Spatial use of Drakes Estero, California, by harbor seals correlated to anthropogenic disturbance and natural variation during 1982-2009

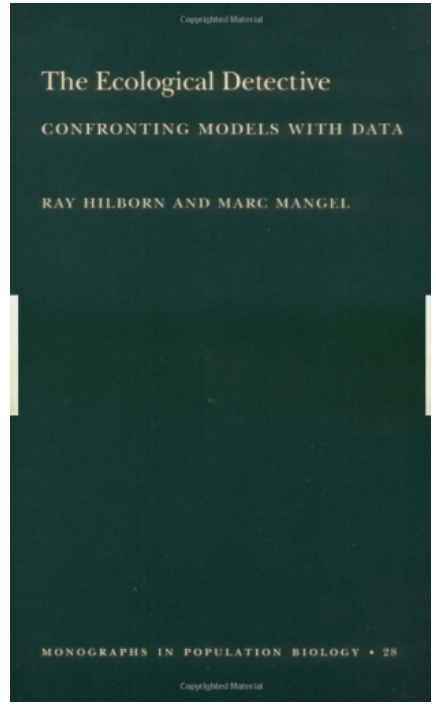
Ben Becker, Dave Press, and Sarah Allen

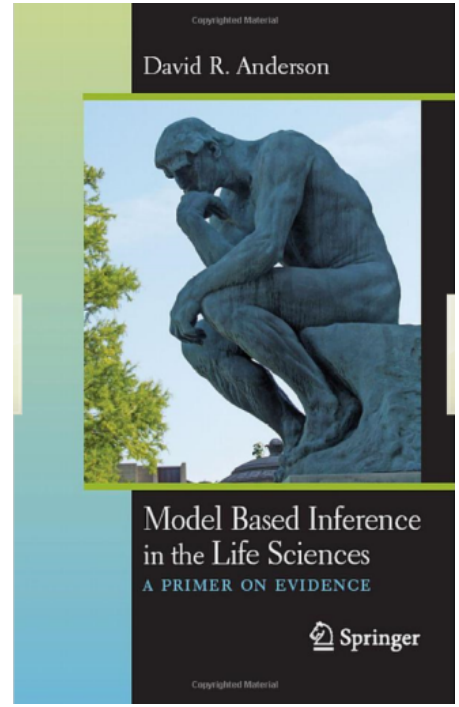
Research Context

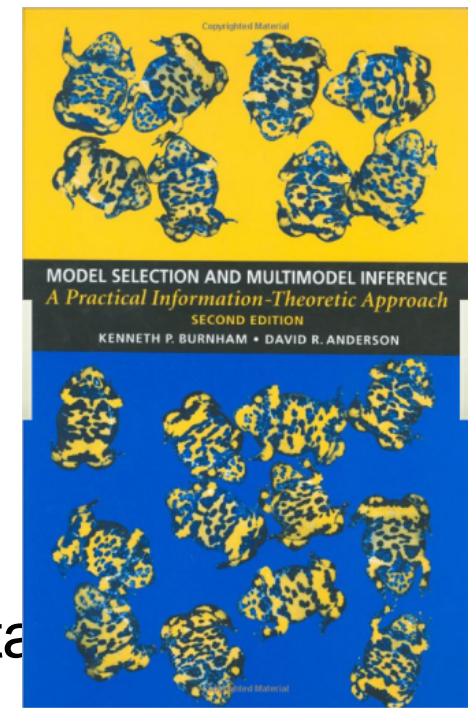
Exploratory
Confirmatory
Experimental

Becker et al. 2009
- *a priori* hypotheses
- Semi-exploratory
- Semi-confirmatory
- Still correlational

Current study
- Confirmatory
- Not experimental
- Not exploratory
- Confronting *a priori* hypotheses with data







Overview

Becker et al. MMS 2009

Potential negative inte

Data: 11 year

Input / comments from:

NRC

3 Anonymous

2 NOAA/WHOI/2 USC

Goodman

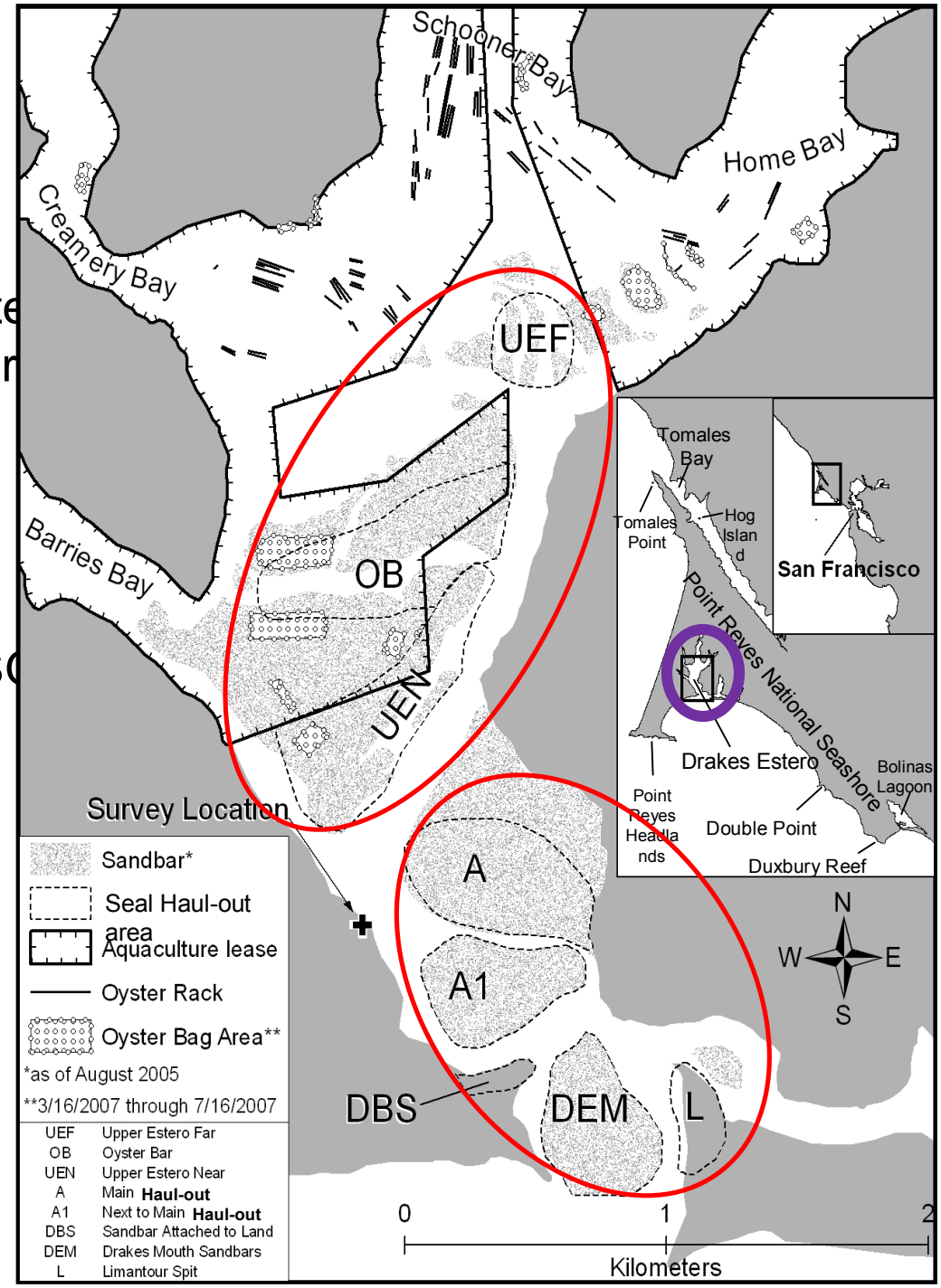
Current analysis

15-21 years

Subsite

Colony

Region



Subsite scale predictions

1)Isolated island sandbars which are buffered from predators and human disturbance should be more important for pupping. Measured by higher pup:adult ratios.

2)Short-term human-induced disturbance should not be related to a fewer seals using a subsite, since more seals could also lead to more opportunity for disturbance.

3)Interannual variation in disturbance should affect use of sandbars by females with pups (as measured by the pup:adult ratio)

Subsite Scale Data

Dependent variables

Subsite maximum count for year
Maximum pup:adult ratio of year

Explanatory variable

March-May of each year disturbance rate =
# of human related disturbances / number of surveys

Park visitors, kayaks (not after 1996), airplanes, mariculture activity, etc.)

Head alert, a flush or a flush of seals into the water

Daily (per survey) and hourly disturbance rate $r^2 = 0.99$

Subsite Scale Analysis

Annual maximum seal counts (or pup:adult ratio) ~ disturbance rate.

Within subsites and across all subsites between 1997 - 2009.

Counts were modeled as quasi-Poisson, and the ratio model as binomial.

Generalized linear mixed-effect models

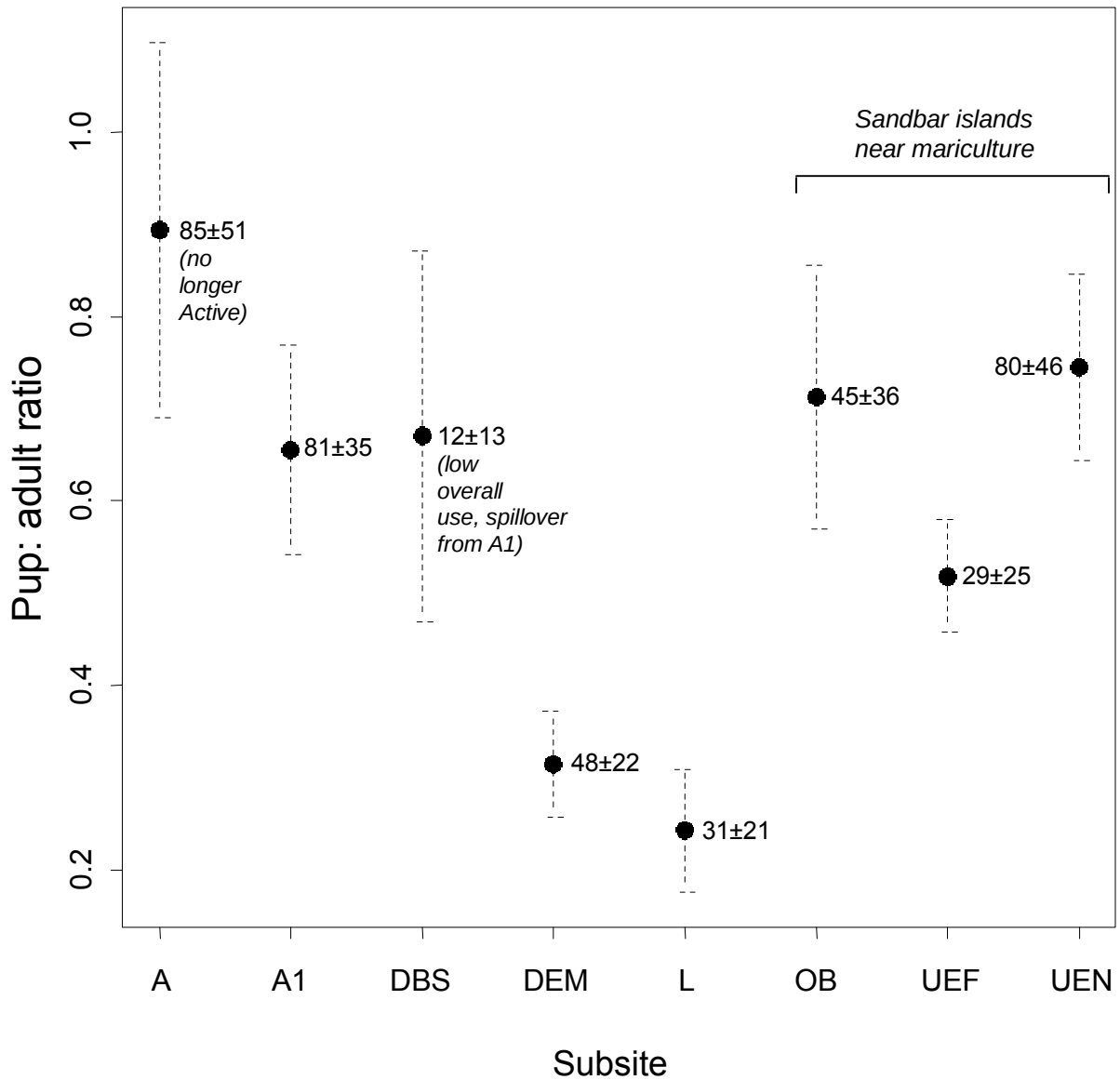
Random intercept, random intercept and slope, & null models

Compared with AIC and likelihood ratio tests

Checked to ensure randomly distributed residuals.

Pup:adult ratios during the peak breeding season at the 8 Drakes Estero subs

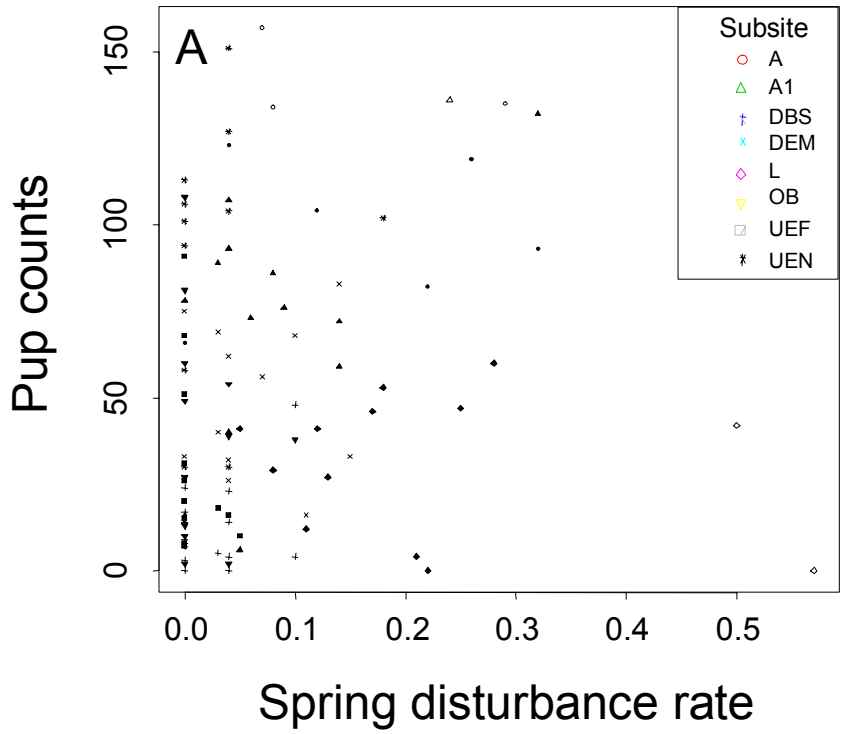
<u>Prediction</u>:
Isolated island sandbars should be more important for pupping

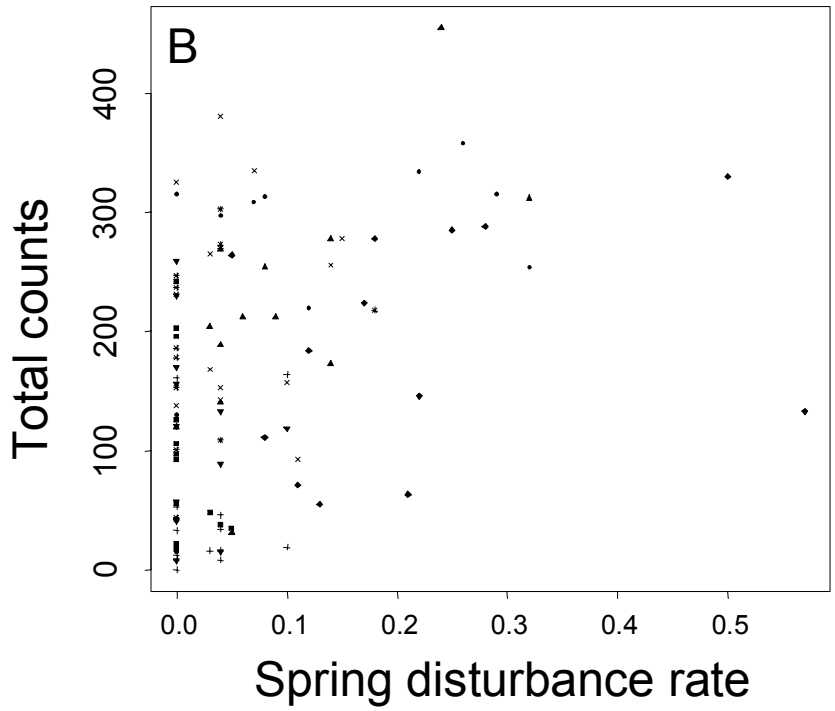


Subsite scale

Anthropogenic disturbance rate and subsite counts

<u>Prediction</u>: Short-term human-induced disturbance would not be related to a reduced number of seals using subsites in Drakes Estero, since more seals could also lead to more opportunity for disturbance.

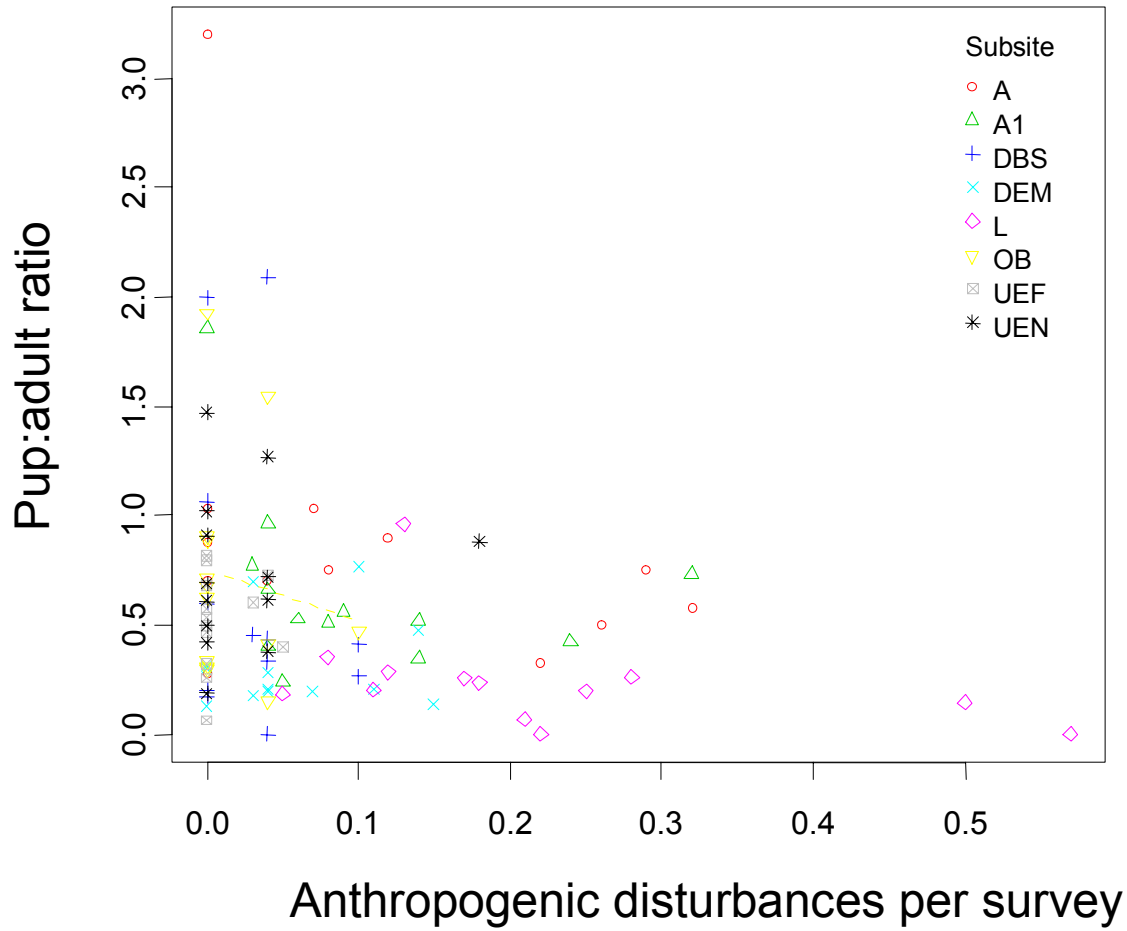




Subsite scale

Anthropogenic disturbance rate and subsite pup:adult ratios

<u>Prediction</u>: Interannual variation in disturbance should affect use of these island sandbars by females with pups (as measured by the pup:adult ratio)



Subsite scale

Colony Scale Predictions

Upper estero seal use ~

Regional population size
Mariculture activity (as measured by harvest level).
ENSO
Human disturbance rate

Oyster harvest (long-term) > overall human disturbance (short-term)

Despite the fact that documented disturbances by visitors are far more common than by those by mariculture activities (Becker et al. 2009, NPS Data).

NRC (2009) and NPS: Monitoring of disturbances not best for trends

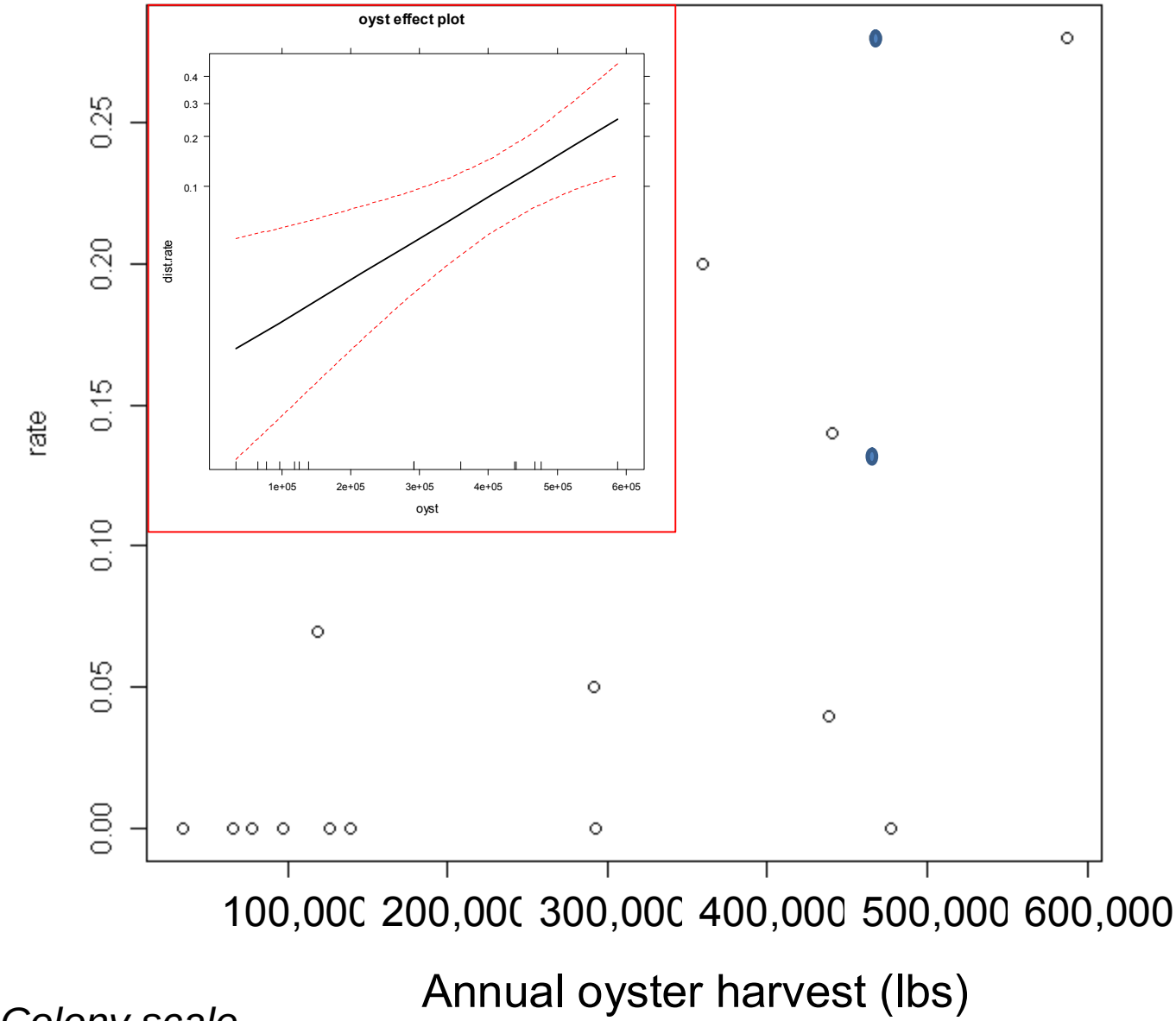
Many disturbances missed due to tide, timing; difficult to verify, etc.

but as an *Indicator of potential new disturbance issues (NPS Monitoring Plan).*

This study: Is it reasonable to model annual oyster harvest?

Colony scale

Mariculture related March–May disturbance rate per survey from 1982-1983 & 1996-2008. *By # subsites affected.*



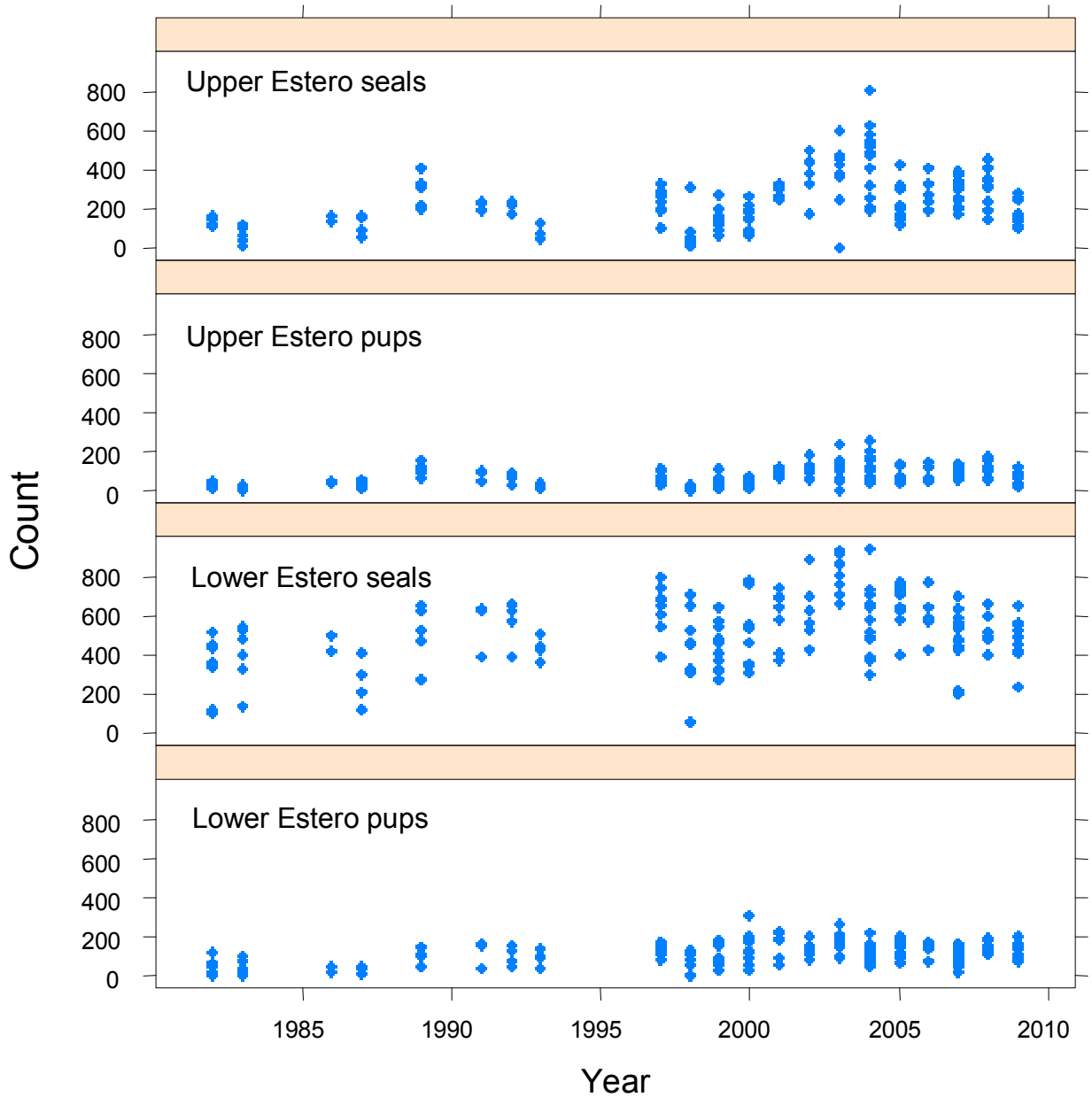
Binomial model
AIC = 46.9
AIC null = 79.0
r^2 = 0.53
P < 0.006 (quasi)

● *If omit disputed 2007*
AIC = 42.0
AIC null = 58.8
r^2 = 0.49
P < 0.01 (quasi)

This study: reasonable to model annual oyster harvest

Colony scale

Peak pupping season seal counts in Drakes Estero 1982 - 20



Colony scale

Analysis - Colony scale

Proportion of seals using the upper (near mariculture) versus lower (away from mariculture) estero ~

ENSO events
Oyster harvest level
Spring (March – May) pooled human disturbance rate (disturbances / # surveys)
Regional population size
Year (random effect)

All data for 15 years binomial GLMM (to rank models - AIC)
Then subset of data for 21 years binomial GEE – P values, LRTs

Improvements over Becker et al. (2009):

GEEs explicitly model the temporal autocorrelation, flexible distributions for the entire dataset and for the within year counts,

Binomial models of near and far from mariculture

Inclusion of spring (March – May) anthropogenic disturbance rates for the upper and lower estero

Include regional population size

Oyster harvest and ENSO best explain use of upper estero.

Disturbance rate possibly important for pups

Regional population size not important

Table 2a. Direct comparison of rounded delta AIC values from binomial GLMMs explaining the proportion of pups or total seals using the upper estero for the years 1982-83 and 1997-2009. "Oyst": high/low oyster value; "Oyster": continuous oyster value; "ENSO": El Nino; "up dist": spring upper estero disturbance rate; "lo dist": spring lower estero disturbance rate; "Regional pop"; annual maximum regional population size (total or pups respectively, less Drakes Estero). Models less than 4 AIC units from the best model are shaded grey.

	ΔAIC	
Model	**Pups**	**Total**
Oyst+ENSO	1	0
Oyster+ENSO	3	2
Oyst+ENSO+up dist	0*†	4
Oyst+ENSO+up dist+lo dist	1	6
ENSO+up dist	4	6
ENSO+up dist+lo dist	4	6
Regional pop	17	9
Regional pop+up dist	18	11
Regional pop+lo dist	17	11
Regional pop+up dist+lo dist	16	13
Oyst	20	18
Null	14	19
up dist+lo dist	17	19

*Pup model upper estero disturbance coefficient = -0.62 ± 0.35.

†Likelihood ratio test indicates that *Oyst+ENSO+up dist* is not a better fit than *Oyst+ENSO* alone (X^2 = 2.97, P < 0.08).

Colony scale

Colony Scale – Increase dataset to 21 years, GEE analysis.

Best models suggest -14 pups and -59 total seals in upper estero during higher oyster harvest years

Table 2b. Coefficients, proportional change, and effect size from binomial generalized estimating equation (GEE) for proportion of Drakes Estero Seals using the upper (OB, EUF + EUN) versus lower estero based on the 21 year time series. Effect size is proportion * mean Drakes Estero population size for time series and can be interpreted as the change from the long-term average number of seals. The mean of the maximum seal counts for 1982 - 2009 was 775 total and 180 for pups.

	Pups				**Total seals**			
Model	**Coefficient**	**Proportion**	**Effect size**	**P**	**Coefficient**	**Proportion**	**Effect size**	**P**
Intercept	-1.39 ± 0.34			< 0.001	-1.50 ± 0.25			< 0.001
log(ENSO + 1)	0.65 ± 0.20			< 0.001	0.52 ± 0.14			< 0.001
Oyster high/low	-0.41 ± 0.19	-0.08 ± 0.03	-14 ± 4	< 0.03	-0.44 ± 0.14	-0.08 ± 0.02	-59 ± 15	< 0.003

Colony scale

Regional Scale Predictions

1)ENSO effects on seal use of Drakes Estero as a whole, would be the same as for other colonies in the region

2) Regional population size expansion would only affect the *proportion* of regional seals using Drakes Estero if the estero had more good habitat than other colonies

3) Overall Drakes Estero human disturbance rates would not be related to overall seal use because disturbance rate should increase with population size

4) Relative use of Drakes Estero compared to other seal colonies would be influenced by

(a) Within site sandbar dynamics
(b) Nearby colony dynamics
(c) Mariculture activity would partially explain overall use of Drakes Estero in relation to other regional colonies. Especially if seals had reduced options for haul out areas due to factors (a) and (b).

Data

Maximum annual counts of pups and adults from the maximum total count day during the peak breeding season.

Pooled maximum counts (of pups and adults) at the other six colonies in the region

Regional Scale: Analysis

Drakes Estero compared to surrounding colonies

Year

Proportion of Drakes Estero seals using haul out subsite A

Maximum annual count of seals at nearest colony (Double Point)

Annual spring (March-May) human related disturbance rate (disturbances/survey) in Drakes Estero

Years since the last major ENSO (1982-83 and 1997-98)

Regional annual maximum count (less Drakes Estero)

Annual oyster harvest OR

Five-year and six-year periods of lowest oyster harvest (2000-2004 and 1999-2004)

Modeled pups and the total population was separately

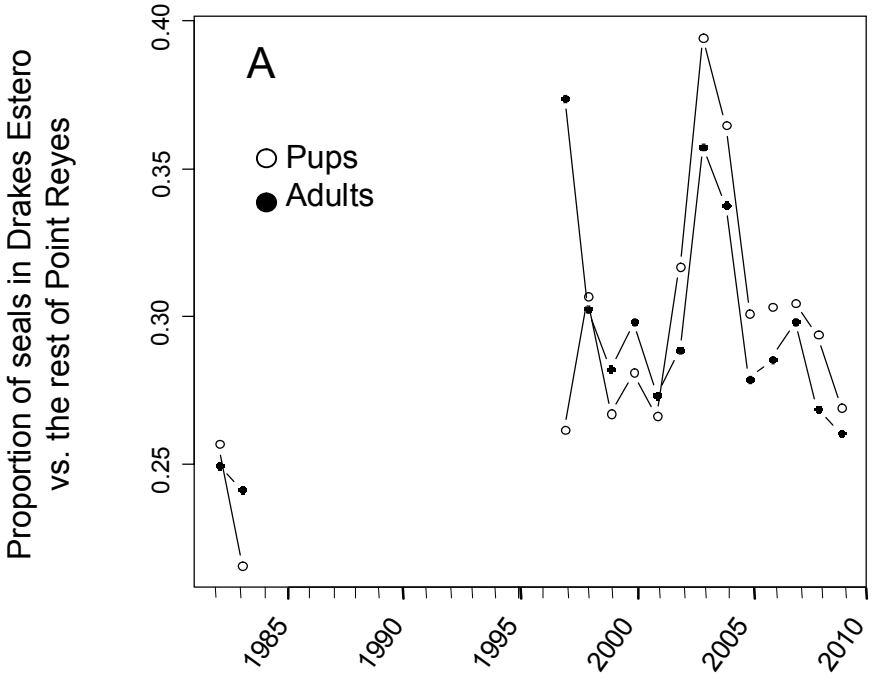
1) may be more sensitive to disturbance
2) seek out more isolated haul out sites.

Regional Analysis Continued

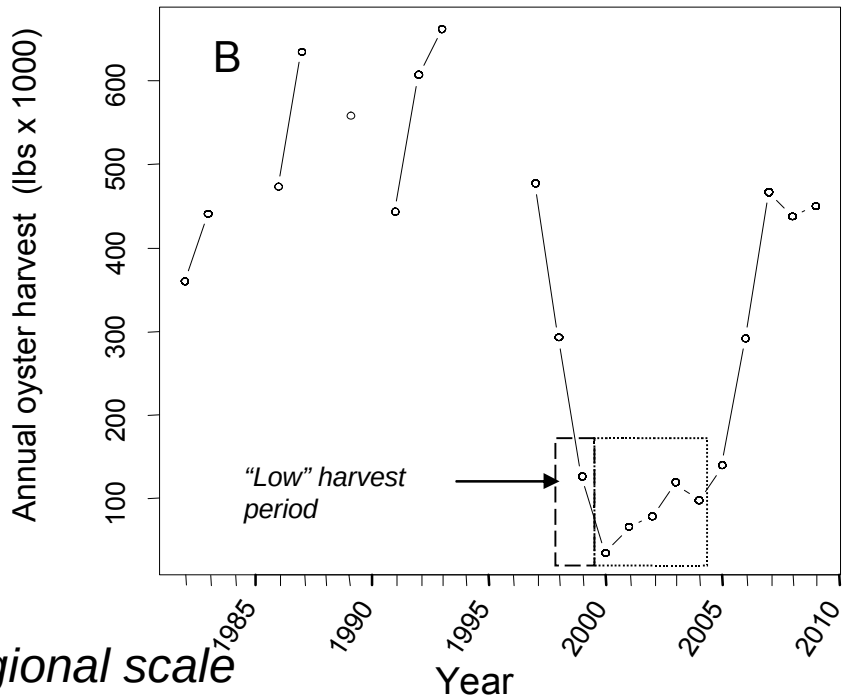
No correlated covariates in a single model (VIFs).
No interannual autocorrelation in the proportion of pups and total seals

Binomial generalized linear models (GLM)
Ranked by QAICc
Overdispersion adjusted
Bootstrapped SEs
Multimodel averaging (Multimodel inference)
Logit coefficients → proportions → * mean regional population size

Regional scale: proportion of seals using Drakes Estero



(A) proportion of Point Reyes region pup and adult harbor seals in Drakes Estero during the breeding/pupping season



(B) oyster harvest in Drakes Estero. Due to uncertainty in classification (Table 1), 1999 was modeled as both a "high" and "low" oyster harvest year. The 2009 oyster harvest is estimated based on 2007-2008 harvest.

Regional scale

Proportion of seals using Drakes Estero

Table 4. *A priori* models ranked by delta QAICc for the proportion of Point Reyes seal pups and total seals using Drakes Estero. Δi indicates QAICc distance from the best model and wi indicates model weight. Modeling oyster harvest as a continuous variable or low oyster during 1999-2004 gives similar results (see appendix). Models ranking within the lowest 4 QAICc units (in grey) were used for multimodel inference in table 5. Oyst: low oyster harvest from 2000-2004; DP: Double Point Counts; A: proportion of Drakes Estero seals using subsite A; Dist: anthropogenic disturbance rate.

Age class	Model	Δi	wi	r^2
Pup	Oyst + Double Point (DP)	0.0	0.35	0.51
	Oyst + DP + A	1.3	0.18	0.63
	Oyst + A	1.4	0.18	0.46
	Oyst + ENSO	2.6	0.09	0.42
	Oyst	3.3	0.06	0.26
	Year	5.0	0.03	0.20
	Oyst + Dist	5.6	0.02	0.32
	Oyst + DP + Dist + A	6.3	0.01	0.66
	DP + Year	6.4	0.01	0.29
	DP	7.3	0.01	0.12
	Null	7.7	0.01	0.00
	Regional pup count	10.3	0.00	0.02
Pup + Adult	Oyst + Double Point (DP)	0.0	0.55	0.54
	Oyst + DP + A	2.4	0.16	0.61
	Oyst + A	3.9	0.08	0.42
	Oyst	4.3	0.06	0.29
	Oyst + Dist	4.5	0.05	0.41
	Oyst + DP + Dist + A	6.1	0.02	0.67
	Oyst + ENSO	6.3	0.02	0.35
	Regional total count	7.9	0.01	0.19
	Year	8.5	0.01	0.17
	DP + Year	9.6	0.00	0.25
	DP	10.4	0.00	0.11

Oyster harvest and Double Point counts best explain use of Drakes Estero

"A" potentially important

"Oyst" alone a reasonable model

Regional population size and disturbance rate not important

Regional scale

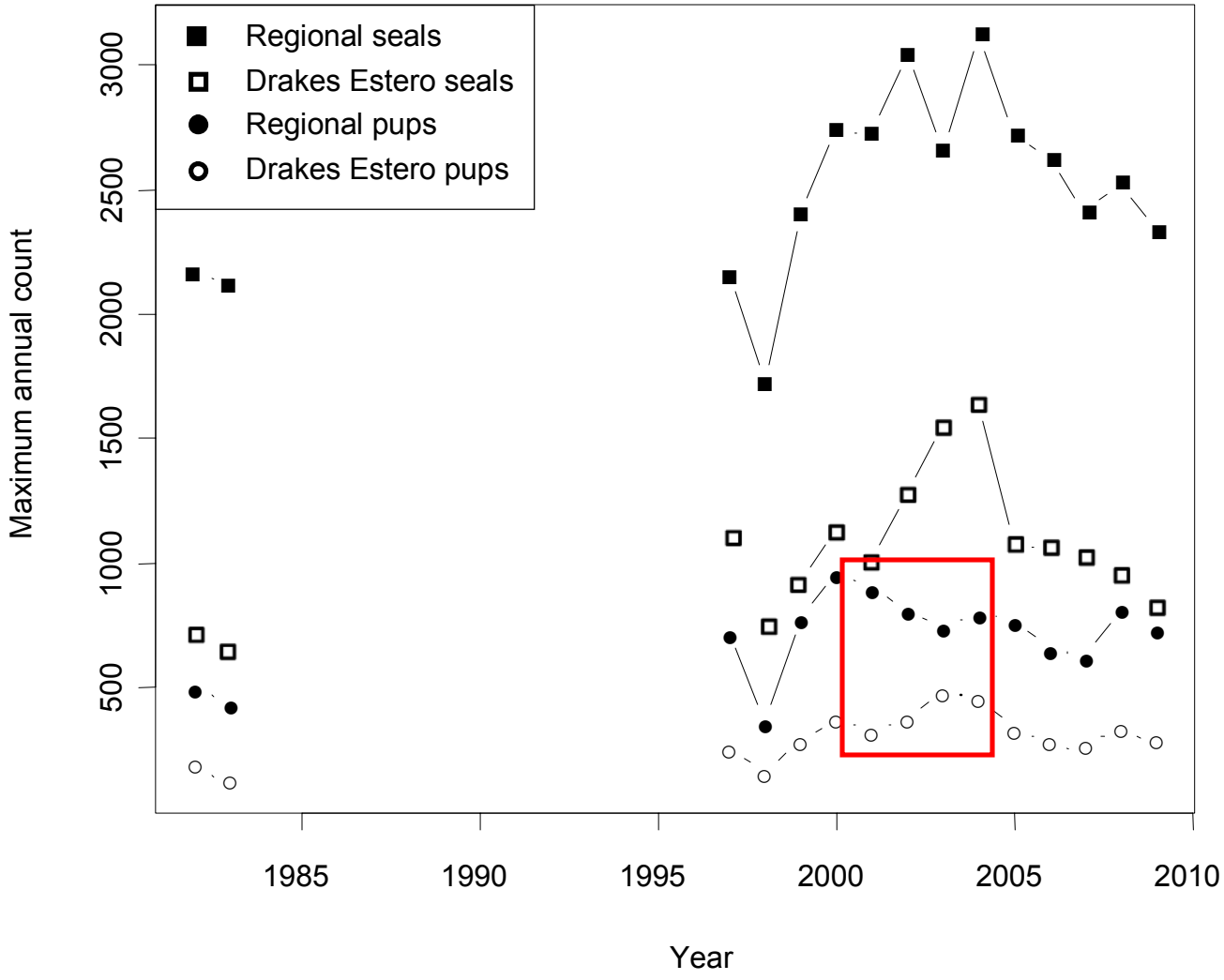
Table 5. Multimodel weighted coefficients of all models within 4 QAICc of the best model for pups and total seals in Drakes Estero (see table 4). Models represent an Akaike weight (wi) of 0.87 for both pups and total. Number in parentheses after the "low oyster" coefficients represent the bootstrapped standard error estimate of 2000 replicates. Proportional change represents change in use of Drakes Estero. Effect size is based on mean seal counts of all Point Reyes area colonies during the study period.

	Logit Coefficients		Proportional change		Effect Size	
Variable	**Pups**	**Total**	**Pups**	**Total**	**Pups**	**Total**
Intercept	-0.26 ± 0.19	-0.37 ± 0.16				
Low oyster (low/high)	-0.27 ± 0.08 (0.05)	-0.23 ± 0.07 (0.03)	-0.07 ± 0.02	-0.05 ± 0.02	-65 ± 18	-192 ± 58
Double Point (per 100 seals)	-0.04 ± 0.02	-0.04 ± 0.02	-0.010 ± 0.005	-0.010 ± 0.005	-10 ± 5	-36 ± 18
Subsite A (low to high)	-0.43 ± 0.22	-0.11 ± 0.07	-0.09 ± 0.05	-0.03 ± 0.02	-91 ± 51	-106 ± 71
Oyster (per 100,000 lbs)*	-0.06 ± 0.02	-0.08 ± 0.03	-0.019 ± 0.006	-0.020 ± 0.007	-19 ± 6	-71 ± 25

*not multimodel: from Oyster + Double Point count model.

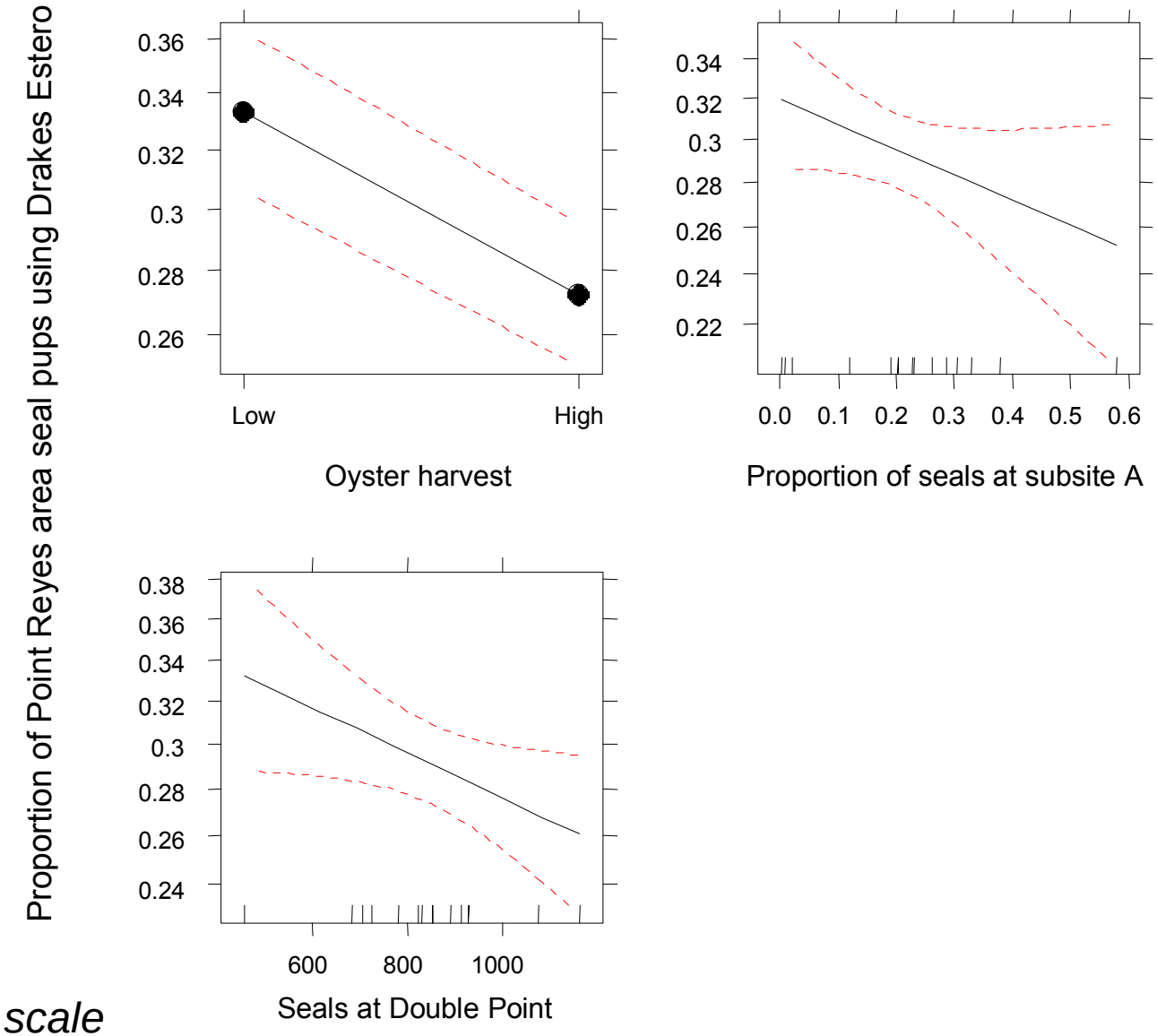
Regional scale

Drakes Estero and regional seal counts



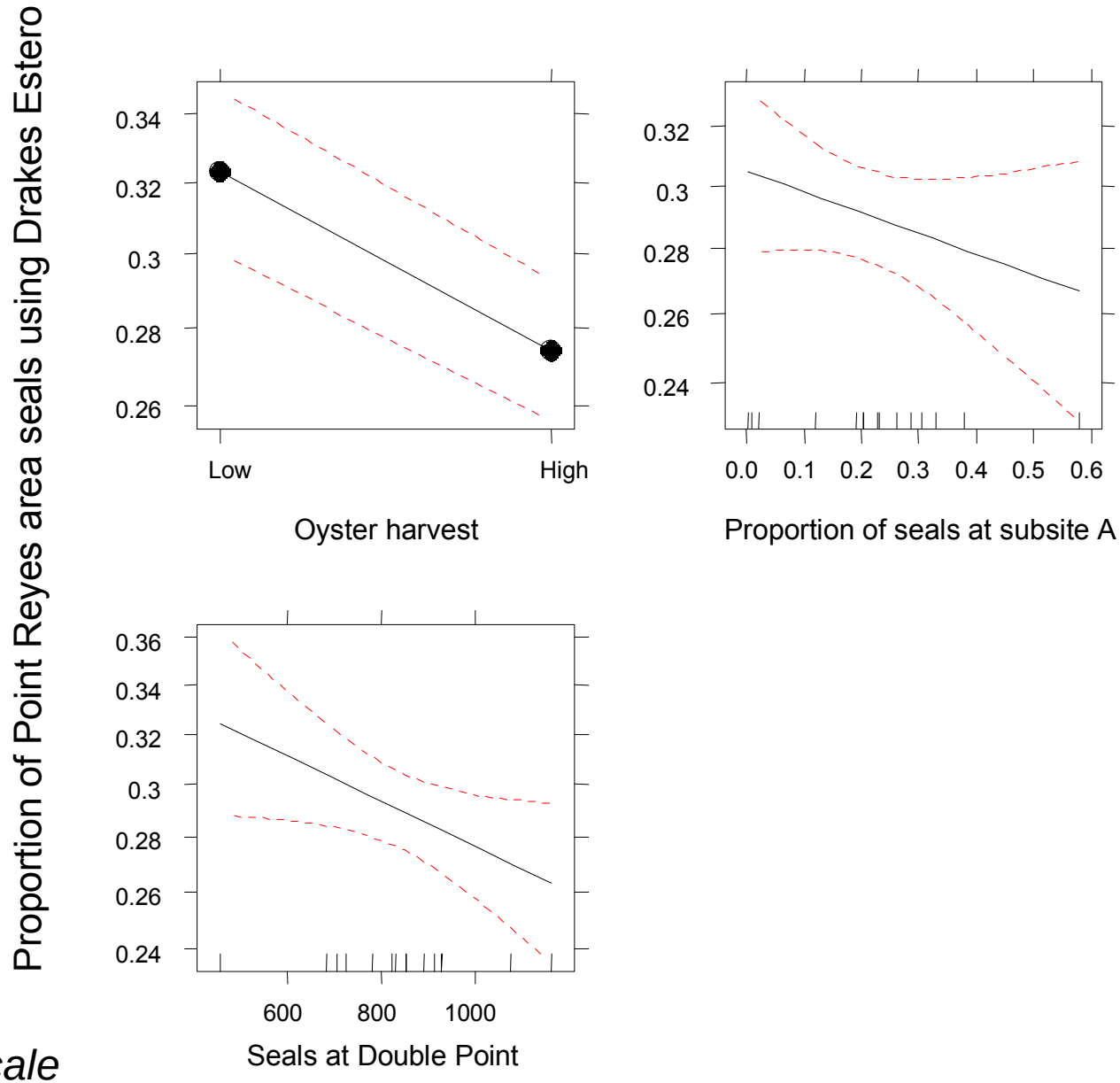
Regional scale

Effects plots from top model (pups)



Regional scale

Effects plots from top model (total seals)



Regional scale

Confirmatory Conclusions

1.Mothers with pups prefer isolated subsites.

2.Interannual variation in short-term anthropogenic disturbance does not affect counts or pup:adult ratio. Subsite preference set by background disturbance and isolation.

3.Proportion of seals using upper Drakes Estero explained by ENSO and Oyster harvest.

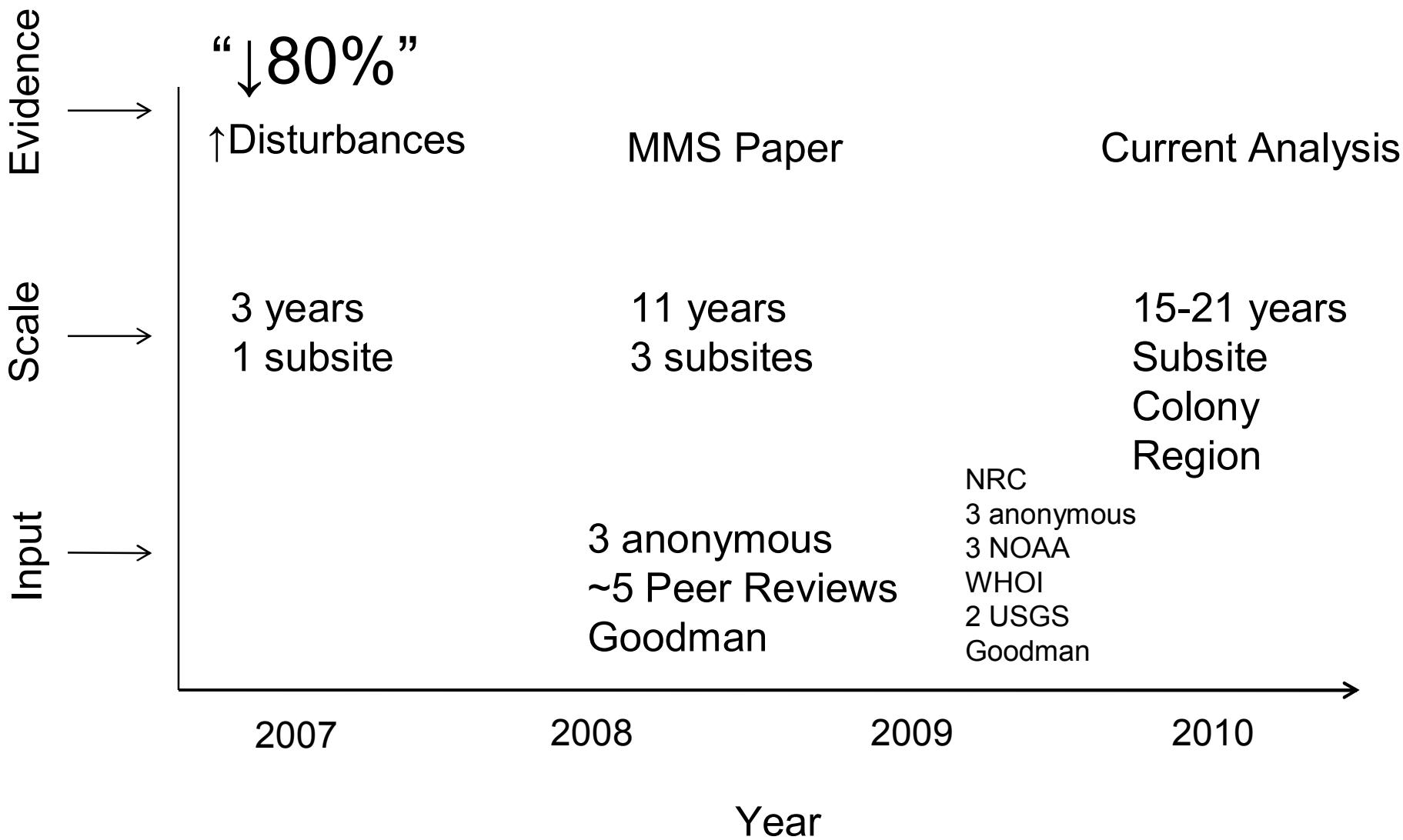
- *Not* explained well by regional population size or short-term disturbance.

4.Proportion of regional seals using Drakes Estero explained by additive affects of:

Nearby colony (Double Point)
Oyster harvest (continuous or categorical)
Important sandbar *(subsite A)?*

Not explained well by regional population size, short-term human disturbance, ENSO or year

Progression of evidence

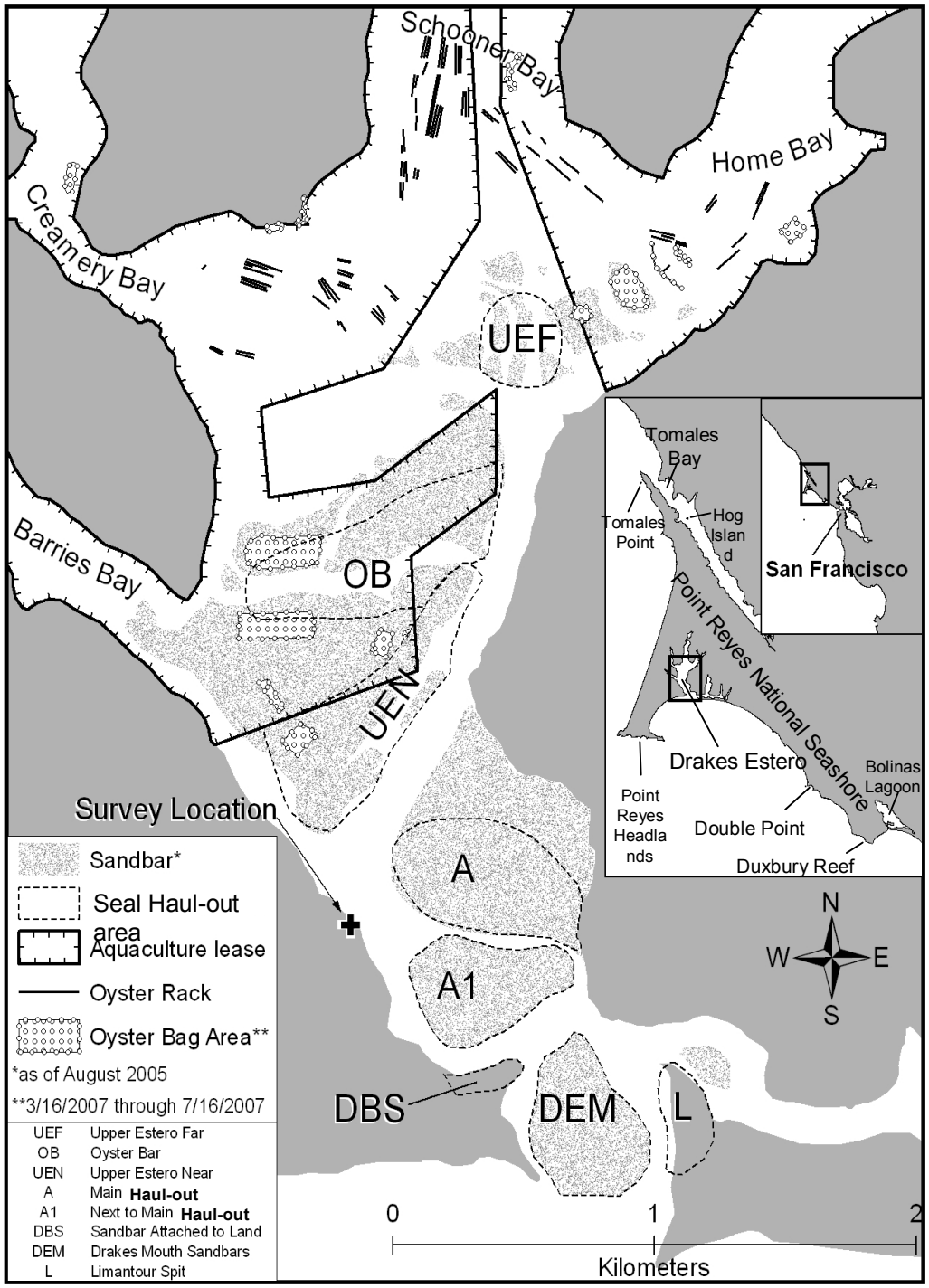


Acknowledgements

Pinniped Monitoring Volunteers and Staff

Many reviewers

NRC – Ocean Studies Board


Schooner Bay
Home Bay
Creamery Bay
Barries Bay
UEF
OB
UEN
A
A1
DBS
DEM
L
Survey Location
Sandbar*
Seal Haul-out area
Aquaculture lease
Oyster Rack
Oyster Bag Area**
*as of August 2005
**3/16/2007 through 7/16/2007
UEF Upper Estero Far
OB Oyster Bar
UEN Upper Estero Near
A Main Haul-out
A1 Next to Main Haul-out
DBS Sandbar Attached to Land
DEM Drakes Mouth Sandbars
L Limantour Spit
0
1
2
Kilometers
N
W
E
S
Tomales Bay
Tomales Point
Hog Island
San Francisco
Point Reyes National Seashore
Drakes Estero
Bolinas Lagoon
Point Reyes Headlands
Double Point
Duxbury Reef