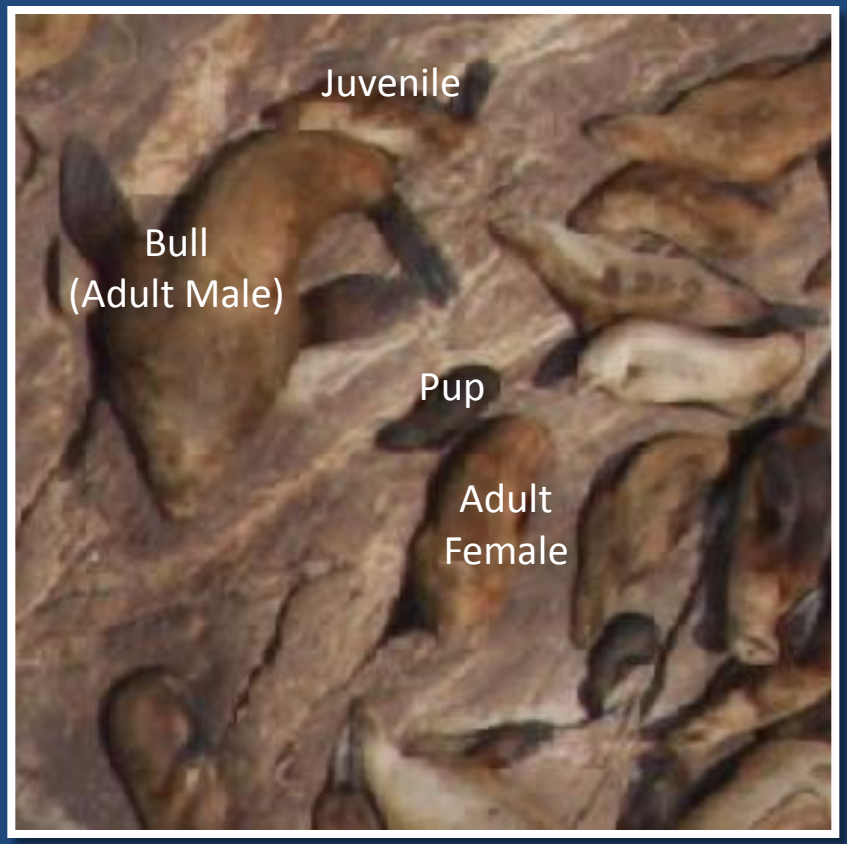
Region	Sites	# Lengths	# Female
SE AK (eDPS)	**8**	**1284**	**241**
wDPS	**60**	**4737**	**1001**
EGOA	7	865	66
CGOA	15	783	221
WGOA	11	1365	258
EAI	7	725	193
CAI	15	861	225
WAI	5	138	38
Total	**68**	**6021**	**2243**

Broad Regional Comparisons

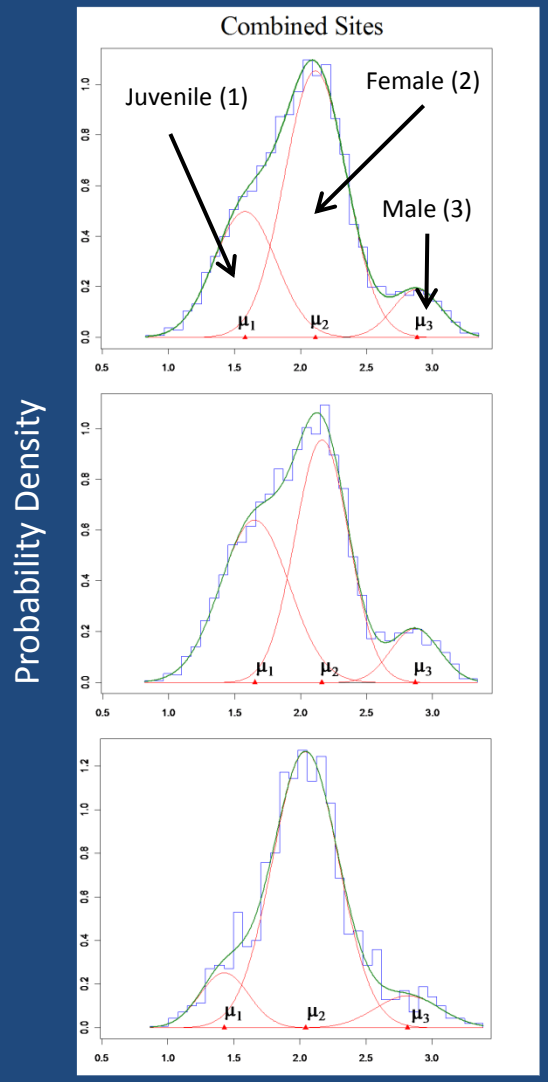


FMD Modeling Results

- Mean length and range of Juveniles and Adults (F & M)
- Proportion of measured sample (area under curve) composed of Juveniles and Adults (F & M)



Rookeries and Haulouts



Western DPS

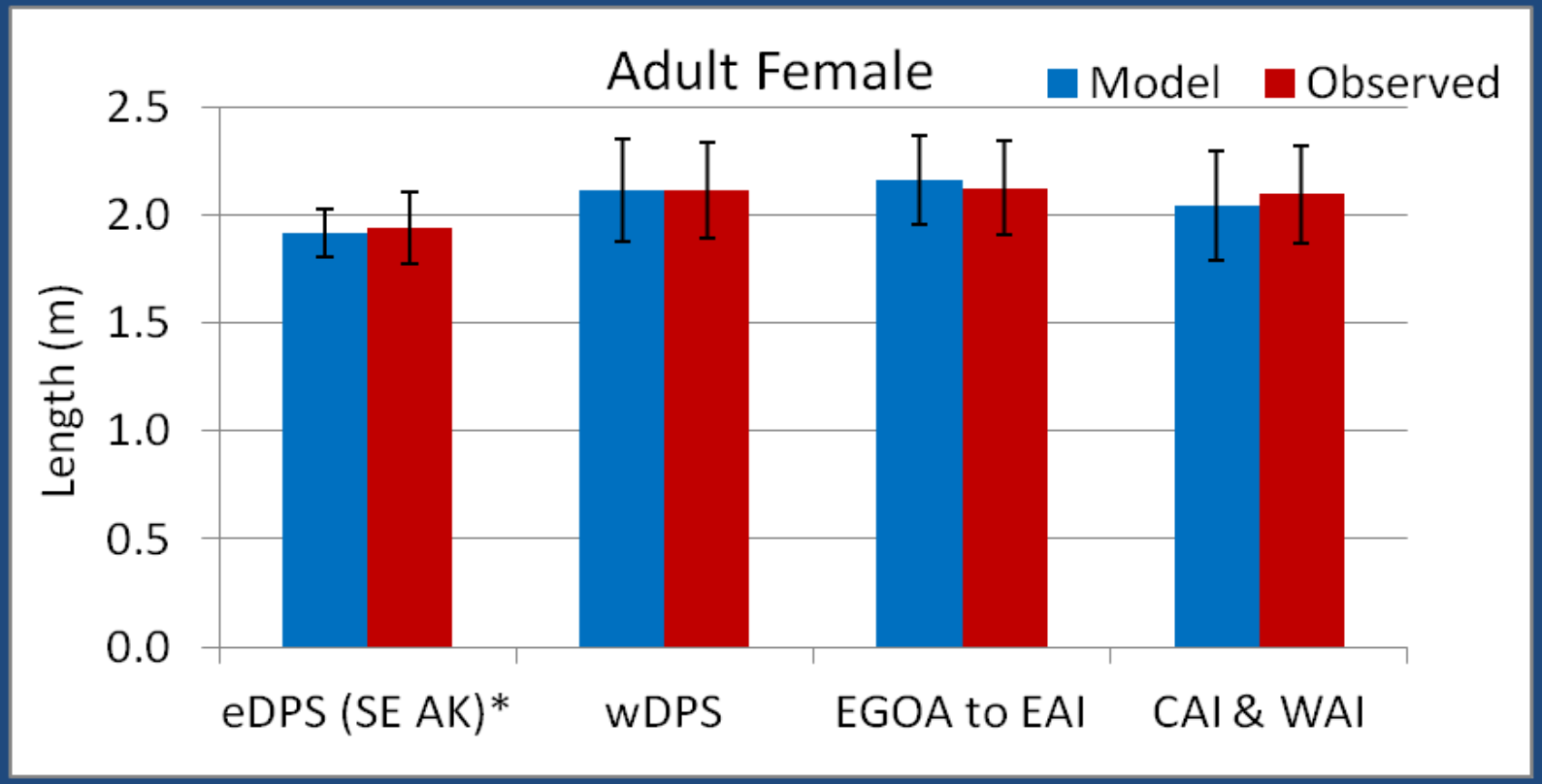
EGOA EAI

CAI WAI

FMD Modeling Results

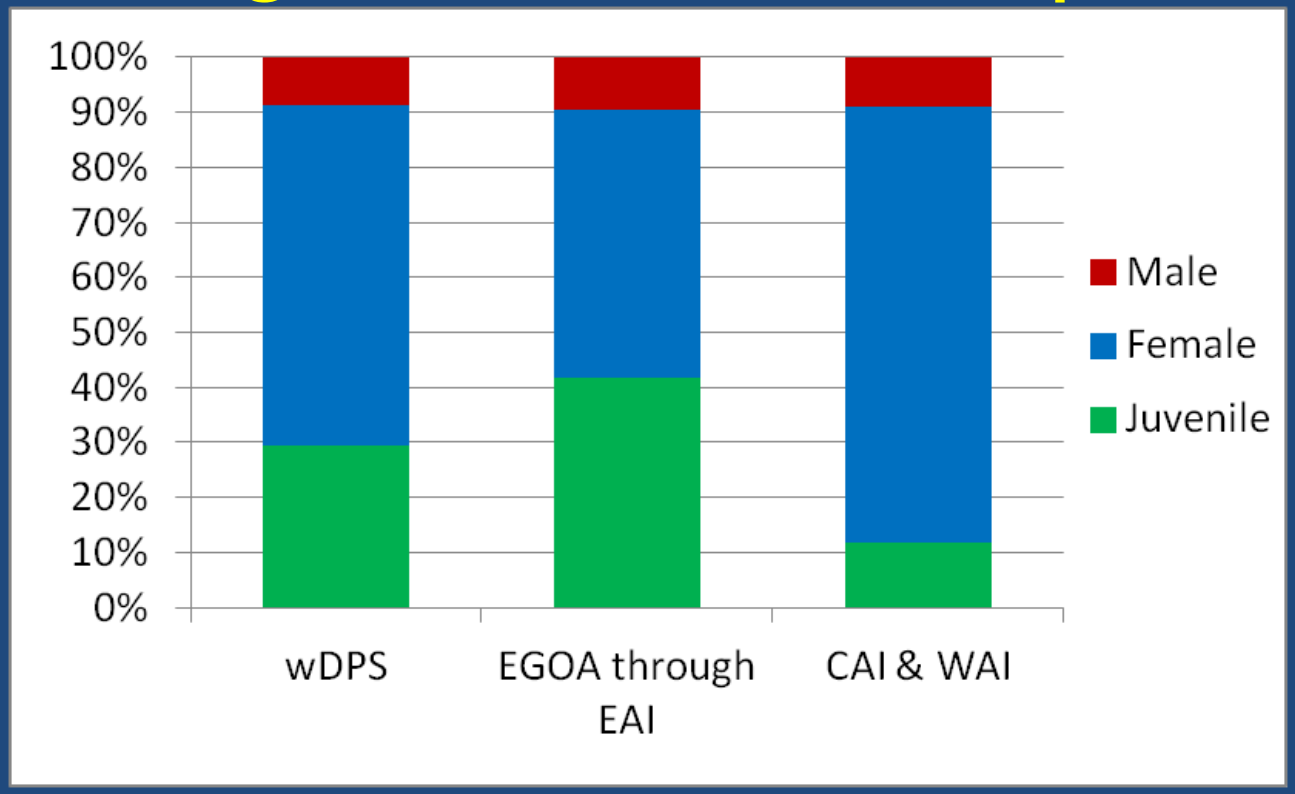
Eastern DPS females are significantly smaller than the Western DPS

No difference between Model and Observed female length



*significantly smaller

FMD Modeling Results: Age-sex Class Proportions



- Proportion juvenile: EGOA-EAI > CAI-WAI
- Population trend: EGOA-EAI > CAI-WAI
- Juvenile survival and/or natality low?

Questions on Composition – Age, Sex, Length?

Next: Movement to and from Aleutian Islands and Russia

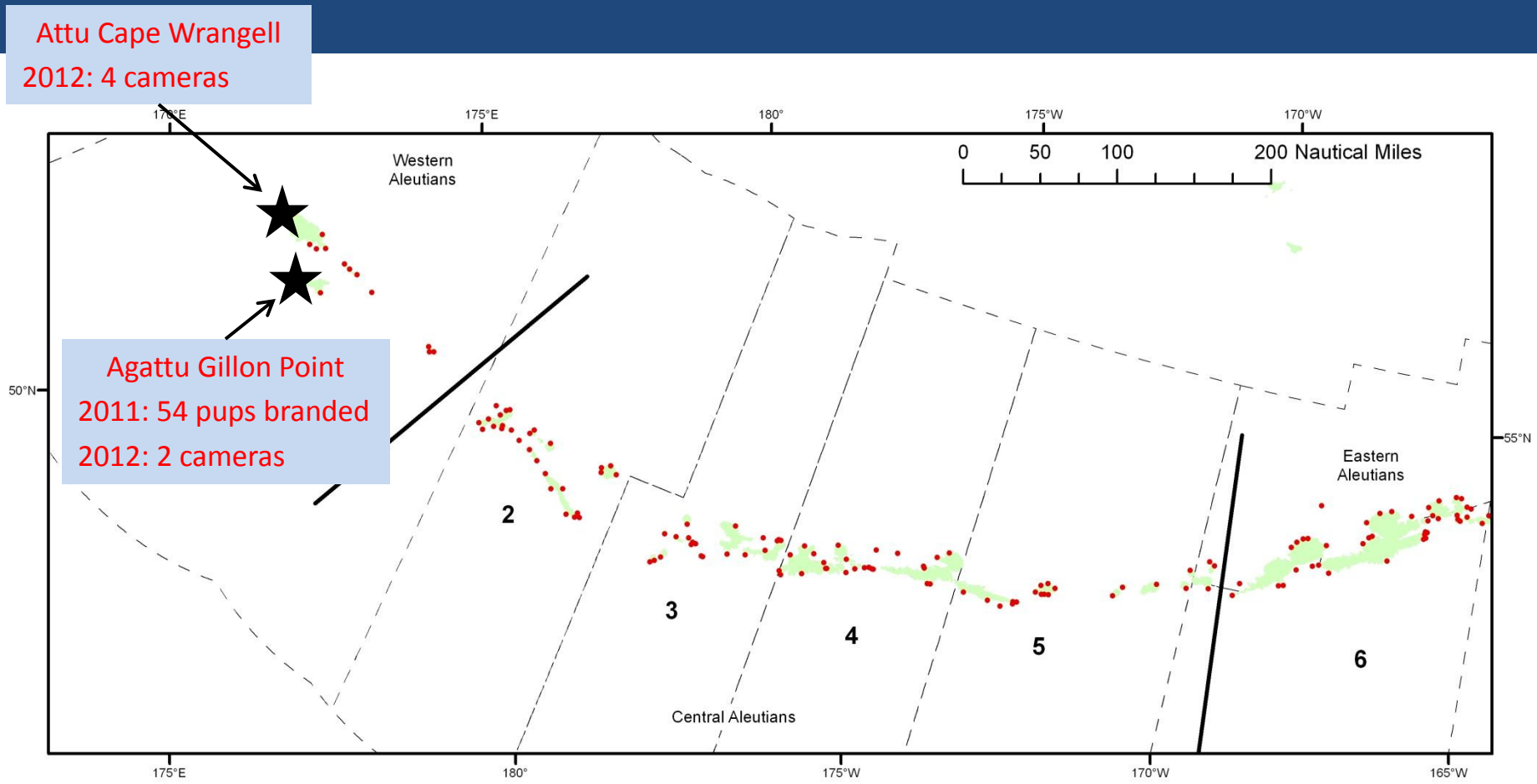
Movement of Branded Sea Lions to and from Aleutian Islands and Russia

- Russian brands in US
- US brands
  - Eastern DPS
    - SE AK, OR & CA
  - Western DPS
    - E Gulf, C Gulf & E Aleutians
    - W Aleutians – Agattu
      - ~ brands
      - 2011, N=54

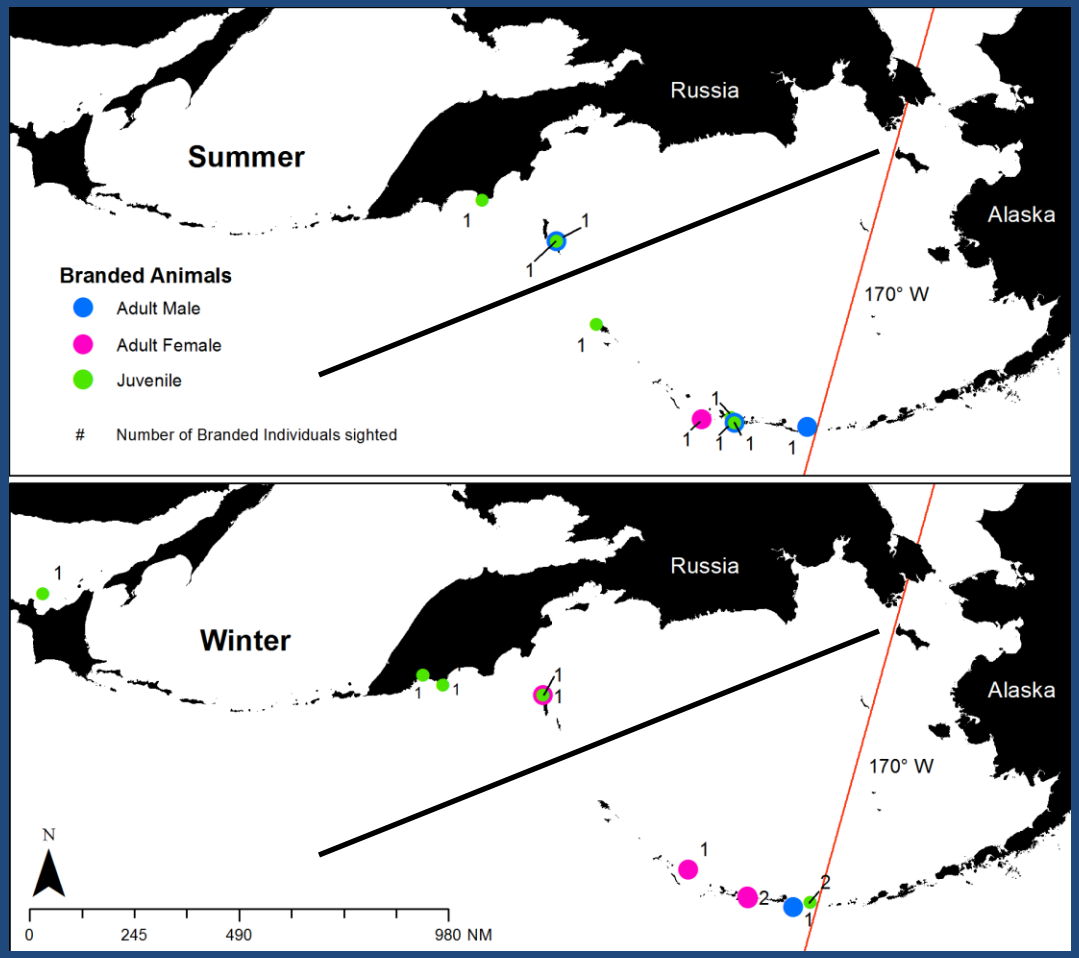
~5: 5-month old pup branded
On Agattu 6/24/2011
Observed 11/13/2011 on Bering I,
Commander Islands, Russia

M539: Sub-adult male branded
as pup on Medny I.
Observed 7/16/2011 on Attu

NMML Branding and Camera Installations in Western Aleutians 2011-12



Movement of E Aleu – E Gulf (w DPS) brands

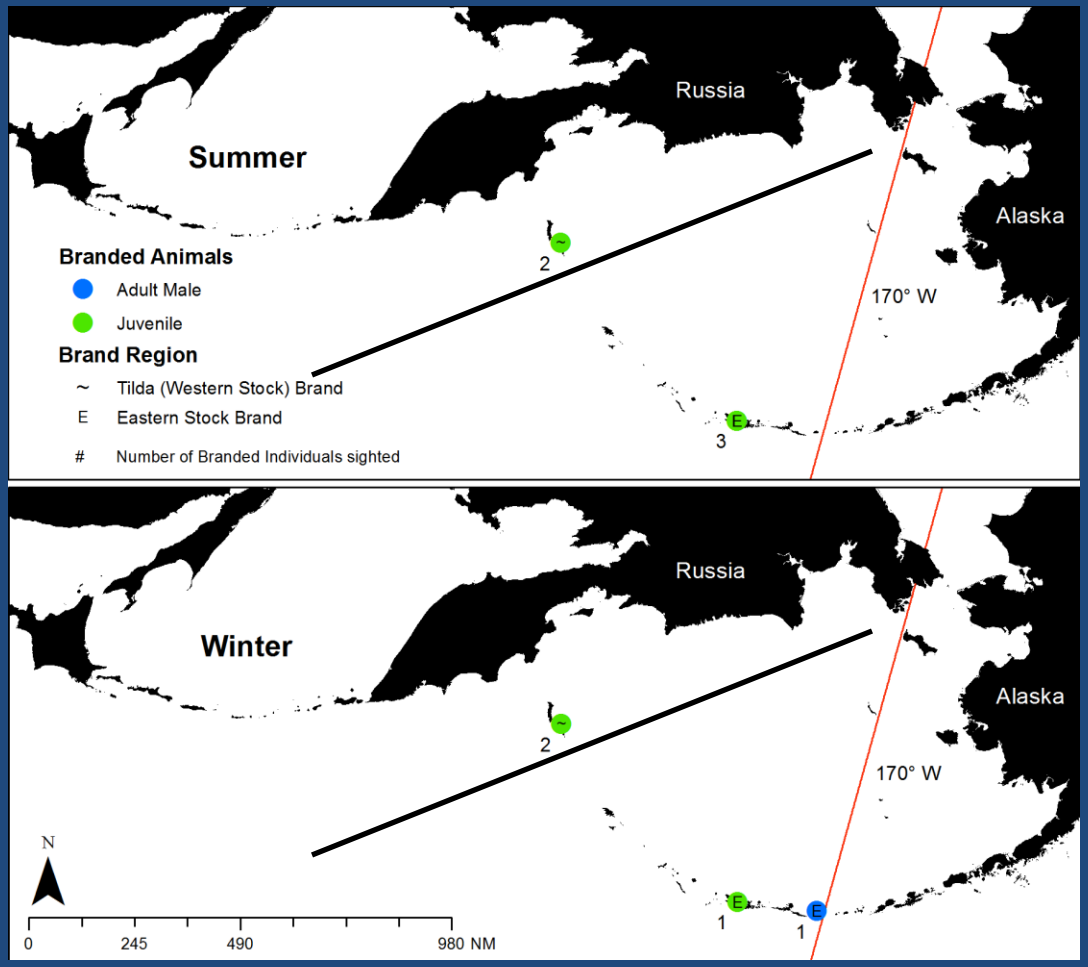


- Few West of Samalga Pass 170W
  - 9 in summer
  - 13 in winter
- Summer (breeding)
  - 3 in Russia - all juveniles
  - 1 adult female in Aleu
  - 2 adult males in Aleu
- Winter (non-breeding)
  - 5 in Russia – all juveniles
  - 3 adult females in Aleu

	Rookery	Summer	Winter
	Marmot	5	
wDPS	Sugarloaf	1	2
	Ugamak	2	9
	Total Individuals	**8**	**11**

note: branded individuals seen multiple times at new locations

Movement of Eastern DPS and Agattu ~ brands

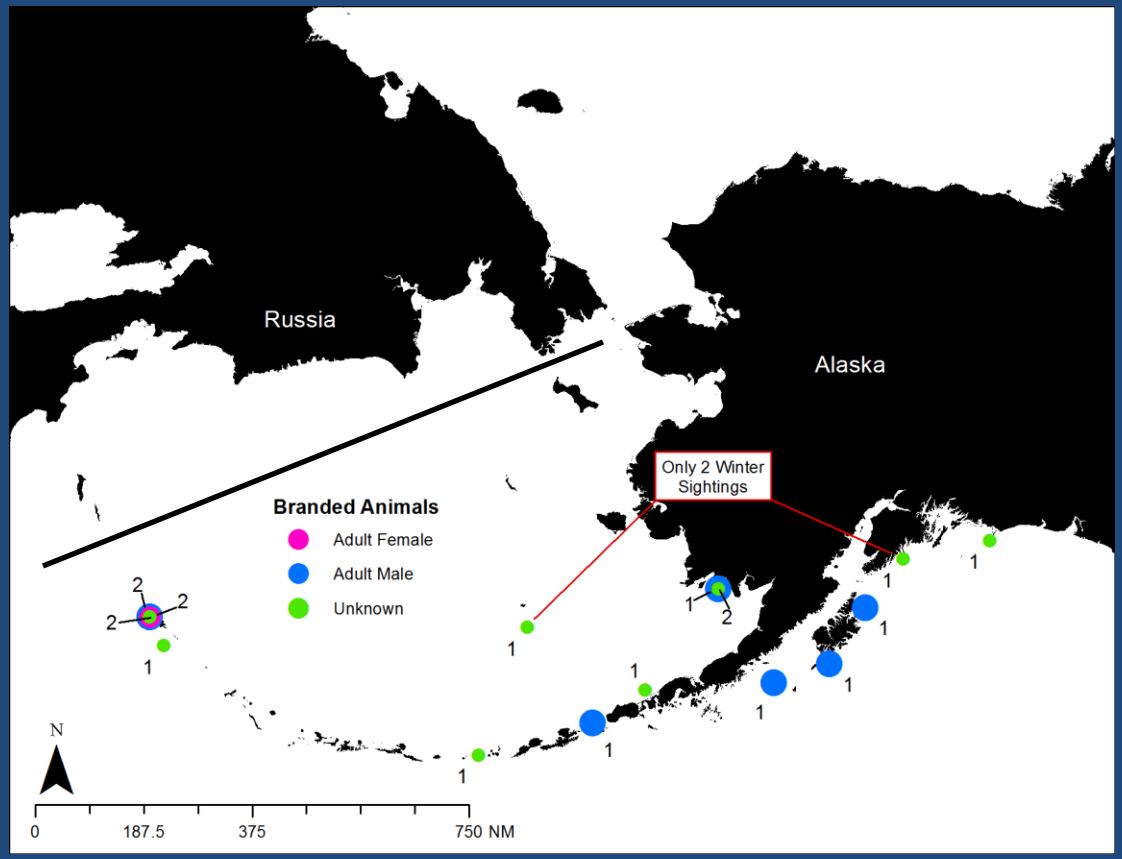


- Few eDPS West of Samalga Pass 170W
  - 3 males in summer
  - 2 males in winter
- W Aleutian ~ brands move to Russia
  - Commander Islands
  - 2 ~ yearlings in summer
  - 2 ~ pups in winter

	Rookery	Summer	Winter
	Agattu Gillon Point	2	2
	Forrester		1
eDPS	Rogue Reef (OR)	2	1
	St. George Reef (CA)	1	
	Total Individuals	**5**	**4**

note: branded individuals seen multiple times at new locations

Movement of Russian brands

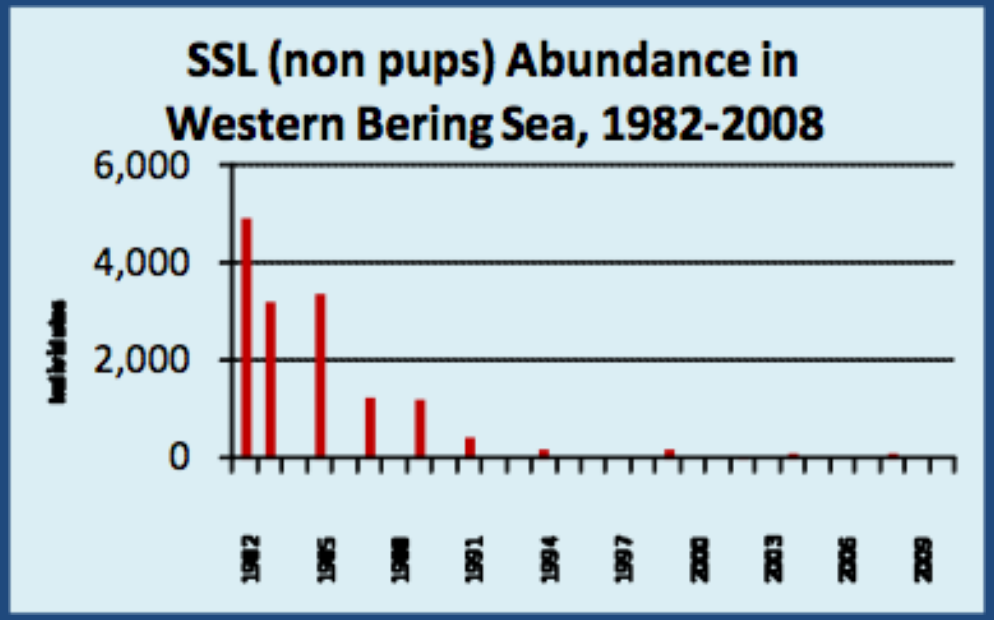


- Summer (breeding)
  - 2 adult females on Attu
  - 7 adult/sub-adult males as far as CGOA
  - 17 individuals
- Winter (non-breeding)
  - 2 individuals (juveniles)

Rookery	Summer	Winter
Srednego	1	
Kozlova Cape	2	
Antsiferov	3	
Medny	11	2
Total Individuals	**17**	**2**

note: M642 observed in summer & winter season

Russian Data through 2009

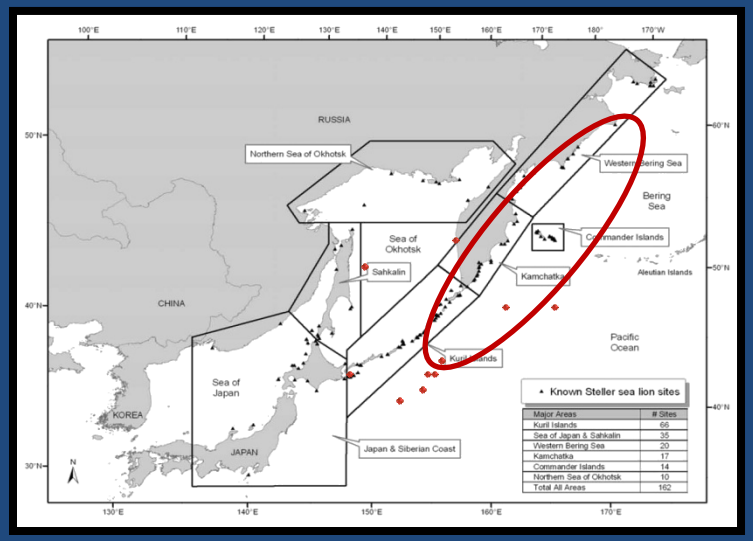


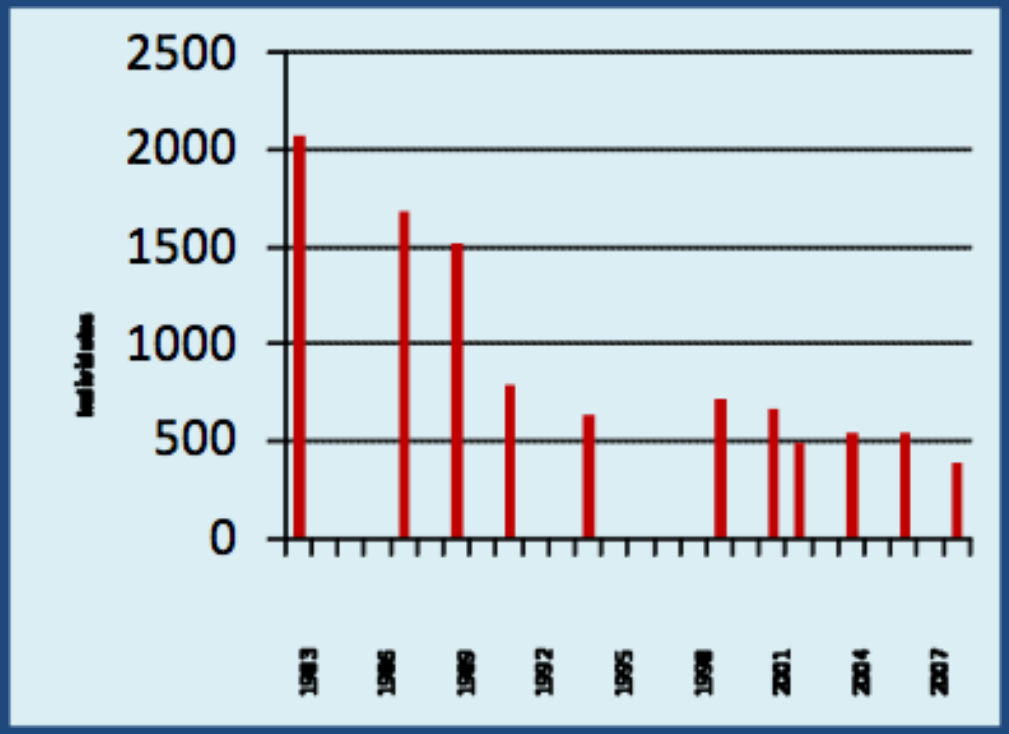
Western Bering Sea Non-Pups

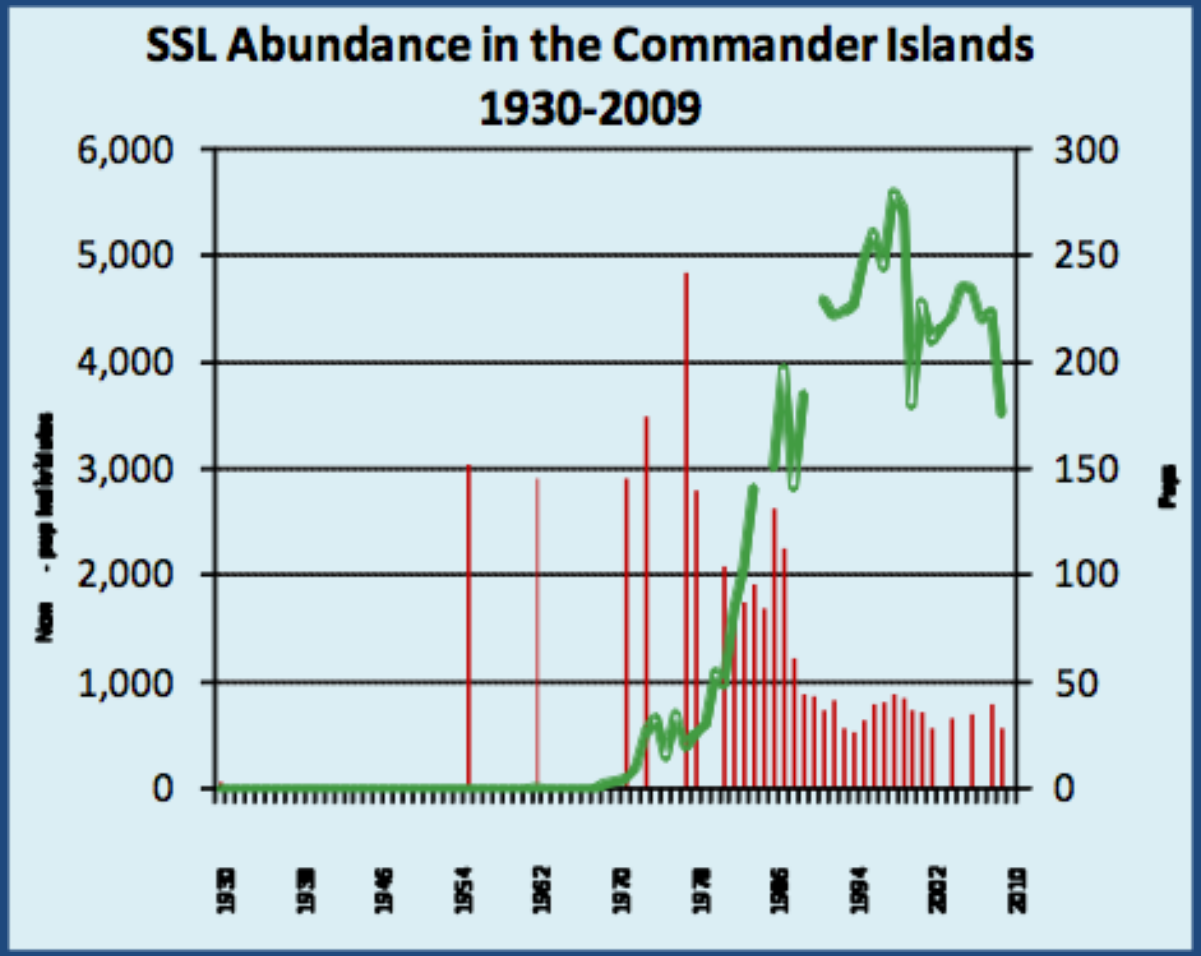
98% decline since 1982

Eastern Kamchatka Non-Pups

-81% decline since 1983







Commander Island SSLs

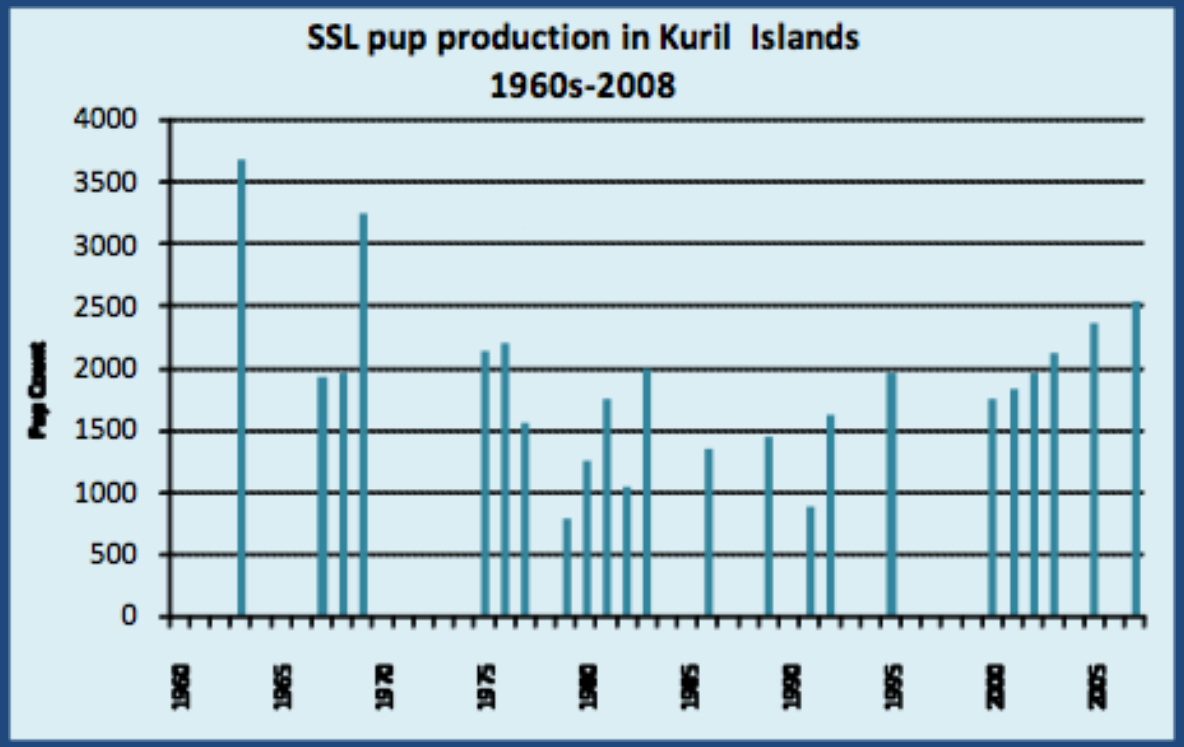
- Increase 1930-1950s
- Decline through 1980s
- Rookery re-established: late 1970s
- Pups increase through 1990s
- 2000-2008: stable at low level
  - 700-800 non-pups, 220-250 pups

Medny I. rookery 2009

		Change from 2008
Pups born	175	-21%
Non pup (max)	391	-27%
Females (max)	244	-17%
Bulls (total, max)	80	-10%
Bulls (terr, Max)	44	-20%

No decline in number "M" branded animals resighted in 2009

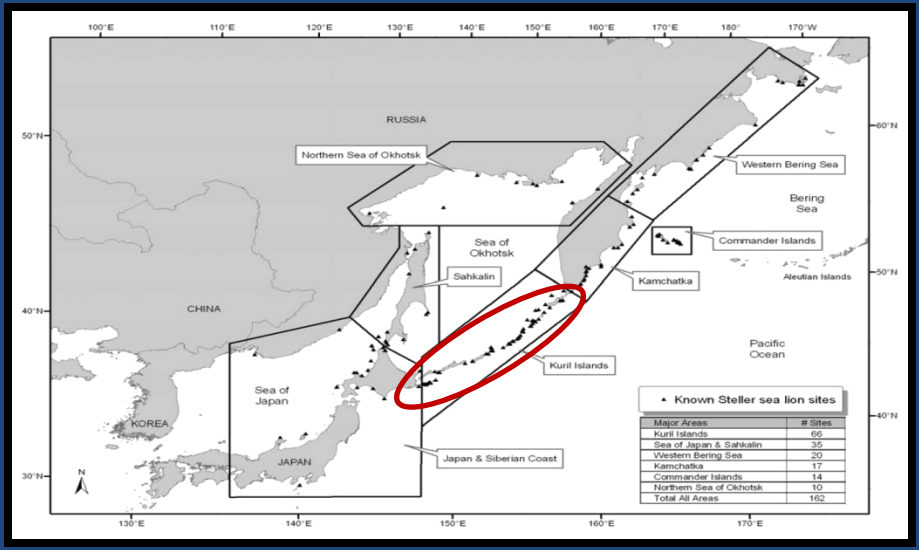
- Preliminary estimates (analysis in progress):
  - **Negative trend in female birth rates**
  - **No significant changes in survival rates**

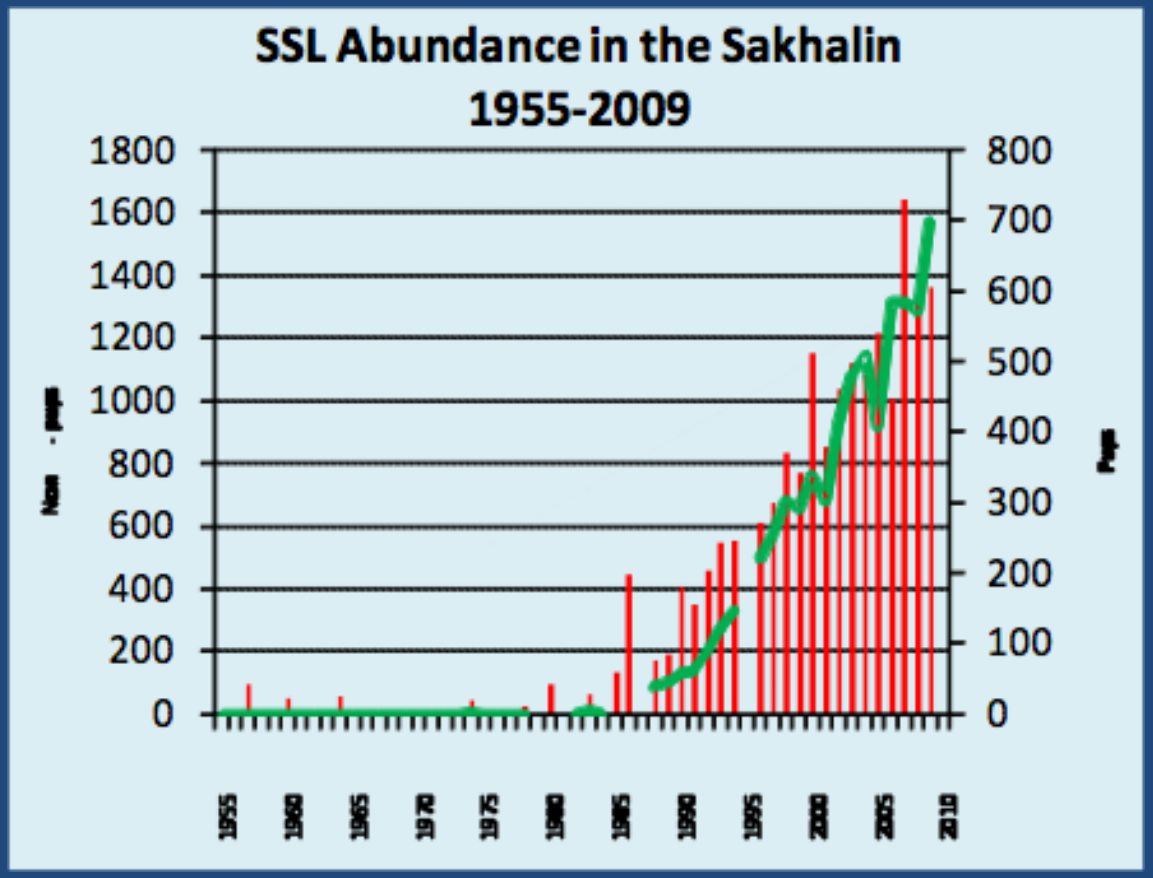


Kuril Island Pups:

2000 – 2007 increase 6% / year

2009 – No significant change
(analysis in progress)





Sakhalin Island SSLs

- VERY low number till early 80s.
- One rookery established in early 80s on Tuleny (Robben) I.
- Pups number is growing rapidly through 1990s and 2000s
  - Mean trend in pup production 1983-2009 is **21%**
- High pup trend due to immigration SSL from Iony I. in northern Sea of Okhotsk (brand resight data)
- Tuleny I Rookery in 2009:
  - ~ 1200 non-pups
  - ~ 500-700 pups

2009 survey results:

- three more SUMMER SSL haulout sites re-established in southern Sakhalin (they were only winter sites in the past)
- 2,000 non-pups and 11 pups were counted on the three haulout sites
- branded SSL were from northern Sea of Okhotsk and Kuril Islands

Extra Slides

Steller Sea Lion Growth

- Asymptotic length:
  - 90% final adult length reached around sexual maturity for males and females (Winship et al. 2001).

Straightness Classification: Assigned to Length Measurements

1

2

3

4

Due to small sample size of SC 1 and 2 and significant curvature of SC 4…

Only SC 3 lengths used in analysis

Observed Known Adult Females

Females in close proximity to a pup/juvenile on a rookery

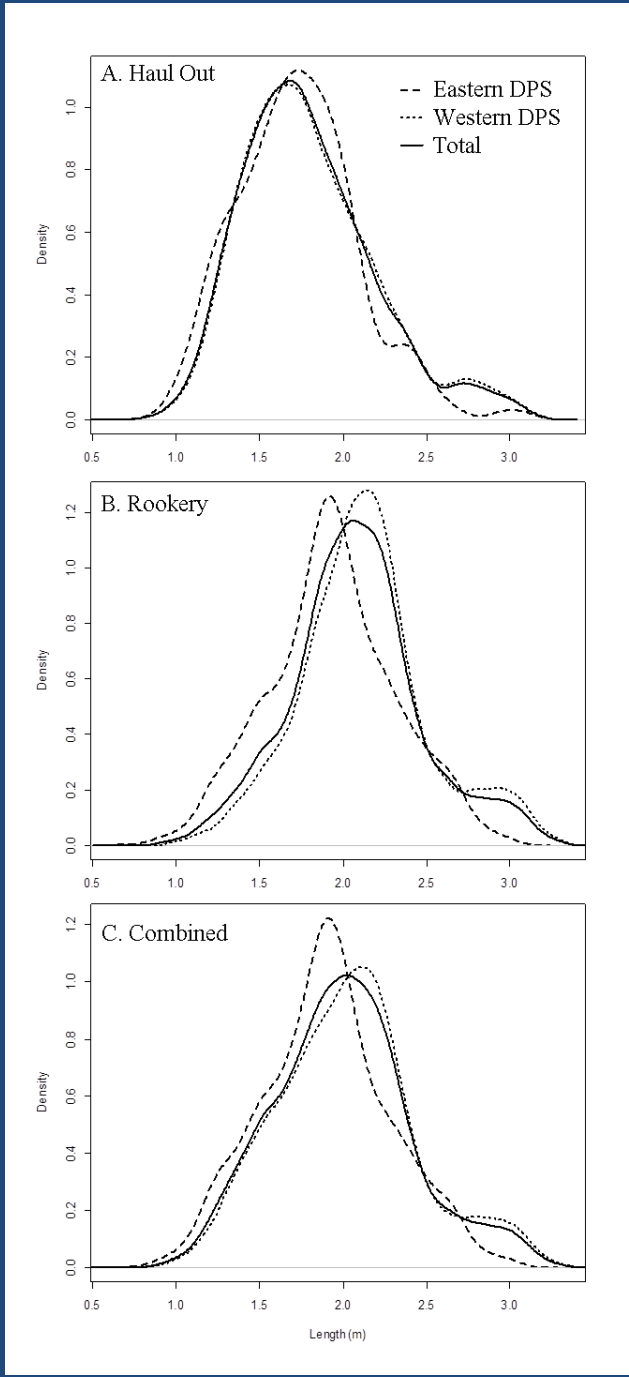
		Number Females	**Mean Length (m)**	SD
Eastern DPS	SE AK	241	**1.941**	0.167
Western DPS	All Range	1001	**2.116**	0.221
Regions:	EGOA	66	**2.052**	0.280
	CGOA	221	**2.137**	0.221
	WGOA	258	**2.119**	0.216
	EAI	193	**2.137**	0.192
	CAI	225	**2.102**	0.224
	WAI	38	**2.054**	0.223
	RCA 1-3	146	**2.056**	0.208

Finite Mixture Distribution (FMD) Modeling

- Developed for fisheries science (Bhattacharya 1967; Prager & Shertzer 2005)
- Broad application (DeVries 2002)
- Three age-sex classes:
  - Juvenile (male and female), adult female, and adult male

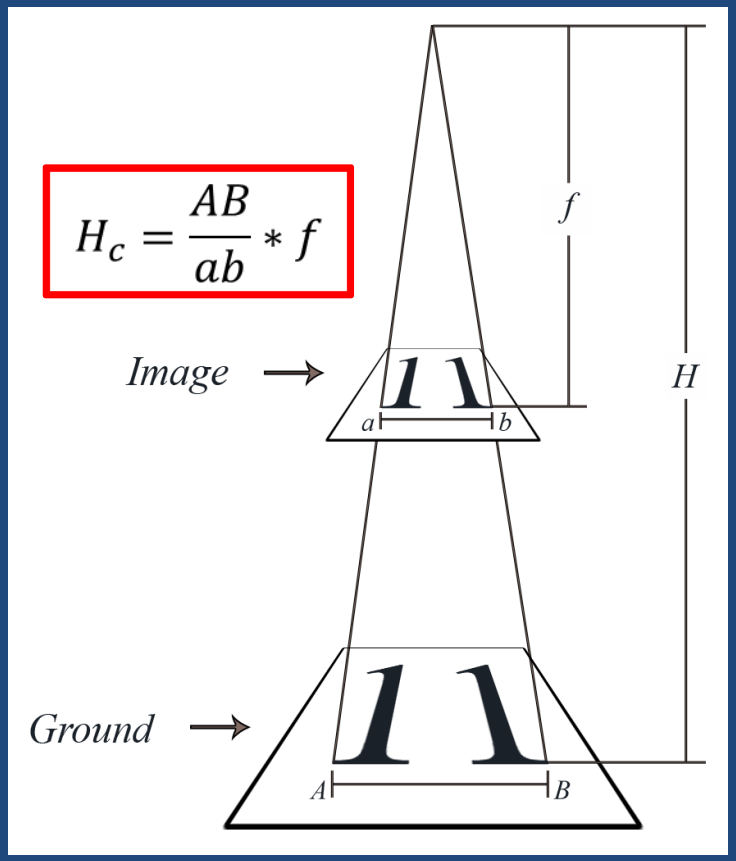
$$f(L_t|\pi,\mu,\sigma) = \sum_{i=1}^{I} \pi_i g_i(\pi|\mu_i,\sigma_i)$$

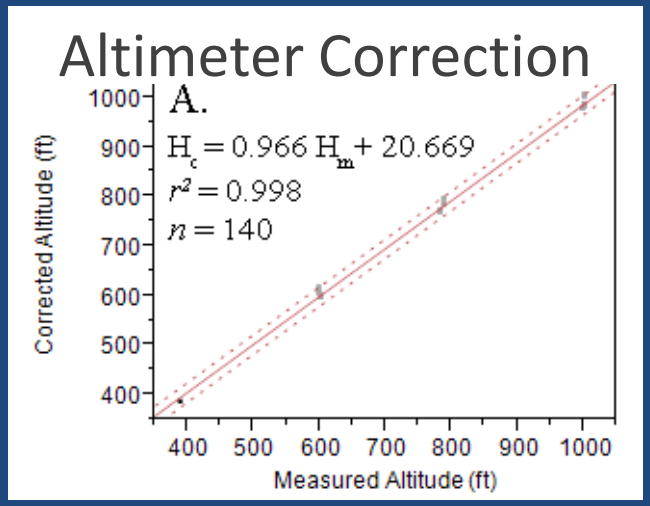
Distribution of sea lion lengths = Sum of 3 age-sex classes weighted by proportion

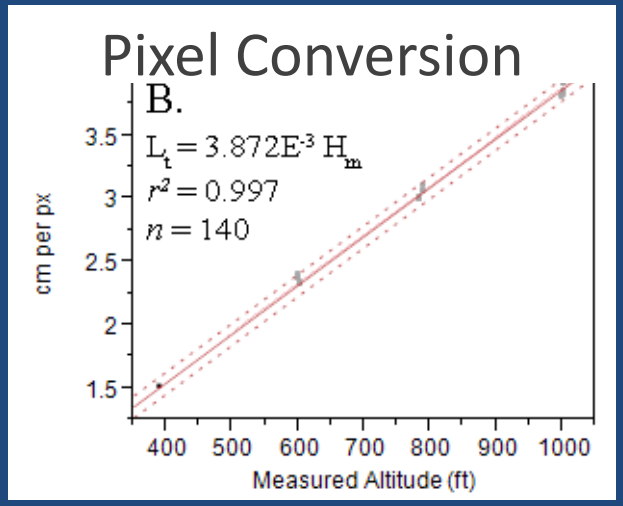


Calibration Equations

- Photographed runway number—known ground measurement (Sitka, AK)
  - Scale Factor (Wolf 1987)
  - Correct for altimeter bias (Gilpatrick 1998)
  - Pixel /cm ratio calibration
- Linear regressions







Final Conversion Equation

$$L_p = 3.742E^{-3}L_t H_m + 8.003E^{-3}L_t$$

L_t = Measured length (pixels)

H_m = Measured altitude (altimeter; ft)

L_p = Measured length (meters)

FMD Modeling Results

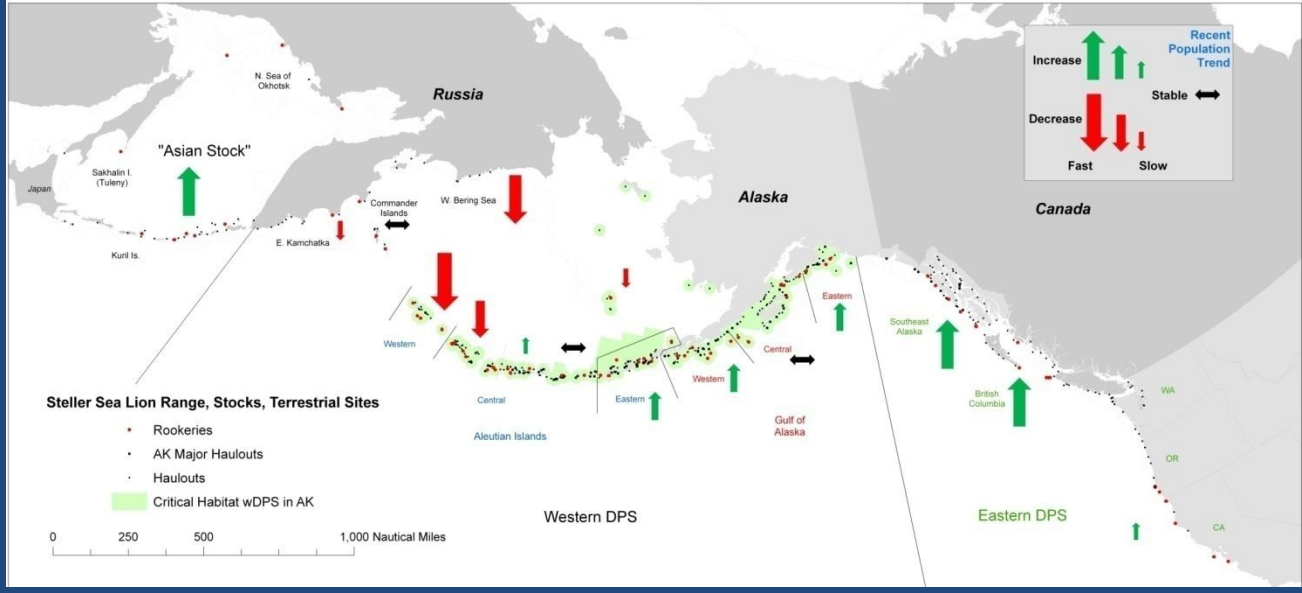
Eastern DPS adults are significantly larger than the western DPS.

Eastern DPS juveniles are significantly smaller than the western DPS.

		Age-Sex Class		
		Juvenile	Female	Male
Eastern DPS	Mean	1.524	1.914 (1.941)	2.187
	SD	0.249	0.111 (0.167)	0.320
Western DPS	Mean	1.580	2.113 (2.116)	2.883
	SD	0.236	0.235 (0.221)	0.183
EGOA through EAI	Mean	1.653	2.162 (2.123)	2.869
	SD	0.260	0.203 (0.219)	0.182
CAI & WAI	Mean	1.600	2.057 (2.056)	2.692
	SD	0.236	0.184 (0.208)	0.245

* units in meters

Non-pup Trends



- Eastern DPS
  - SE Alaska increasing at 3% per year since mid-1970s
- Western DPS
  - EGOA increasing at 6% per year 2000-2011
  - CGOA stable 2000-2011
  - EAI increasing at 3% per year 2000-2011