FOIA 10 755 Miguel #8

CD "Harbor Seal Monitoring Data"; per Dave Press:

The enclosed CD contains harbor seal data collected within Point Reyes National Seashore (PORE) and Golden Gate National Recreation Area (GOGA) from 1996 through July 2009. As per your request (FOIA item #8), the enclosed CD includes all "supporting raw data" for "any and all documents for harbor seal population from 2006 to present in, on, and around Drakes Estero".

The data has been compiled from our current monitoring program, which falls under the direction of the San Francisco Area Network (SFAN) Inventory and Monitoring Program, but also includes incidental counts of harbor seals collected during northern elephant seal surveys and data that precedes our current monitoring program.

Each of the databases is provided in Microsoft Access 2003 format. The databases contain complete definitions of all tables and data fields, which can be viewed in the Relationships window.

Two additional files representing Drakes Estero harbor seal data from 1982-1993 have been made available in Microsoft Excel.

In accordance with Executive Order 12906, these data files have been provided with metadata records following the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM). We suggest that you thoroughly review the provided metadata records and understand the content of these data files (1.2.1 Abstract), the use constraints of the data files (1.8 Use Constraints, 2.1.1 Attribute Accuracy Report), and the statement of liability assumed by the National Park Service (6.3 Distribution Liability).

The metadata files have been provided in standard XML format, which require a metadata reader for proper viewing. As a courtesy, we have also provided the metadata files in TXT format, which can be read using a variety of text readers, including Microsoft Word, Notepad, and WordPad.

The databases provided on the enclosed CD are:

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**SFAN_PHOCA_2000_2009**

Harbor Seal Monitoring, San Francisco Area Network, March 2000 – July 2009. Maximum counts per survey for all locations. Additional data include the sources of disturbance to harbor seals and associated harbor seal responses.

**PORE_PHOCA_SUBSITE_2008_2009**

Harbor Seal Monitoring, Point Reyes National Seashore, August 2007 – July 2009. All subsite counts per survey for all monitoring locations. Additional data include the sources of disturbance to harbor seals and associated harbor seal responses.

**GOGA_PHOCA_2000_2009**

Harbor Seal Monitoring, Golden Gate National Recreation Area, April 2000 – July 2009. All subsite counts per survey for Point Bonita. Additional data include the sources of disturbance to harbor seals and associated harbor seal responses.

**PORE_PHOCA_DE_SUBSITE_1997_2007**

Harbor Seal Monitoring, Point Reyes National Seashore, Drakes Estero Subsite Data, March 1997 – July 2007. Maximum counts per survey of Drakes Estero reported according to subsite. Additional data include the sources of disturbance to harbor seals and associated harbor seal responses.

**PORE_PHOCA_1996_1999**

Harbor Seal Monitoring, Point Reyes National Seashore, March 1996 – August 1999. Maximum counts per survey for all locations, reported according to subsite for some surveys. Additional data include the sources of disturbance to harbor seals and associated harbor seal responses.

**PORE_PHOCA_PRH_1997_2009**

Incidental Harbor Seal Counts, Point Reyes Headlands, Point Reyes National Seashore, October 1997 – July 2009. Incidental harbor seal counts from pinniped surveys at Point Reyes Headlands. Additional data include the sources of disturbance to harbor seals and associated harbor seal responses.

**PORE_PHOCA_DE_1982_1993**

Harbor Seal Monitoring Count Data, Drakes Estero, Point Reyes National Seashore, 1982-1993. Maximum counts per survey of Drakes Estero reported according to subsite.

**PORE_PHOCA_DE_DISTURBANCES_1982_1983**

Harbor Seal Monitoring Disturbance Data, Drakes Estero, Point Reyes National Seashore, 1982-1983. Harbor seal disturbances observed in Drakes Estero.

02/10/10 Email from Dave Graber to Tim Ragen, George Turnbull, et al w/"Drakes Estero Seal Report 020610"

06/23/09 Document entitled "Inclusion of 2008 harbor seal data into the analysis presented in Becker et al 2009", Ben Becker, Dave Press and Sarah Allen

National Park Service "SFAN I&M Program Harbor Seal Monitoring", David Press, Ecologist/Data Manager

"Harbor seals and their use of Drakes Estero", Sarah Allen, Science Advisor, Point Reyes NS, was presented to the Marine Mammal Commission at a public meeting on February 20, 2010, and was posted to the MMC website a few weeks later.

"Modeling the effects of El Nino....Drakes Estero...1997-2007", Ben Becker, Dave Press and Sarah Allen

**Don Neubacher/PORE/NPS**
02/10/2010 01:47 PM

To Ann Nelson/PORE/NPS@NPS
cc
bcc
Subject Spatial use of Drakes Estero by harbor seals, 1982-2009

For files

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Don Neubacher
Superintendent
Point Reyes National Seashore
Point Reyes Station, CA 94956

415-464-5101 (office)
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The National Park Service cares for special places saved by the American people so that all may experience our heritage.

----- Forwarded by Don Neubacher/PORE/NPS on 02/10/2010 01:47 PM -----

**David Graber/SEKI/NPS**
02/06/2010 12:31 PM

To tragen@mmc.gov
cc "Gordon Bennett" <gbatmuirb@aol.com>, "Neal Desai" <ndesai@NPCA.ORG>, "Cassidy Teufel" <cteufel@coastal.ca.gov>, "Kirsten Ramey" <KRamey@dfg.ca.gov>, sroberts@nas.edu, George Turnbull/OAKLAND/NPS@NPS, John Dennis/WASO/NPS@NPS
Subject Spatial use of Drakes Estero by harbor seals, 1982-2009

Dear Tim:

The scientific staff at Point Reyes National Seashore have assembled, for the use of the Marine Mammal Commission and any other interested parties, a peer-reviewed report of seal activities encompassing all available data. This report will be made available on the park public web site, and you are free to distribute as you wish. Please see my cover letter by way of explication.

Sincerely,
Dave Graber

Drakes Estero Seal Report 02-06-2010.pdf DMG Cover letter 10-02-06.pdf

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**David M. Graber, Ph.D.**
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# United States Department of the Interior

NATIONAL PARK SERVICE
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February 6, 2010

Dr. Tim Ragan
Executive Director
Marine Mammal Commission
4340 East-West Highway, Suite 700
Bethesda, Maryland 20814

Dear Dr. Ragen:

We are providing a report entitled *"Spatial use of Drakes Estero, California, by harbor seals correlated to anthropogenic disturbance and natural variation during 1982-2009"* by B. H. Becker, D. T. Press, and S. G. Allen for your panel to include in their review of the effects of human activities on harbor seals in Drakes Estero. The report addresses many of the questions and analysis recommendations that the National Academy Panel raised in its 2009 report (NRC 2009). The NRC reported that the National Park Service (NPS) pinniped monitoring program provides "as yet untapped potential for assessing trends in the abundance of harbor seals in Drakes Estero in relation to wider regional trends" (NRC 2009, p. 84). Based on the NRC's suggestions, the authors have expanded the Becker et al. (2009) analysis of seal use within Drakes Estero in response to mariculture by 1) adding ten additional years of data between 1982 and 2009, 2) improving the statistical methods, and 3) testing multiple factors (anthropogenic disturbance, regional scale population size, etc.) that may be related to seal use at three spatial scales. These scales ranged from *subsite* level seal counts and pup:adult ratios, to the *colony* level for distribution of seals within all of Drakes Estero, to the *regional* level comparing seal counts in Drakes Estero to the other surrounding colonies at the Point Reyes Peninsula.

The highlights of the results include:

1. The patterns found were consistent with the findings in the earlier Becker *et al.* (2009) paper.
2. They found no detectable relationship between human disturbance rate and the number of seals or pup:adult ratios at haul-out sites within Drakes Estero, suggesting that short-term human disturbance did not have a significant effect on spatial use.
3. Within Drakes Estero, the proportion of seals (total seals and pups only) hauled out near mariculture activities was lower during years of higher oyster harvest ($-0.08 \pm 0.02$, ~ 59 seals). Regional population size was not a good predictor of seal use of the upper estero subsites near mariculture.
4. At the regional scale, oyster harvest, the counts at a nearby colony (Double Point), and the gradual loss of a major haul out site (subsite A) within Drakes Estero best explained pup and total seal use of Drakes Estero. Regional population size, short-term anthropogenic disturbance rate, and other factors were not important in explaining overall seal use of Drakes Estero compared to other colonies.

5. The proportion of regional area seals using Drakes Estero declined by -0.07 ± 0.02 for pups (-65 ± 18 total pups), and -0.05 ± 0.02 for total counts (-192 ± 58 total seals) during higher oyster harvest years.
6. The authors suggest how naturally fluctuating seal haul out availability may interact with mariculture activities to affect the proportion of regional Point Reyes area harbor seals (particularly pups) using high quality (isolated) subsites within upper Drakes Estero and Drakes Estero as a whole.

In addition to addressing the NRC's recommendations, this paper incorporates methodological and statistical suggestions from A. Solow (WHOI Statistician who advised the NRC on the analysis of seal-mariculture interactions in Drakes Estero), J. Laake (NOAA-National Marine Mammal Lab), and two anonymous reviewers. The report also benefitted greatly from comments by T. Gerrodette (NOAA) and G. Fellers (USGS), and a comprehensive statistical review by B. Halstead (USGS Statistician/Ecologist). The paper has undergone the draft NPS peer review protocols for scientific products.

We look forward to discussing these results and the underlying methodologies when the panel convenes at Point Reyes. These analyses and conclusions represent the work of the authors and do not represent an official policy or position of the National Park Service.

Sincerely,

David Graber, Ph.D.
Chief Scientist
Pacific West Region
National Park Service

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

Benjamin H. Becker[1], David T. Press, and Sarah G. Allen

Point Reyes National Seashore

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**Abstract**

Long-lived, slowly reproducing K-selected species maximize their long-term survival and are predicted to respond to anthropogenic disturbances by moving away or remaining vigilant rather than habituating. Thus, spatial buffers in breeding areas may provide some resilience for populations facing disturbance as well as climate change, urbanization, and other anthropogenic and natural impacts. To better understand pinniped vulnerability to anthropogenic disturbance and displacement effects in a National Park, we used data collected between 1982 – 2009 to explore potential mechanisms which may affect the proportion of Point Reyes (California) harbor seals (*Phoca vitulina*) selecting haul-out sites within a large colony (Drakes Estero), and utilization of that colony in relation to other nearby colonies. Isolated sandbars had higher pup:adult ratios, indicating they are generally more important for pupping. There was no detectable relationship between human-related disturbance rate and the number of seals or pup:adult ratios at specific haul-out sites within Drakes Estero, suggesting that short-term human disturbance did not have a significant effect on spatial use, but rather that spatial use is

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determined by general sandbar isolation. However, within Drakes Estero, after removing effects of El Niño, the proportion of seals (total seals and pups only) hauled out near mariculture activities (a longer-term disturbance) was lower during years of higher oyster harvest (-0.08 ± 0.02, ~ 59 seals). Compared to oyster harvest, regional population size did poorly in explaining total seals or pups in the upper estero. Binomial generalized linear models ranked by quasi-AICc indicated that oyster harvest, seal counts at a nearby colony, and loss of a major haul out site within Drakes Estero, best explained pup and total seal use of Drakes Estero. Regional population size, short-term human disturbance rate, and other factors were not important in explaining overall seal use of Drakes Estero. Concurrent with higher oyster harvest and after removing effects of other covariates, the proportion of Point Reyes regional seals using Drakes Estero declined by -0.07 ± 0.02 for seal pups (-65 ± 18 total pups), and -0.05 ± 0.02 for total counts (-192 ± 58 total seals). This study, while correlational, supports the prediction that chronic human disturbance (as measured by mariculture activities) coupled with natural processes, affects seal haul out patterns at both the colony and regional scales.

**Key Words**

Phoca vitulina, *mariculture, disturbance, harbor seal, resilience, generalized estimating equations.*

## Introduction

A variety of factors may influence habitat availability for breeding and molting pinnipeds, including coastal development (Seuront and Prinzivalli 2005), human encroachment and disturbance (Yochem et al. 1987, Gerrodette and Gilmartin 1990, Suryan and Harvey 1999, Thompson et al. 2001), predation (Nordstrom 2002), climate change (Freitasa et al. 2008), and natural variation in habitat suitability. Moreover, since longer lived, slowly reproducing K-selected species maximize their long-term survival, they tend to respond to anthropogenic disturbances by increasing heart rates and energetic costs. Thus, we expect seals to move away from, or remain vigilant to, disturbance sources rather than habituate as some smaller, quickly reproducing species do (Bisson *et al.* 2008). This might be particularly evident for females with pups which should be more risk averse than adult males. Further, Frid and Dill (2002) found that chronic, long-term disturbance stimuli resulted in habitat shifts and subsequently reduced access to resources in all of the fourteen bird and mammal studies they reviewed. In marine mammals, bottlenose dolphin (*Tursiops* sp.) declined in relative abundance due to long-term disturbance, primarily from tour boat vessels (Bejder *et al.* 2006). Similarly, Hawaiian monk seal (*Monachus schauinslandi*) pup survival was lower when seals were displaced to suboptimal habitats (Gerrodette and Gilmartin 1990). In the few disturbance studies where alternative habitat was not available, disturbed animals did not move, but may have sustained higher stress levels and reduced reproductive success (manatees: Buckingham *et al.* 1999, diving ducks: Knapton *et al.* 2000).

Wursig and Gailey (2002) stated that there is a "need to consider potential loss of feeding and breeding habitat from shellfish and finfish farms, particularly given predicted

increases in these facilities in nearshore environments." Negative impacts of aquaculture also have been found in ranging bottlenose dolphins (Watson-Capps and Mann 2005). Similarly, several questions are generated by recent findings that oyster harvest activities may have "potential negative interactions" with harbor seal use (*Phoca vitulina*) at two sites near mariculture operations in Drakes Estero, California (NRC 2009, Becker et al. 2009) and it is "likely that visits to these areas by oyster farm workers (within 500 m of seals) can be expected to lead to short-term disturbance of any seals using these haul-out areas at the time" (NRC, P. 49). First, are these potential negative interactions detected with additional years of monitoring data? Second, are females and pups sensitive to negative interactions? Third, is there a difference in the impact of typically short-term park visitor disturbance versus potentially longer-term activities that place and service mariculture structures on and adjacent to the sandbars where seals haul out? Last, could any spatial effects on seal use cascade up from the subsites near the oyster operations to throughout the entire estuary's breeding and pupping season population and to surrounding areas?

It is likely that proximate impacts of oyster harvest activities (or other disturbances) disturb seals and potentially cause them to move away from the subsites in Drakes Estero and elsewhere (NRC 2009, Becker et al., 2009, Allen and Huber 1984a, Montgomery et al. 2007). This would reduce available habitat for hauled out seals on either short or long time scales, depending on the length and frequency of the disturbance / displacement (Gill 2007). Affected seals might choose to haul out nearby, or leave the Estero for other areas. If the seals simply moved to other areas within the Estero, the proportion of the population using Drakes Estero compared to the rest of Point Reyes

would not change. Conversely, if there were some competition for space or reduced use of other naturally or anthropogenically deteriorated haul-outs by females with pups, it could cause crowding on limited sand bar sites, and lead to a cascading population level effect causing some seals to not use the estuary (Gill 2007).

The National Research Council (NRC) reported that the National Park Service (NPS) pinniped monitoring program provides "as yet untapped potential for assessing trends in the abundance of harbor seals in Drakes Estero in relation to wider regional trends" (NRC 2009, p. 84). Based on the NRC's suggestions, we expanded the Becker et al. (2009) analysis of seal use within Drakes Estero in response to mariculture by 1) adding ten additional years of data for a total of 21 years of survey between 1982 and 2009, 2) improving the statistical methods, and 3) testing multiple factors at three spatial scales that may be related to seal use (for total seals and pups). The scales ranged from a) *subsite* level seal counts and pup:adult ratios (13 years of data: 1997 - 2009), to b) *colony* level for distribution of seals within all of Drakes Estero (21 years of available data during 1982 – 2009), to c) the *regional* level comparing seal counts in Drakes Estero to the other surrounding colonies at the Point Reyes Peninsula (15 years of data during 1982 – 2009) (Fig. 1). This last regional effect would be somewhat surprising, since mariculture chiefly occurs in a limited area in the upper sandbars of Drakes Estero. However, cascading spatial effects in ecology are possible (Elkin and Possingham 2008) and reduced seal use of individual subsites where breeding/pupping occurs could lead to overall reduced use of the estero, and increased migration to other less disturbed colonies if available. Furthermore, the upper intertidal sandbars that are isolated from the mainland (and therefore from park visitors and predators) have historically had more

females and pups than the sandbars attached to the mainland near the mouth of the estero (Allen Miller 1988). We made several predictions that scaled from *subsite* to *intra-colony* to *regional* scales (Fig. 1).

*Subsite scale* - We predicted that 1) isolated island sandbars in Drakes Estero which are buffered from predators (Nordstrom 2002) and human disturbance should be more important for pupping (as measured by higher pup:adult ratios); 2) disturbance should reduce use of these island sandbars by females with pups (as measured by the pup:adult ratio); and 3) 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.

*Intra-colony scale* – We predicted that 1) changes in regional population size should be manifested in increased or decreased use of the upper estero due to density-dependence, and 2) increased mariculture activity (as measured by harvest level) would shift seal use away to other haul-outs. The second prediction is based on the assumption that oyster harvest should explain seal distribution better than overall human disturbance since the former is more likely to consist of long-term and persistent events (placement and tending equipment, long-term presence of equipment (NRC 2009, Fig. 1), while the latter is typically of brief duration by hikers and park visitors. We predicted this despite the fact that documented disturbances by visitors are far more common than by those by mariculture activities (Becker et al. 2009, NPS Data).

*Regional scale* - We predicted that 1) the effects of El Niño - Southern Oscillation (ENSO) 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 would increase with population size and human disturbances are typically of short duration; and 4) relative use of Drakes Estero compared to other seal colonies would be influenced by (a) within site sandbar dynamics (e.g., natural loss of a major pupping subsite), (b) nearby colony dynamics (disturbance at a nearby colony that could move more seals to Drakes Estero), and (c) mariculture activity that would partially explain overall use of Drakes Estero in relation to other regional colonies. The latter could occur if seals were displaced locally by mariculture activity, but had reduced options for haul out areas due to factors (a) and (b).

## Methods

### Study Area

The Point Reyes peninsula is along the north-central California Coast (38°30'N to 37°30'N). The peninsula is located within the Point Reyes National Seashore, a unit of the National Park Service (NPS). The topographic diversity of the peninsula provides a broad range of substrates for harbor seals to haul out of the water. These include tidal mud flats, offshore and onshore rocky tidal ledges, and sandy beaches. A "haul-out site" is defined as a terrestrial location where seals aggregate for periods of rest, birthing, and suckling of

young (Harvey 1987). A colony may be a collection of haul-out sites within a limited geographic area. Drakes Estero and Estero de Limantour encompass a complex of eight subsites where seals haul out (Fig. 1), which are referred to collectively as the Drakes Estero/Limantour colony. Seals used the subsites at various times of the year depending upon their reproductive status, molting condition, and the level of disturbance encountered (Allen Miller 1988). Within a day, seals shifted to adjacent sandbars when crowding occurred or when the tide rose limiting the amount of haul out space. At rising tides, seals also floated over submerged sandbars until the sand bars reemerged with receding tides.

All subsites were used during the breeding and molt seasons, and some were used regularly year-round. Females with pups disproportionately used the sand bars exposed at low tide in the upper and middle portions of the Estero that are isolated from the mainland, and consequently from humans and predators. Limantour Spit was mostly used by non-breeding seals during the breeding season (Allen Miller 1988). Subsites in the lower estero, which are generally closer or attached to the mainland, have historically suffered higher annual human disturbance rates during the breeding season when compared to the isolated island sandbars of the upper estero (Becker et al. 2009).

Human access to the seal haul-out sites within Drakes Estero was limited because it is part of a national park and a congressionally designated wilderness area. During the breeding season (1 March--1 July), no motorized boats were allowed within the Estero except for those from a commercial mariculture operation. Non-motorized boats, primarily Kayaks, were allowed until 1996, but thereafter were excluded during the breeding season to avoid seal disturbance. Research and rescue boats may enter the estero

in rare instances. Three of the subsites where seals haul out are proximate to the commercial mariculture operation (OB, UEN and UEF). Subsite OB was within the mariculture lease but was not used much for culture in the recent past (~1999-2004), portions of subsite UEN were within or adjacent to the lease, and subsite UEF was in a navigational channel that bisects a gap in the mariculture lease where mariculture boats traversed Drakes Estero (Fig. 1). The mariculture operation raised oysters and the California Department of Fish and Game (CDFG) produced an annual report on oyster harvest production. No annual report or data is available on manila clams produced (Kirsten Ramey, CDFG, E-mail: Jan. 14, 2010).

*Datasets*

*Disturbance data* - Survey methods are described in Becker et al. (2009). Disturbance rate was derived from the number of human related disturbances (park visitors, kayaks, airplanes, mariculture activity, etc.) that resulted in a head alert, a flush or a flush of seals into the water during March-May of each year, divided by the number of surveys conducted during that time period. Surveys were typically of similar duration throughout the study period (~2 hr), except for three longer surveys (5-9 hrs) during 1982-83. We also compared (with Spearman tests) daily and hourly disturbance rate between the years 1982 – 2009 (15 years surveyed) to ensure that variation in survey length during 1982-83 did not affect realized disturbance rate.

*Intra-colony data* - When assessing *intra-colony* variation in use (rather than population size), we used the daily counts (converted to binomial proportions when modeled) at each

subsite for all surveys during the peak breeding season (April 15 – May 15 of each year). For data from 1997 – 2009, QA/QC was identical to that used in Becker et al. (2009). We augmented the NPS seal count database with additional subsite data from 1) the years 1982 - 1983, 1986 – 1987, 1989, and 1991 - 1993 derived from field notes of SGA which were reviewed twice before transcribing the data to spreadsheets for analysis, and 2) annual maximum breeding season pup and adult colony counts derived from tables in Allen and Huber (1984a, 1984b), for a total of 21 years between 1982 and 2009. Oyster harvest data was obtained from the California Department of Fish and Game (1982 – 2006), the National Research Council (2007 – 2008), and was roughly estimated as 204,000 kg (450,000 lbs) for 2009[2], based on recent harvest values for 2007-2008.

*Regional data* - We used the maximum counts of pups and adults from the maximum total count of the day during the peak breeding season. Values for Drakes Estero were compared (again, in a binomial proportion) with pooled maximum counts (of pups and adults) at the other six colonies in the region (Tomales Bay, Tomales Point, Point Reyes Headlands (only one count per survey day at this site), Double Point, Bolinas Lagoon, and Duxbury Reef) (Fig. 1).

*Analyses*

*Subsite scale: Subsite counts and pup:adult ratios related to disturbance rate* - Linear mixed-effect models (the "lmer" function in R) were used with subsite as a random effect to test if spring anthropogenic (March – May) disturbance rate (explanatory variable) was

[2] Actual harvest values are determined from tax records and the 2009 harvest should be available in mid-2010 (Pers. Comm., Tom Moore, Cal. Dept. of Fish & Game).

related to annual maximum seal counts, maximum pup counts, and pup:adult ratios (response variables) within subsites and across all subsites between 1997 - 2009. Some upper estero subsites (OB, UEN, UEF) were occasionally pooled in the 1982-1993 field note data, so we therefore did not use those years for this within subsite analysis. However, this pooling did not affect data when pooling the total upper estero versus lower estero seals when analyzed at the colony scale (next section). The counts were modeled as quasi-Poisson, and the ratio model as binomial. Random intercept, random intercept and slope, and null models were compared with AIC and likelihood ratio tests, and were checked to ensure randomly distributed residuals.

*Colony scale: shifts in haul-out (subsite) use in Drakes Estero related to mariculture, ENSO, disturbance rate, and regional population size* - These models were designed to test if variation in the proportion of seals using the upper (near mariculture) versus lower (away from mariculture) estero were related to ENSO events, oyster harvest level, the spring (March – May) pooled disturbance rate (disturbances / # surveys) in either the upper or lower estero (Fig. 1), or the pooled maximum annual seal counts of all other Point Reyes area colonies (regional population size). We used a two-step process for modeling. Using the 15 year dataset, we used generalized linear mixed models (GLMMs) to asses for effects on seal distribution between the near (upper) and far (lower) mariculture areas of the estero due to *a priori* combinations of ENSO, binary high/low oyster harvest, anthropogenic disturbance rates, and regional counts (pup and total counts). We then tested models for the full time series (all 21 years) without regional

counts and disturbance covariates using generalized estimating equations (GEEs) (Venables and Ripley 2002, Faraway 2006, Zuur et al. 2009).

Binomial and quasibinomial GLMMs were ranked using AIC with the "lmer" and "glmmML" packages in R. Both of these packages report rounded AIC values. GLMMs were used rather than GEEs for this step because GLMMs allow calculation of AIC to compare non-nested models. Since regional population size and oyster harvest were correlated, they could neither be modeled together nor compared via likelihood ratio tests in nested models. Similarly, regional population size was tested *a priori* with disturbance measures, but not with ENSO since there is no reason to believe that ENSO should interact with regional population or size differently at different colonies. Year was considered a random effect.

We expanded and improved the analysis in Becker et al. (2009) in three significant ways. First, the GEEs explicitly model the temporal autocorrelation of multiple harbor seal counts taken during the breeding season within each year. GEEs are therefore a form of mixed-effects (or hierarchical) modeling (Gelman and Hill 2009). The GEEs also allow flexible distributions for the entire dataset and for the within year counts, neither of which were normally distributed. Second, the GEEs and GLMMs were run as binomial models comparing the three subsites near mariculture (OB, UEN, UEF) against the five subsites farther away from mariculture (A, A1, L, DEM, DBS). Third, the aforementioned inclusion of spring (March – May) anthropogenic disturbance rates for the upper and lower estero and regional population size (pups or total seals) were included as covariates for step one of the analysis for 1982 - 1983 and 1997 - 2009.

We modeled "years since ENSO" as *log(years since ENSO+1)* because both observational and theoretical evidence suggest that any ENSO effects should taper off and not be linear. Annual changes in the areal extent of sandbars in Drakes Estero and other regional colonies are not available and were therefore not modeled. However, dramatic changes in the size and access of subsite A were documented and we explicitly modeled that process in the following "*regional scale*" section.

GEEs were run in the software R 2.9.2 using the "geeglm" function in the "geepack" library with year as the grouping variable to account for within year autocorrelation of counts at the same subsite. The correlation structure was set as autoregressive since the counts were during the one month peak pupping period (April 15 – May 15) in each year and counts closer together should have higher correlation since seal counts generally rise, peak, and decline during this time.

Nested models (e.g., ENSO + oyster vs. ENSO only) were tested for differences with likelihood ratio tests with the simplest adequate (difference not less than $P < 0.05$) model retained. We then transformed the final model logit coefficients (Crawley 2007) to calculate the proportional change in seals using the three subsites near mariculture model, and multiplied the proportion by the mean seal count (pups and total) in the estuary during the time series to estimate a change in the number of seals using those subsites due to any significant factors.

*Regional Scale: Drakes Estero compared to surrounding colonies* - We examined regional anthropogenic effects during the breeding season by comparing maximum seal counts (pups and total) in Drakes Estero, and all other Point Reyes colonies combined

(Tomales Bay, Tomales Point, Point Reyes Headlands, Double Point, Bolinas Lagoon, and Duxbury Reef) (Fig. 1). We examined several variables, as well as a null model, in relation to the annual maximum proportion of seals (total seals and pups only) using Drakes Estero compared to the proportion using the other six Point Reyes area colonies (Fig. 4A). These included:

- *Year*, to account for any linear time trends.
- *Proportion of Drakes Estero seals using haul out subsite A*, a major pupping subsite in Drakes Estero that attached to the mainland and exposed to predators around 2004. This should account for variation in the importance of this site through time.
- *Maximum annual count of seals at nearest colony (Double Point)*. Seals are thought to transit easily between Double Point and Drakes Estero, and in 2003 an elephant seal likely displaced numerous harbor seals from Double Point to Drakes Estero.
- *Annual spring (March-May) human related disturbance rate (disturbances/survey) in Drakes Estero*. This includes disturbances by hikers, kayakers, dogs, airplanes, and mariculture. Kayaks have been prohibited from the estero during the breeding season since 1996.
- *Years since the last major ENSO* (1982-83 and 1997-98). Strong ENSO events appear to depress reproductive success and thus may influence habitat choice.

- *Regional annual maximum count (less Drakes Estero).* Density-dependent effects could alter spatial use of Drakes Estero, especially if all haul-out sites are not equally desirable.
- *Annual oyster harvest* (Table 1) as a measure of mariculture activity and equipment placement in the estero.
- *Five-year and six-year periods of lowest oyster harvest* (2000-2004 and 1999-2004) (Table 1). This binary value may be useful for analyses for two reasons. First, the oyster harvest metric might not be linearly related to actual harvest activity near the seal haul-outs, and using a binary measure eliminates assumptions of such a relationship. Second, we do not have an official estimate for 2009 yet; the 2008 estimate departed from the actual harvest by 12%, indicating that some caution is needed when using estimates. While the use of total annual oyster harvest in the estuary was negatively correlated (when modeled with ENSO) with nearby seal haul out use (Becker et al. 2009, NRC 2009), total oyster harvest is surely not a perfect measure of activity near the seals (NRC 2009). The number and distribution of mariculture equipment (bags) on sandbars near seals for extended time periods is another potential measure. Bags need to be tended, potentially causing disturbance, and the simple presence of the bags themselves may cause seal displacement. We did have to make a decision as to where the cut point was for high/low and we did this based on the inferences in Table 1 regarding increased presence of oyster

equipment at sites near seal haul out sites and an apparent break point of around 138,000 lbs of oysters.

Aerial images confirm that oyster bags were present on top of and adjacent to seal haul out sites in 2005 – 2009. Personal observations (DTP) during regular fieldwork indicate that there were few or no bags on the upper seal islands from 2002-2004. We infer from the oyster harvest records that there were few or no bags in 2000-2001 since the harvest was lower than 2002-2004, and conversely that there likely was infrastructure from 1997-1998 when harvest was higher. The year 1999 is difficult to categorize based on the available data. Thus, we modeled the oyster harvest covariate for 1999 as both a high and low oyster harvest year (Table 1).

Modeling the pups and the total population was done separately because there is potential to have a greater disturbance/displacement effect on females with pups that 1) may be more sensitive to disturbance, or 2) seek out more isolated haul out sites (Allen Miller 1988, Allen and Huber 1984a Nordstrom 2002). We did not combine any covariates in a single model if the variance inflation factors (VIFs) were above 3 (Zuur et al. 2009). VIFs were calculated from models without the complementary covariate. For example, the VIF for low/high oyster was calculated without "oyster", since these would never be used in the same model. We also tested for interannual autocorrelation in the proportion of pups and total seals in Drakes Estero using detrended time series and the autocorrelation and partial autocorrelation functions in R.

We used binomial generalized linear models (GLM) which modeled the probability that any random seal is found in Drakes Estero (success) versus somewhere else in Point Reyes (failure). We bound "Drakes Estero" and "non-Drakes Estero" seal

maximum counts for each breeding season into a single matrix (pups or total) for use as the dependent variable in this model. Because of over-dispersion (variance larger than expected for binomially distributed data), we used a quasi-binomial family to assess *P* values and over-dispersion, and the binomial distribution to derive log-likelihoods to rank models using an over-dispersion adjusted Akaike's Information Criteria for small sample sizes (QAICc; Burnham and Anderson 2002). We also bootstrapped (refit the model with data from each year sampled at random with replacement) the best ranking models 2000 times to gain unbiased standard errors for the oyster harvest variable (Crawley 2007). Bootstrapping should also uncover any highly leveraged effects from one or two years of data. We report models and QAICc values for both the oyster harvest and the low/high oyster models, but only consider the 2000-2004 low/high variable when reporting Akaike weights and model averaging. Final model coefficients were calculated from the weighted (by Akaike weights) model coefficients of the best performing models (i.e., lowest 4 QAICc units). These weighted coefficients were then back transformed from binomial logits to proportions and multiplied by the mean number of pups or total seals in the Point Reyes area seal population during the study period. All analyses were done in R 2.9.2 (R Development Core Team 2009).

**Results**

During 1982 – 2009, the mean number of breeding season harbor seals hauled out in Drakes Estero was 775 ± 269 total seals and 180 ± 94 pups. The mean of the maximum annual breeding season counts in Drakes Estero were 1052 ± 279 total seals (range: 656-1644) and 302 ± 102 pups (range: 122-486). The other regional colonies had a combined

mean maximum breeding season count of 2499 ± 369 total seals (range: 1728-3125) and 710 ± 167 pups (range: 366-962). Oyster harvest experienced a low period from ~2000-2004 (Table 1, Fig 6B) and manila clam harvest levels are unknown. Daily maximum Drakes Estero seal breeding season counts varied throughout the study period, with upper estero seals showing a peak during 2002 – 2004 (Fig. 4). Annual maximum counts of harbor seals in Drakes Estero also peaked around 2002 – 2004, while the regional population size (less Drakes Estero) peaked from about 2000 – 2005 with two very high years in 2002 and 2004 (Fig. 5). Pup counts in Drakes Estero climbed from 2000-2004, while those in the rest of the region slowly declined (Fig. 5). Excluding the period from 2000 – 2004, the pup counts between Drakes Estero and the region appeared to have similar trends.

*Subsite Scale: Seal counts, pup:adult ratios and disturbance rate* – During 1997 – 2009, the upper intertidal sandbars (OB, UEN, UEF) generally had higher pup:adult ratios than the sandbars attached to the mainland or near the mouth of the estero (L, DEM, DBS: Fig. 2). Subsite A, while showing a high pup:adult ratio, lost nearly all of its productivity since attaching to the mainland in 2004, but subsite A1 was still the one major subsite away from mariculture that maintained a high pup ratio and high overall pup production each year. Lower estero subsites DBS and L (attached to the mainland), and DEM (at the mouth of the estero in high current), tended to have either low pup:adult ratios *or* relatively low absolute numbers of pups produced each year.

Annual human disturbance rate during spring (March-May) of each year (1982-83 and 1997-2009) had a similar pattern whether using daily or hourly rate ($r_s = 0.99$, n =

15) and so we used daily rate in all subsequent models and calculations. There were 153 spring anthropogenic disturbance events during this time. The daily disturbance rate averaged about 0.71 ± 0.41 for each year, with about 23% of disturbances being seal head alerts, 10% flushes without entry into the water, and 67% flushes into water. Neither subsite pup counts ($P > 0.38$) nor total seal subsite counts ($P > 0.28$) were related to spring anthropogenic disturbance rates in Drakes Estero (Figs 3A & B). When using a random intercepts (fixed slopes) model, spring disturbance rate appeared to be negatively related to reduced pup:adult ratios at seal haul outs within Drakes Estero (n = 104, groups = 8, $P < 0.001$, AIC = 889.3) (Fig. 3C). However, the random intercepts and random slopes model had a lower AIC (882.0), was a better fit in a likelihood ratio test ($X^2 = 9.2$, $P < 0.001$), and indicated no effect ($P > 0.32$) of spring disturbance rate on pup:adult ratios. The null model was a much poorer fit than either of the disturbance models (AIC = 910.5). Since "flushes" and "flushes into water" represented the majority of disturbances (~77%), removing the "head alerts" from the analysis should not alter the results. Based on this, we conclude that there is not a robust, detectable relationship between spring anthropogenic disturbance rate and pup:adult ratios. Further, individual subsite based binomial GLMs for the years 1997 – 2009 indicated that subsite pup:adult ratio trends with disturbance rate were not significant (Fig. 3C).

*Colony Scale: Drakes Estero subsite models* – Binomial GLMMs found that high-low oyster harvest and ENSO best explained the proportion of seals (pups and total) using the upper estero (Table 2a). Both the "lmer" and "glmmML" functions in R reported similar AIC rankings, as did quasibinomial and binomial distributions (for "lmer" only). Upper

estero disturbance rate was somewhat important in explaining pup presence in the upper estero, but this model was not a significantly better fit than the oyster + ENSO model alone (likelihood ratio test: $X^2 = 2.97$, $P < 0.08$). Regional population size was not important in explaining the proportion of seals using upper Drakes Estero with ΔAIC values of 9 (total seals) and 17 (pups) from the top ENSO + Oyster models.

Since disturbance rate and regional population size were not important in these 1982-83 and 1997 – 2009 models. We used GEEs to analyze the full time series including 1986-1987, 1989, and 1991-1993 for the relationship between the proportion of seals using the upper estero and just oyster harvest and ENSO as covariates. ENSO and oyster harvest (high/low) were not collinear ($P > 0.89$). The GEE showed that both ENSO and oyster harvest continue to explain seal use at sites closest to mariculture activity (Table 2b). Residual plots versus model predictions showed no model fitting issues with the GEE model. Within year autocorrelation was moderate (0.45 - 0.60), indicating that GEEs are an appropriate tool for this dataset. A nested likelihood ratio test indicated the Oyster + ENSO binomial model was a better fit over the ENSO only binomial model for both pups ($X^2 = 4.6$, $p < 0.03$) and total seals ($X^2 = 9.5$, $P < 0.002$). After accounting for the ENSO effect and not including the non-significant anthropogenic disturbance terms, the best GEE models estimated 14 ± 4 fewer pups and 59 ± 15 fewer total seals in the three "near mariculture" subsites during the higher oyster harvest years (Table 2b).

*Regional Scale: Drakes Estero compared to surrounding colonies* - The proportion of pups and adult seals using Drakes Estero versus the other Point Reyes colonies varied throughout the study period, with a peak from 2003-2004. The pup and adult time series

were generally similar, with the exception of 1997, when relative pup presence in Drakes Estero was low, but adult use was high (Fig. 6A). Because 1997 was an outlier for the adult and/or pup proportion of seals in Drakes Estero, we weighted the total seal count data for 1997 by the ratio of the proportion of pups to adults in that year (~0.3) (Venables and Ripley 2002). We felt this was reasonable (and preferable to omitting the data) since there was an anomalous harbor seal die-off of mostly adult females which began during the breeding season in 1997 that did not appear to affect pups, and appears to have affected other colonies (specifically Double Point) more than Drakes Estero (D. Grieg and F. Gulland, The Marine Mammal Center, pers. comm. & NPS unpubl. data), although the sampling from that study was not random.

Oyster harvest was alternately classified as low for both the 2000 – 2004 and 1999 – 2004 periods (Fig. 6B). Seal use of subsite A in Drakes Estero was high from 1982 – 2004, and dropped rapidly thereafter when the sandbar connected to the mainland. Seal use of Double Point increased from 1997 – 2002, dropped rapidly in 2003 due to an aggressive elephant seal (see Hayward 2003), and then rebounded in 2004 – 2005, followed by another smaller decline after 2005.

Spearman rank correlations indicated no issues with collinearity among the variables in the models tested (Table 3a). Variance inflation factors (VIF) also found no evidence of collinearity as long as year or ENSO were not modeled with subsite A (Table 3b). The detrended proportion of pups and total seals using Drakes Estero did not exhibit interannual autocorrelation or partial autocorrelation at any lag distance. Quasi-binomial GLMs showed that models of the proportion of seals in Drakes Estero were moderately over-dispersed for the seal pup global model (4.5) and somewhat more over-dispersed for

the total seal count global model (8.6). We used these values to calculate the QAICc for all the competing models. Binomial models almost always have some degree of over-dispersion with count data because there is no variance parameter in the model (Gelman and Hill 2009).

Among the models tested for pups, the two and three-way combinations of *low oyster* + *Double Point* + *subsite A* (always containing low oyster) models had an Akaike weight of 0.77), and the $r^2$ for the top model had a good fit ($r^2$ = 0.46 - 0.63) (Table 4). Annual change at Double Point, disturbance rate, ENSO, and year were poor predictors of seal use of Drakes Estero. ENSO appeared once in model 6, but we did not include it in the multimodel averages since the Akaike weight was only 0.09 and the weighted coefficient would have overlapped with a slope of zero. Similar patterns occurred for the total seal count models, with the exception of ENSO which did not appear at all in the top models (Table 4). Low/high oyster harvest alone had an $r^2$ of 0.26 and 0.29 for pups and total counts, respectively and a significant ($P < 0.05$) over-dispersion corrected P-value. Bootstrapped estimates of model coefficients were similar to those in Table 4 and the oyster harvest standard errors were smaller than those reported by model fitting alone, indicating robust and conservative estimates from the GLM (Table 5). After removing the effects of Double Point and subsite A, the best fit weighted coefficients suggest that there were about 65 ± 18 fewer seal pups and 192 ± 58 fewer seals overall using Drakes Estero (Table 5, Figs. 7 & 8) during high oyster harvest years.

**Discussion**

Long-lived, slow reproducing species that invest their energetic resources in long-term survival rather than rapid reproduction tend to have pronounced physiological costs

(increased heart rates and overall energetic costs) associated with human induced disturbance (Bisson *et al.* 2008, Ellenberg *et al.* 2006). Harbor seals have both a long lifespan (~20-25 years), and a single pup per year, suggesting that they are a candidate for realizing significant stress due to disturbance and might respond defensively (by moving) rather than quickly assimilating and continuing reproduction as is the case with short-lived, rapidly reproducing songbirds (Bisson *et al.* 2008). Our findings support those of Frid and Dill (2002) whereby long-term, chronic disturbance or displacement stimuli (in this case mariculture activity including equipment on haul out sites) is related to a habitat shift and subsequent reduced access to subsites in the estero. Conversely, shorter term disturbance stimuli (primarily park visitors) were not related to reduced pup:adult ratios at subsites in the estero, or strongly to detectable patterns in intra-estero (upper versus lower) or inter-colony proportional use by seals. Rather, pup:adult ratios at subsites appear to be strongly driven by their physical isolation from the mainland (Nordstrom 2002). Oyster harvest and ENSO were the primary variables associated with temporal variation in spatial use by seals in Drakes Estero. Our prediction that regional population size would be an important factor in partially explaining the proportion of Drakes Estero seals using the upper estero was not supported. Regional population size and human disturbance rate were also unimportant in explaining seal use of Drakes Estero in relation to the rest of the colonies. Instead, oyster harvest, internal subsite, and nearby colony dynamics were consistently important.

These analyses address suggestions of the NRC (2009) for research into factors driving seal spatial patterns in Drakes Estero. Although the results are correlational, we propose that the variation in oyster harvest paired with *a priori* multiple competing

mechanistic hypotheses represents a robust "natural" experiment which can be used to draw reasonable inferences. Oyster harvest was a human induced rather than a natural covariate, and so there is no reason to believe that oyster harvest is mechanistically correlated with some other unmeasured, non-anthropogenic parameter that also influences seal distribution. The apparently random correlation between oyster harvest and regional population size warrants some caution when interpreting the *colony scale* results. The fit of the oyster harvest models, though, were so much more parsimonious than those of regional population size (lower by 9-16 AIC units), that the pattern appears quite robust to both statistical methodology and length of the time series. Similarly, in our analysis of the 1997 – 2007 Drakes Estero data (Becker *et al.* 2009), we reported that the 2008 seal counts at one subsite appeared to deviate from the inverse relationship with oyster harvest found for the 1997 – 2007 models. This was based on preliminary information that oyster harvest increased in 2008 along with actual seal counts at one subsite (OB). The 2008 actual oyster production estimate, however, actually *declined* by 12% from 2007 to 2008), and is thus still consistent with the reported model for 1997 - 2007. Further, Becker *et al.* (2009) modeled counts in the estero rather than proportional shifts, so further comparisons are not informative here.

Our results do not indicate that the seals are lost from the overall Point Reyes area population (although that is possible), but rather assume a closed population within each year both within the estero (for the colony scale analysis) and between the estero and other Point Reyes area colonies (for the regional analysis). The use of regional population size as a covariate should account for any density-dependent effects and seals typically do not move between colonies during the breeding season (Lowry et al. 2005).

We focused on low versus high oyster production, but also report nearly identical results when using the continuous linear covariate of oyster harvest. While the binary oyster harvest variable required some inferences (Table 1), it is also somewhat more conservative than the continuous covariate because it does not assume a linear relationship between oyster harvest and seal response. This binary model is more appropriate if the simple presence of oyster equipment caused seal displacement, rather than the frequency of visits. Additionally, the oyster harvest value does not represent activities that may be due to cultivation of manila clams versus oysters in the estero. Any relationships between clam and oyster harvest are currently unknown to us, so a low/high metric may again avoid over-interpreting the impacts of the specific annual oyster harvest. A final benefit of using the high / low oyster metric is that it virtually eliminates the possibility of model errors if the actual 2009 oyster harvest is dramatically higher or lower than our estimate.

There are some inherent difficulties in the use of disturbance rates to infer effects on seals (Frid and Lawrence 2002, Hayward *et al.* 2005, NRC 2009). Johnson and Acevedo-Gutiérrez (2007) reported that disturbance rates of seals in Canada were related to frequency of powerboats nearby, but not the number of seals present. The NRC (2009) also noted that many disturbances related to mariculture in Drakes Estero likely go undetected, especially since about 50% of harbor seal surveys are on weekends and more visitors are out on weekends, while the oyster harvest work occurs primarily daily, but less frequently on Sundays (NRC 2009). Further, surveys may miss any disturbances on the ebb tide that might prevent seals from hauling out (NRC 2009). Nonetheless, we believe that because the survey methodology is standardized, it should represent an index

of annual changes. Similarly, the NRC suggested that additional disturbances by oyster boats during high tide might deter seals from using the upper sandbars when tides receded. However, since we did not partition mariculture and non-mariculture related human disturbance in this paper, these unrecorded and undetected disturbances (of all anthropogenic kinds) would be unlikely to alter our results.

The proportional reduction in seal use was generally larger for the upper estero (-0.08 pups and -0.08 total) versus the estero as a whole (-0.07 pups and -0.05 total counts). However, these proportional values, when scaled up from the Drakes Estero population to the entire Point Reyes regional population, suggests more individual seals were displaced from the overall estero than those simply displaced from the upper estero alone. It is possible that the combined effects of the loss of subsite A, impacts at Double Point, increased oyster activity in the upper estero and other unknown factors, led to the pronounced reduction in counts for the entire estero. Specifically, our findings are consistent with a scenario where subsite A lost habitat in 2003-4, which could have *increased* the proportion of seals using the upper estero. Increasing mariculture activity during 2005 – 2009, though, may have displaced seals away from the upper estero, and without access to subsite A, the overall proportion of seals using Drakes Estero therefore declined. Similarly, prior to 2000 when oyster harvest was generally high and subsite A was an isolated sandbar, the proportion of seals using the upper estero was also low. The additive processes among subsite A, Double Point, and oyster harvest fits a model where seal resilience in the ecosystem is a function of both natural and anthropogenic influences. In a similar scenario, Kent and Crabtree (2008) found that an Australian sea lion (*Neophoca cinerea*) reserve was ineffective because it did not provide suitable

habitat. They concluded that "because environmental conditions are variable over time, a fixed sanctuary zone will only aid in reducing impacts when conditions are suitable in that zone." Similarly, Stevens and Boness (2003) reported an ENSO related decline and recovery pattern in southern fur seals (*Arctocephalus australis*) in Peru. After the 1997-98 ENSO induced a decline in fur seals, the seals returning in 1999 avoided haul-out sites with higher human disturbance. In Drakes Estero, suitable conditions for females with pups may now be more limiting due to variable environmental conditions such as the loss of subsite A, mariculture equipment on the upper estero subsites, and the generally poor suitability of lower estero sites. The estero contains a dynamic system of sandbars and there will surely be additional changes in the future that both create and remove desirable seal habitat.

Subsite (or colony) recolonization may take years, while abandonment due to chronic displacement / disturbance may be rapid (Gerrodette and Gilmartin 1990). Such a decline was noted with abandonment of harbor seal colonies in San Francisco Bay (Allen 1991, Bartholomew 1949). Similarly, Hog Island in Tomales Bay (Fig. 1) was mostly abandoned by harbor seals in the early-1990s coincident with increasing numbers of boaters landing on the east side of the island (Allen and King 1993). Prohibition of boat landings coincided with a gradual resumption of use by seals (NPS Compendium; Unpubl. NPS data). The decline at subsites OB, UEF and UEN in the upper Drakes Estero follows this pattern, whereby after oyster harvest declined around 1999-2000, it took a few years (until 2002) for the proportion of Drakes Estero seals using the area to greatly increase, and then the counts (and proportion of seals using the subsites) rapidly declined again with increased mariculture in 2005. The *a priori* modeling suggested that

an ENSO effect may have explained some of the delayed recolonization in the upper estero, but perhaps simple time delayed movement into the area is also partially responsible (and also density dependence from the concurrent regional population increase). Such a model would then have a lag effect for recolonization as oyster harvest declined, but no lag as it increased, similar to seal response to subsite A attachment to the mainland and exposure to predators..

Additional processes occurring at other colonies in the San Francisco Bay Area could also affect the patterns we observed. This might include excessive disturbance, as well as immigration to or emigration from the entire study area. However, the fact that our modeled covariates (oyster harvest, double point, and subsite A) explain much of the intra- and inter-colony patterns observed, suggests that these are not likely to be spurious correlations.

***Conclusion*** - Our results highlight the importance of building and preserving resilience in natural systems and the sensitivity of K-selected species to chronic disturbance or displacement. Gill (2007) concluded that (in birds), "declines in survival or fecundity will result from density-dependence and not directly through disturbance. Efforts to manage disturbance in order to maintain populations must therefore be based on an understanding of the density-dependent consequences of avoidance of disturbed areas." Our data and analyses are consistent with natural and anthropogenically (mariculture) driven seal colony dynamics both within Drakes Estero and between Drakes Estero and other colonies in the Point Reyes region. Encroachment of mariculture or other persistent activities on preferred pupping sandbars may displace seals but not

have a detectable effect on the colony or the region until natural fluctuations occur which further limit habitat, and cause additional competition for limited space resources.

While density dependence (in the form of regional population size) is likely an important component, it did not fully explain the spatial patterns observed at the colony and subsite scales. Although pup:adult ratios were higher at isolated sandbars presumably because of lower exposure to short-term disturbances, the apparent lack of spatial redistribution at the subsite, colony and regional scales due to short-term anthropogenic disturbance warrants further study since pinniped disturbances are a common concern. At a scale even larger than the Point Reyes region, seals transit between San Francisco Bay and the Point Reyes region (Kopec and Harvey 1995, Grigg et al. 2009), thus anthropogenic impacts on the Marin Coast may indirectly affect the mobility of seals displaced at other colonies in San Francisco Bay or elsewhere. While such a signal would be extremely difficult to detect, this concern may be particularly true for Drakes Estero which supports one of the largest breeding colonies in the state and the largest in the San Francisco Bay region (Lowry et al. 2005).

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**Table 1.** Sources and inferences for level of oyster harvest activity on or near subsites OB, UEF, and/or UEN. Data from. CDFG and NRC. "Analysis scale" summarizes the years where complete seal count or disturbance data available and subsequently modeled in each of the three scales of analysis presented. Data sources: A&H: Allen and Huber 1984a, 1984b; SGA: Sarah G. Allen field notes; NPS: NPS pinniped database.

| | | | | Analysis scale | | | |
|---|---|---|---|---|---|---|---|
| Year | Oyster harvest (lbs) | Inferred level of mariculture use of sandbars near seals | Source(s) of inference | Haul-out site | Intra-colony | Regional | Seal data source |
| 1982 | 360,004 | high | harvest data | | x | x | SGA / A&H |
| 1983 | 440,139 | high | harvest data | | x | x | SGA / A&H |
| 1986 | 437,043 | high | harvest data | | x | | SGA |
| 1987 | 634,869 | high | harvest data, aerial image of bags | | x | | SGA |
| 1989 | 549,953 | high | harvest data | | x | | SGA |
| 1991 | 442,745 | high | harvest data | | x | | SGA |
| 1992 | 606,484 | high | harvest data | | x | | SGA |
| 1993 | 662,388 | high | harvest data | | x | | SGA |
| 1997 | 476,791 | high | harvest data | x | x | x | NPS |
| 1998 | 292,188 | high | harvest data, higher than 2005 | x | x | x | NPS |
| 1999 | 125,749 | modeled high & low | slightly higher than 2000-2004, declining | x | x | x | NPS |
| 2000 | 34,094 | low | lower than 2002-2004 | x | x | x | NPS |
| 2001 | 65,676 | low | lower than 2002-2004 | x | x | x | NPS |
| 2002 | 78,064 | low | DTP, pers. obs, harvest data | x | x | x | NPS |
| 2003 | 118,643 | low | DTP, pers. obs, harvest data | x | x | x | NPS |
| 2004 | 96,754 | low | DTP, pers. obs, harvest data | x | x | x | NPS |
| 2005 | 138,958 | high | aerial image of bags, increasing activity | x | x | x | NPS |
| 2006 | 291,538 | high | increasing harvest, bags in '05 | x | x | x | NPS |
| 2007 | 468,000 | high | aerial image of bags | x | x | x | NPS |
| 2008 | 438,000 | high | aerial image of bags | x | x | x | NPS |
| 2009 | 450,000* | high | aerial image of bags | x | x | x | NPS |

*Harvest estimate based on 2007-2008. Official data likely available in mid-2010. Only affects inferred mariculture level if harvest was less than ~138,000 lbs.

**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).

**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 |

**Table 3a.** Spearman rank correlations between independent variables. Significant ($P < 0.05$) correlations have an asterisk. N = 15. If adjusted for multiple comparisons using Holm's method, only the three oyster values are correlated. Oyster harvest (categorical or continuous) and annual regional population size had an $r_s$ of ~0.78 ($P < 0.001$), and were also not used in the same model.

| | Low oyster harvest 2000-2004 | Low oyster harvest 1999-2004 | Spring Disturbance rate | Proportion of seals at subsite A | Maximum counts at Double Point |
|---|---|---|---|---|---|
| **Low oyster 1999-2004** | 0.87* | | | | |
| **disturbance rate** | 0.23 | 0.13 | | | |
| **Prop. seals at subsite A** | -0.11 | -0.17 | -0.10 | | |
| **Counts at Double Point** | 0.46* | 0.50* | -0.21 | 0.29 | |
| **Year** | 0.00 | 0.09 | -0.02 | -0.92* | -0.24 |

**Table 3b.** Variance inflation factors from full models. VIFs of less than 3 represent no functional collinearity within the models (Zuur et al. 2009).

| | Variance inflation factor | |
|---|---|---|
| **Covariate** | **Pups** | **Total** |
| Oyster harvest | 1.39 | 1.27 |
| Low oyster 2000-2004 | 1.17 | 1.12 |
| Prop. seals at subsite A | 1.23 | 1.05 |
| Counts at Double Point | 1.21 | 1.21 |
| ENSO | 1.09 | 1.06 |
| Disturbance rate | 1.13 | 1.14 |

**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 |

**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.

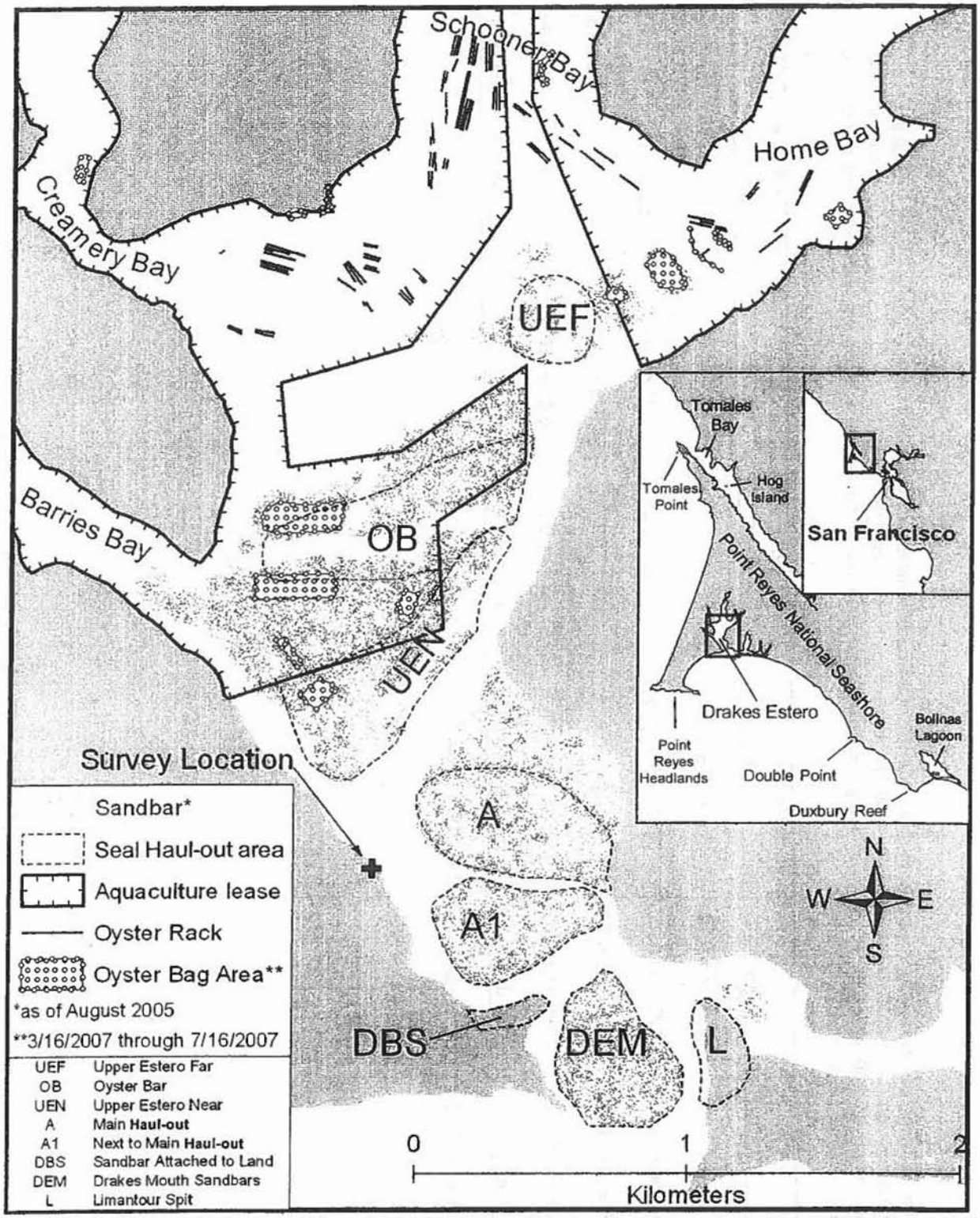


Figure 1. Drakes Estero and the eight labeled seal haul out subsites. Subsites UEF, OB, and UEN are considered "near" mariculture, while A, A1, DBS, DEM, and L are considered "away" from mariculture. Inset shows all the Point Reyes area colonies: Tomales Bay, Tomales Point, Point Reyes Headlands, Drakes Estero, Double Point, Duxbury Reef, and Bolinas Lagoon. Figure modified from Becker et al. (2009).

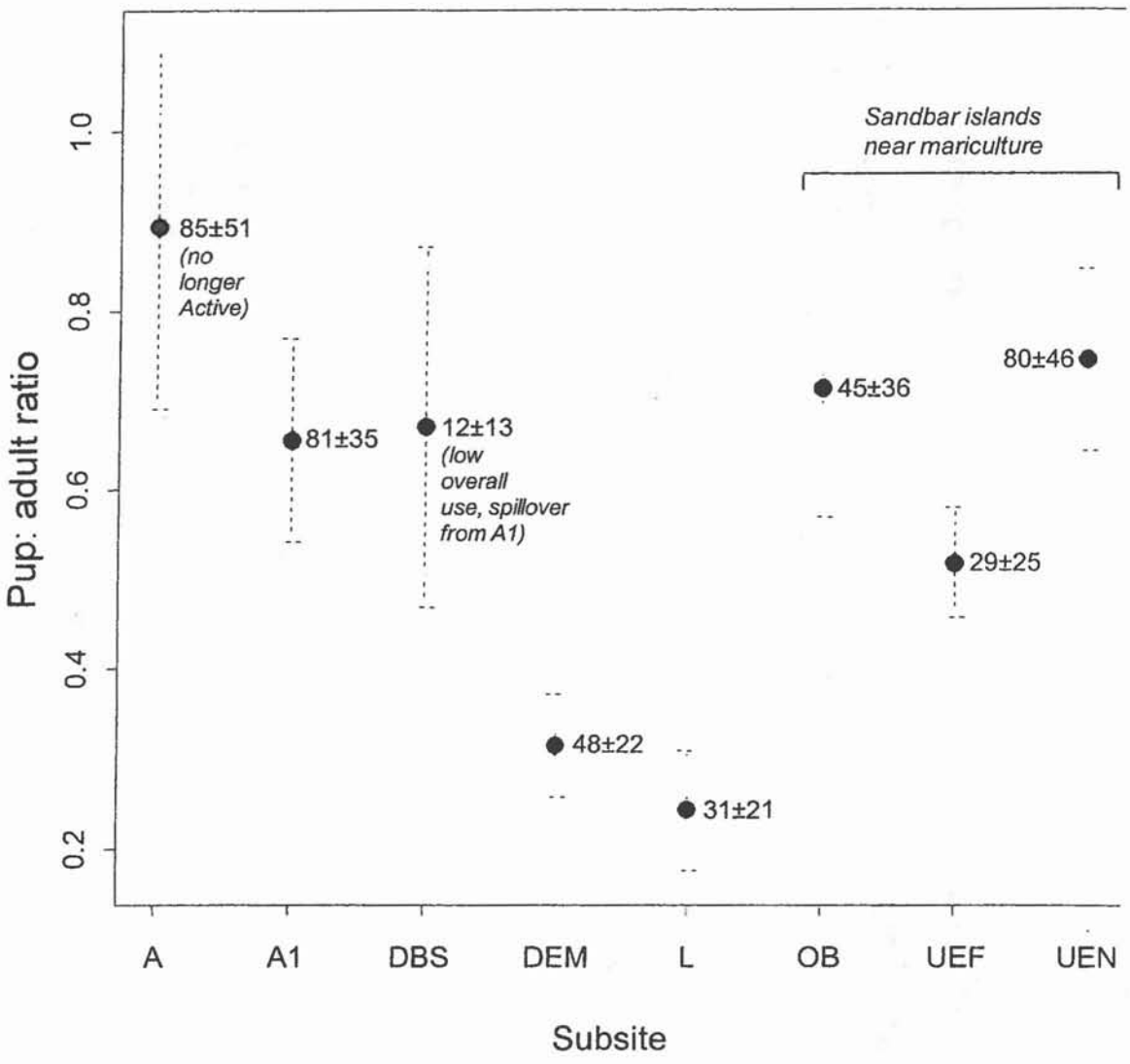


Figure 2. Mean (± SE) of maximum annual pup:adult ratios by subsite in Drakes Estero, 1997 - 2009. Numbers next to points represent the mean (±SD) of the maximum annual pup counts at that subsite from 1997 – 2009. The ratios at the estero mouth (DEM and L) are lower than the other six subsites and UEF is lower than A. DBS is adjacent to A1 has very low seal counts and pup production (~12/yr) indicating it is a minor site that appears to catch spillover seals when A1 gest crowded. Since 2004, seals have abandoned subsite A due to attachment to the mainland and subsequent predator and human access.

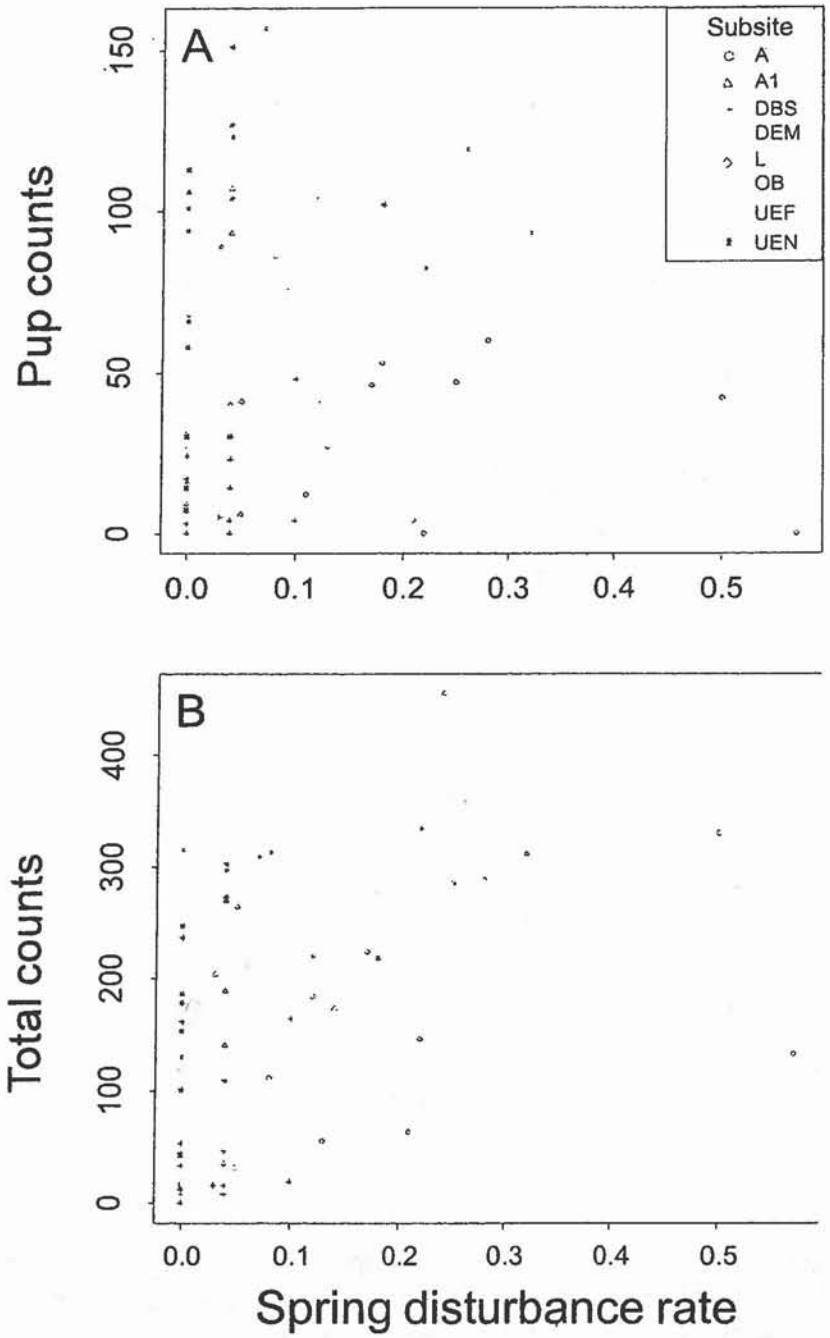


Figure 3 A & B. There is no significant relationship between Spring anthropogenic disturbance rate and (A) maximum annual pup counts at individual Drakes Estero subsites (P > 0.38) or (B) maximum annual total counts at individual Drakes Estero subsites (P > 0.28) for 1997 – 2009. Analyses were done with subsite as a random effect allowing random intercepts.

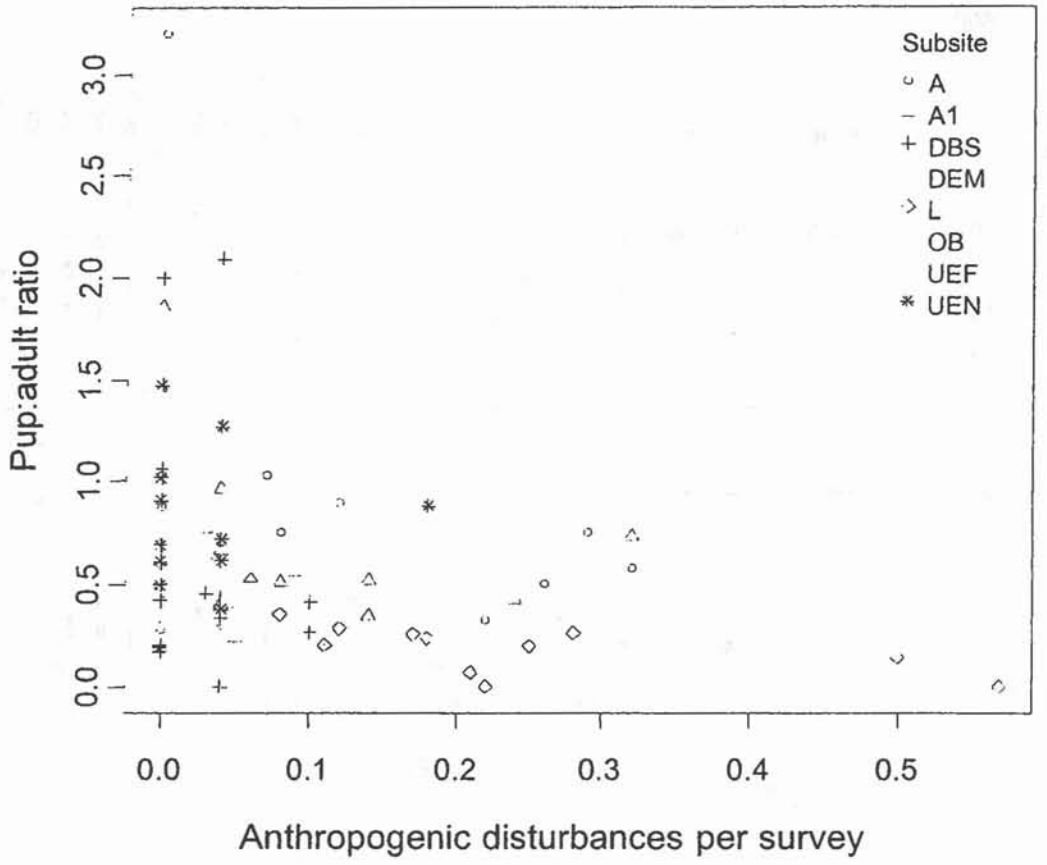


Figure 3C. The pup:adult ratio has no detectable relationship with anthropogenic disturbance rate either at the subsite level or the estero level.

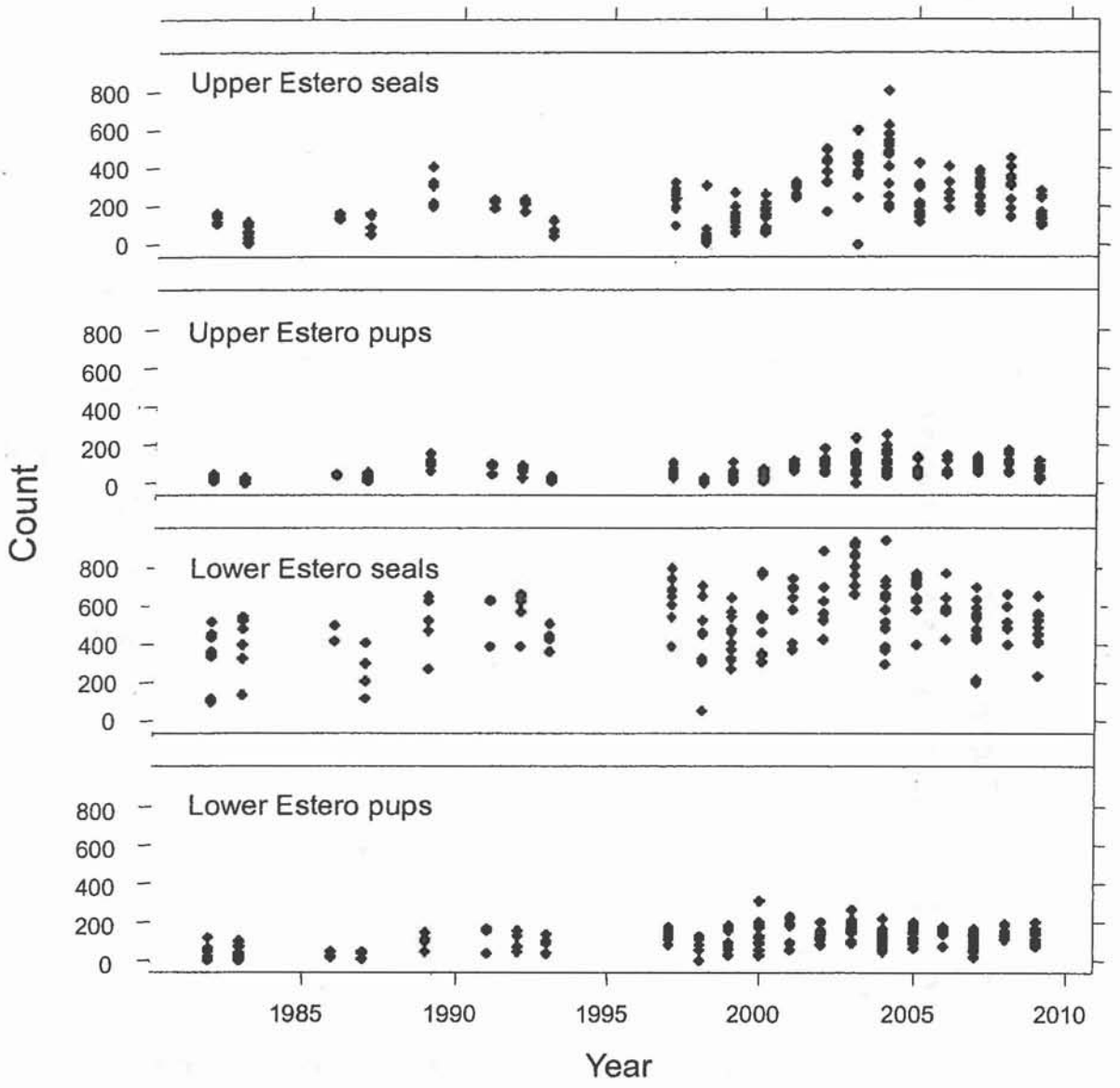


Figure 4. Daily maximum counts of harbor seals in Drakes Estero during April 15 – May 15, between 1982 and 2009.

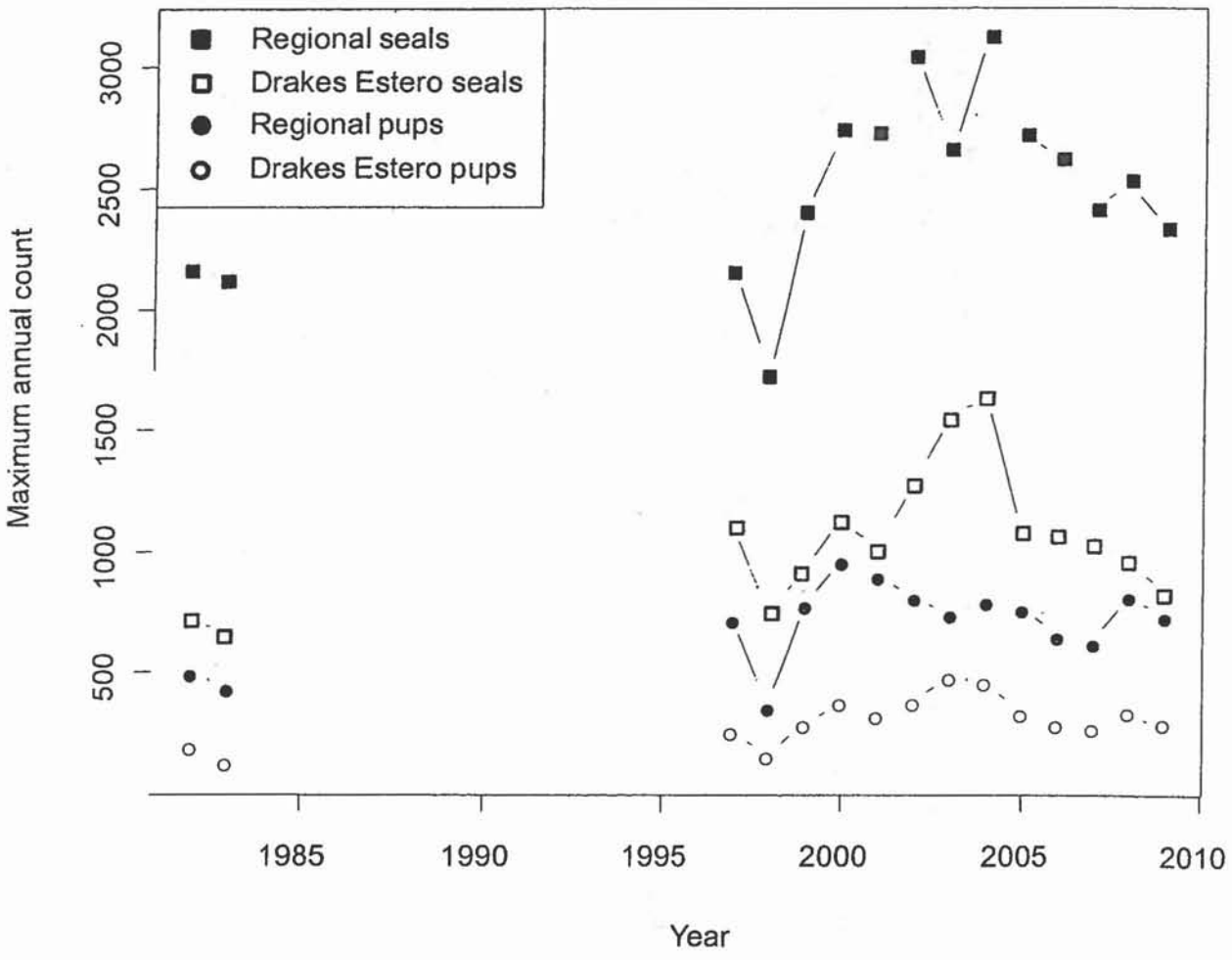


Figure 5. Annual maximum counts of harbor seals in Drakes Estero and the Point Reyes region (less Drakes Estero) during April 15 – May 15, between 1982 and 2009. Regional surveys were not conducted between 1984 and 1996.

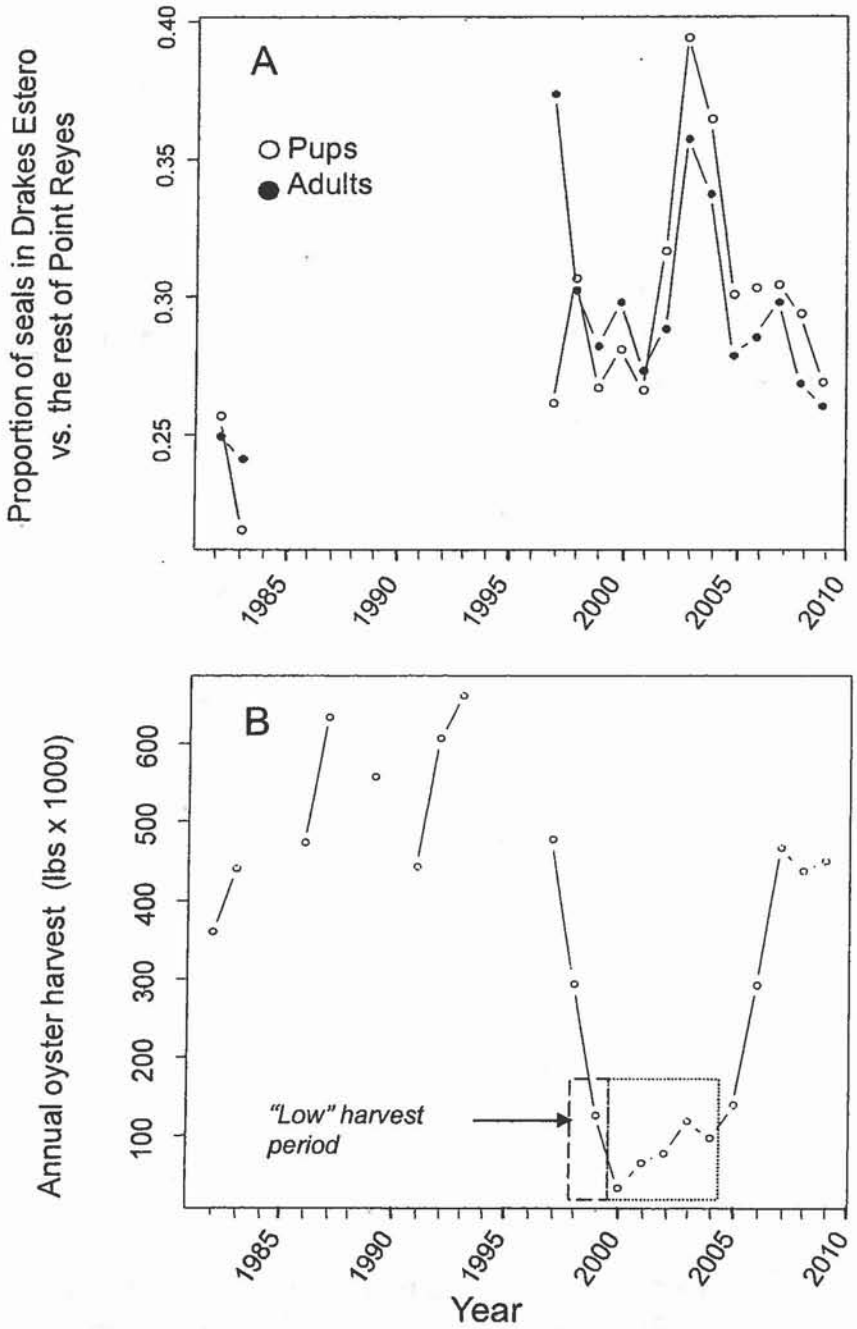


Figure 6. 1982 – 2009 time series of (A) proportion of Point Reyes region pup and adult harbor seals in Drakes Estero during the breeding/pupping season and (B) oyster harvest in Drakes Estero. Due to uncertainty in classification (Table 1), 1999 was modeled as both a "high" and "low" oyster harvest year. The 2009 oyster harvest is estimated based on 2007-2008 harvest.

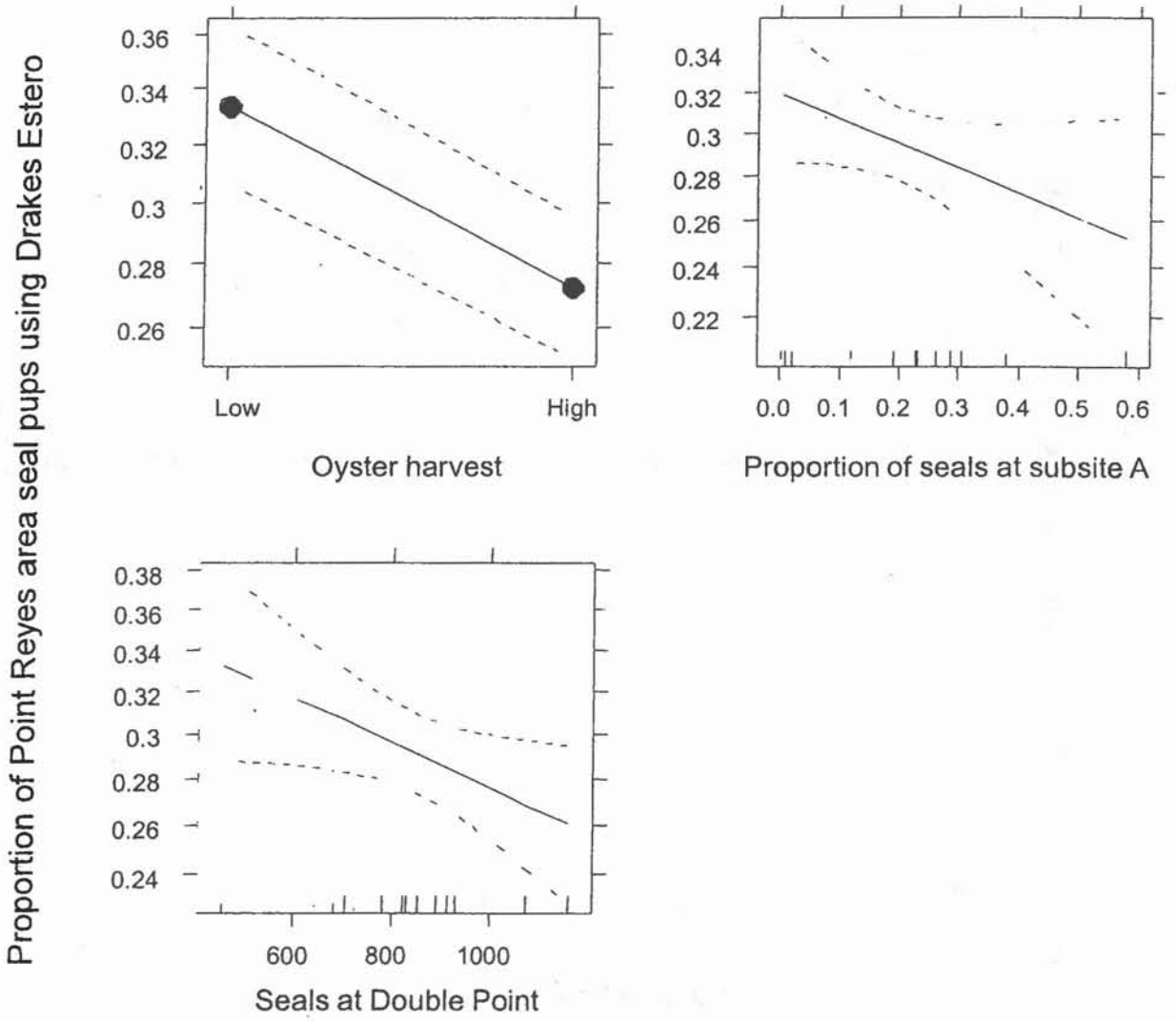


Figure 7. Model effects plots with standard errors for the proportion of Point Reyes area seal *pups* using Drakes Estero. Plots derived from the best model containing all three terms (oyster harvest, subsite A and double point. Multi-model averaged results are similar, but not identical (Table 5).

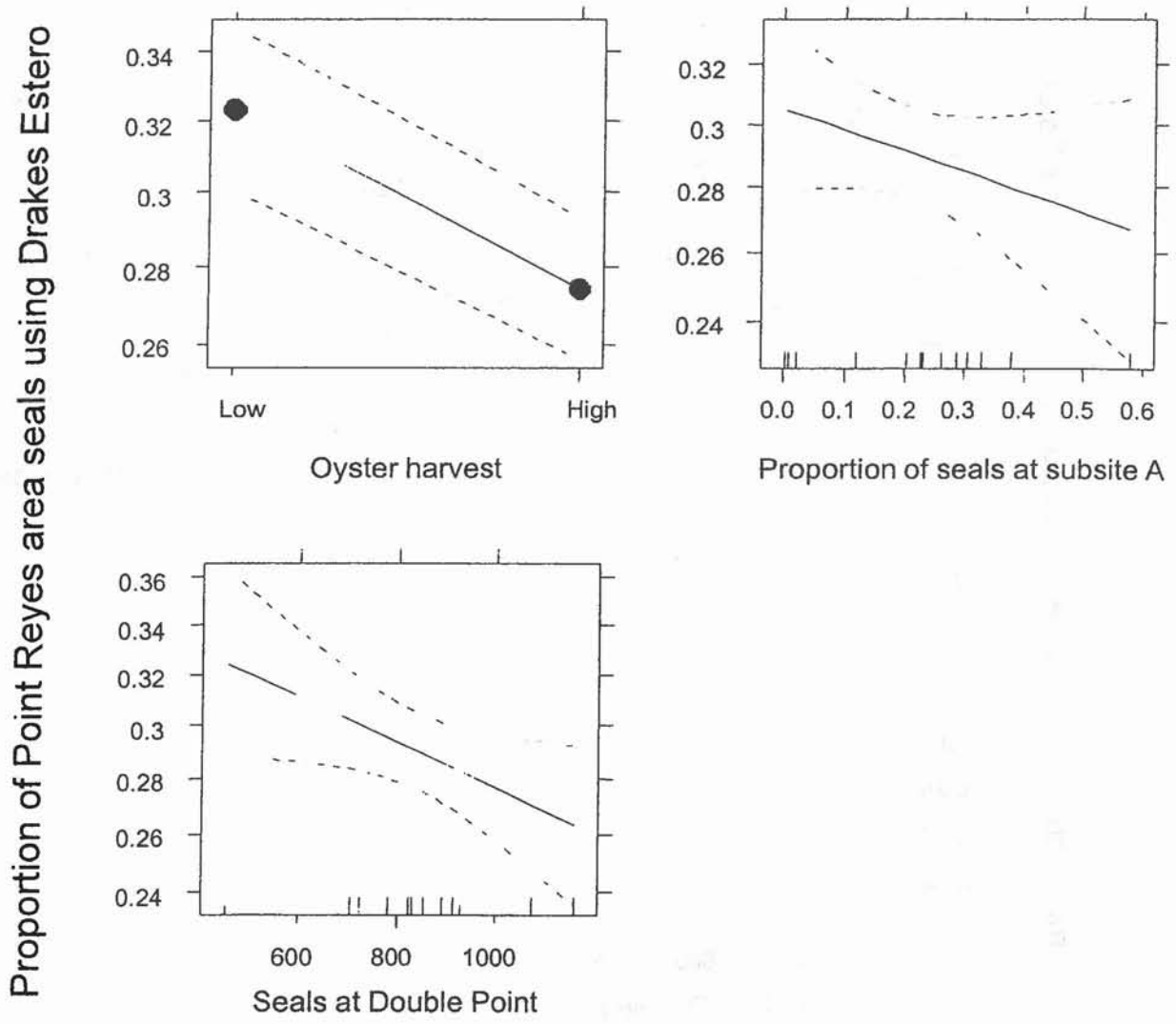


Figure 8. Model effects plots with standard errors for the proportion of Point Reyes area *seals* using Drakes Estero. Plots derived from the best model containing all three terms (oyster harvest, subsite A and Double Point). Multi-model averaged results are similar, but not identical (Table 5).

**Supplement to Table 4.** This table includes information in Table 4 and additional details of models tested. *A priori* models ranked by QAICc for the proportion of Point Reyes area seals using Drakes Estero. An "x" indicates the coefficient was selected in the model. Δi indicates QAICc distance from the best model and wi indicates model weight. "Low oyster 1999-2004" and "Oyster harvest" are only included for reference and not included in Akaike weights. Models ranking within the lowest 4 QAICc units are shaded grey and used for multimodel inference in table 5..

| | | Oyster related | | | Nearby colonies | | Internal colony effects | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age class | Model | Low oyster 2000-2004 | Low oyster 1999-2004 | Oyster harvest | Total regional counts | Double Point counts | Drakes Estero disturbance rate | Seals at A in Drakes Estero | ENSO | Year | Null | Δi | wi | $r^2$ |
| Pup | 1 | x | | | | x | | | | | | 0.0 | 0.35 | 0.51 |
| | 2 | | | x | | x | | x | | | | 1.3 | | 0.63 |
| | 3 | x | | | | x | | x | | | | 1.3 | 0.18 | 0.63 |
| | 4 | x | | | | | | x | | | | 1.4 | 0.18 | 0.46 |
| | 5 | | | x | | x | | | | | | 1.5 | | 0.46 |
| | 6 | x | | | | | | | x | | | 2.6 | 0.09 | 0.42 |
| | 7 | | x | | | x | | | | | | 3.3 | . | 0.40 |
| | 8 | x | | | | | | | | | | 3.3 | 0.06 | 0.26 |
| | 9 | | | x | | | | x | | | | 3.4 | . | 0.40 |
| | 10 | | x | | | | | x | | | | 4.2 | . | 0.36 |
| | 11 | | | | | | | | | x | | 5.0 | 0.03 | 0.20 |
| | 12 | x | | | | | x | | | | | 5.6 | 0.02 | 0.32 |
| | 13 | | x | | | | | | | | | 6.3 | | 0.16 |
| | 14 | x | | | | x | x | x | | | | 6.3 | 0.01 | 0.66 |
| | 15 | | | | | x | | | | x | | 6.4 | 0.01 | 0.29 |
| | 16 | | | x | | | | | | | | 6.5 | | 0.15 |
| | 17 | | | | | x | | | | | | 7.3 | 0.01 | 0.12 |
| | 18 | | | | | | | | | | x | 7.7 | 0.01 | 0.00 |
| | 19 | | | | | | | | x | | | 7.7 | 0.01 | 0.11 |
| | 20 | | | | | | | x | | | | 8.2 | 0.01 | 0.09 |
| | 21 | | | | | x | | | x | | | 9.1 | 0.00 | 0.19 |
| | 22 | | | x | | | x | | | | | 9.2 | | 0.19 |
| | 23 | | | | | x | | x | | | | 9.8 | 0.00 | 0.17 |
| | 24 | | | | x | | | | | | | 10.3 | 0.00 | 0.02 |
| | 25 | | | | | | x | | | | | 10.6 | 0.00 | 0.01 |
| | 26 | | | | | x | x | | | | | 11.0 | 0.00 | 0.13 |
| | 27 | | | | x | | | x | | | | 11.9 | 0.00 | 0.10 |
| Pup + Adult | 1 | x | | | | x | | | | | | 0.0 | 0.55 | 0.54 |
| | 2 | x | | | | x | | x | | | | 2.4 | 0.16 | 0.61 |
| | 3 | | | x | | x | | | | | | 2.5 | | 0.47 |
| | 4 | | x | | | x | | | | | | 2.5 | . | 0.47 |
| | 5 | | | x | | x | | x | | | | 3.8 | 0.09 | 0.57 |
| | 6 | x | | | | | | x | | | | 3.9 | 0.08 | 0.42 |
| | 7 | x | | | | | | | | | | 4.3 | 0.06 | 0.29 |
| | 8 | x | | | | | x | | | | | 4.5 | 0.05 | 0.41 |
| | 9 | | x | | | | | x | | | | 6.0 | | 0.36 |
| | 10 | x | | | | x | x | x | | | | 6.1 | 0.02 | 0.67 |
| | 11 | x | | | | | | | x | | | 6.3 | 0.02 | 0.35 |
| | 12 | | x | | | | | | | | | 6.8 | | 0.22 |
| | 13 | | | x | | | | x | | | | 7.5 | | 0.32 |
| | 14 | | | | x | | | | | | | 7.9 | 0.01 | 0.19 |
| | 15 | | | | | | | | | x | | 8.5 | 0.01 | 0.17 |
| | 16 | | | x | | | | | | | | 8.8 | . | 0.16 |
| | 17 | | | | | x | | | | x | | 9.6 | 0.00 | 0.25 |
| | 18 | | | x | | | x | | | | | 9.6 | | 0.24 |
| | 19 | | | | | x | | | | | | 10.4 | 0.00 | 0.11 |
| | 20 | | | | x | | | x | | | | 10.5 | 0.00 | 0.22 |
| | 21 | | | | | | | | | | x | 10.9 | 0.00 | 0.00 |
| | 22 | | | | | | | x | | | | 11.7 | 0.00 | 0.07 |
| | 23 | | | | | | x | | | | | 12.4 | 0.00 | 0.05 |
| | 24 | | | | | | | | x | | | 12.6 | 0.00 | 0.05 |
| | 25 | | | | | x | | x | | | | 13.0 | 0.00 | 0.15 |
| | 26 | | | | | x | x | | | | | 13.2 | 0.00 | 0.14 |
| | 27 | | | | | x | | | x | | | 13.4 | 0.00 | 0.14 |

National Park Service

EXPERIENCE
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# SFAN I&M Program
# Harbor Seal Monitoring

David Press

Ecologist / Data Manager

EXPERIENCE
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# Outline

- Inventory and Monitoring Program
- Pinniped Monitoring Protocol
- Harbor Seal Field Methods
- Data Management
- Annual Data Work Flow
- Reporting

# National Park Service

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- Harbor seal monitoring is a project of the San Francisco Area Network (SFAN) Inventory and Monitoring (I&M) Program
- SFAN is one of 32 national networks
- I&M program center Fort Collins, CO
- I&M Program a component of NPS Natural Resource Challenge, implemented in 1999

# National Park Service

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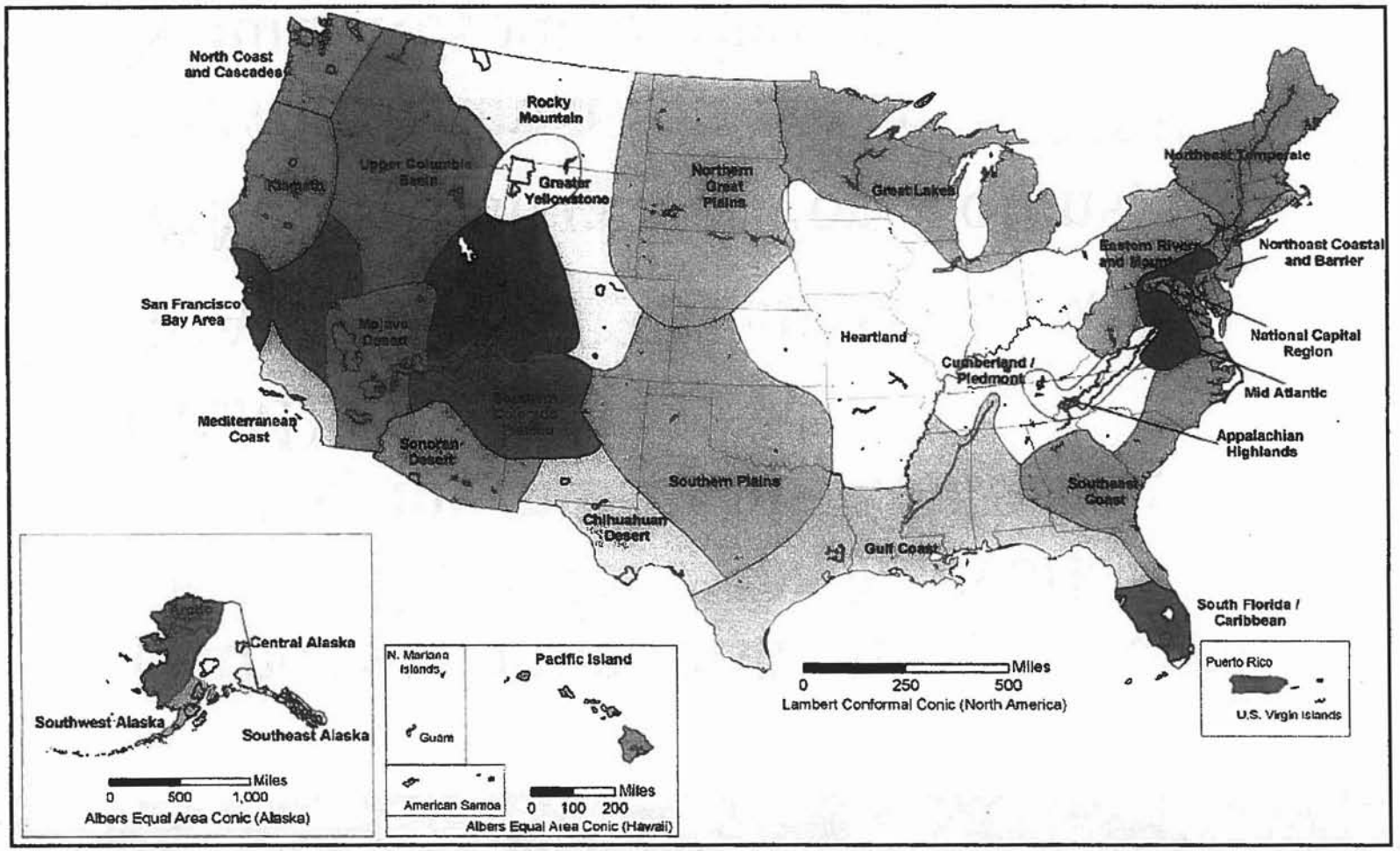


**Map of the 32 I&M ecoregional networks that include more than 270 park units with significant natural resources. The 32 networks share core funding and a professional staff to inventory park natural resources and conduct long-term monitoring of park ecosystems.**

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# I&M National Program

- Techincal assistance: sampling design, statistical analyses, modeling, GIS, data management, website design
- Guidance documents: protocol production, data management, publications
- Tools: national databases, database templates, GIS applications
- Collaboration

# National Park Service

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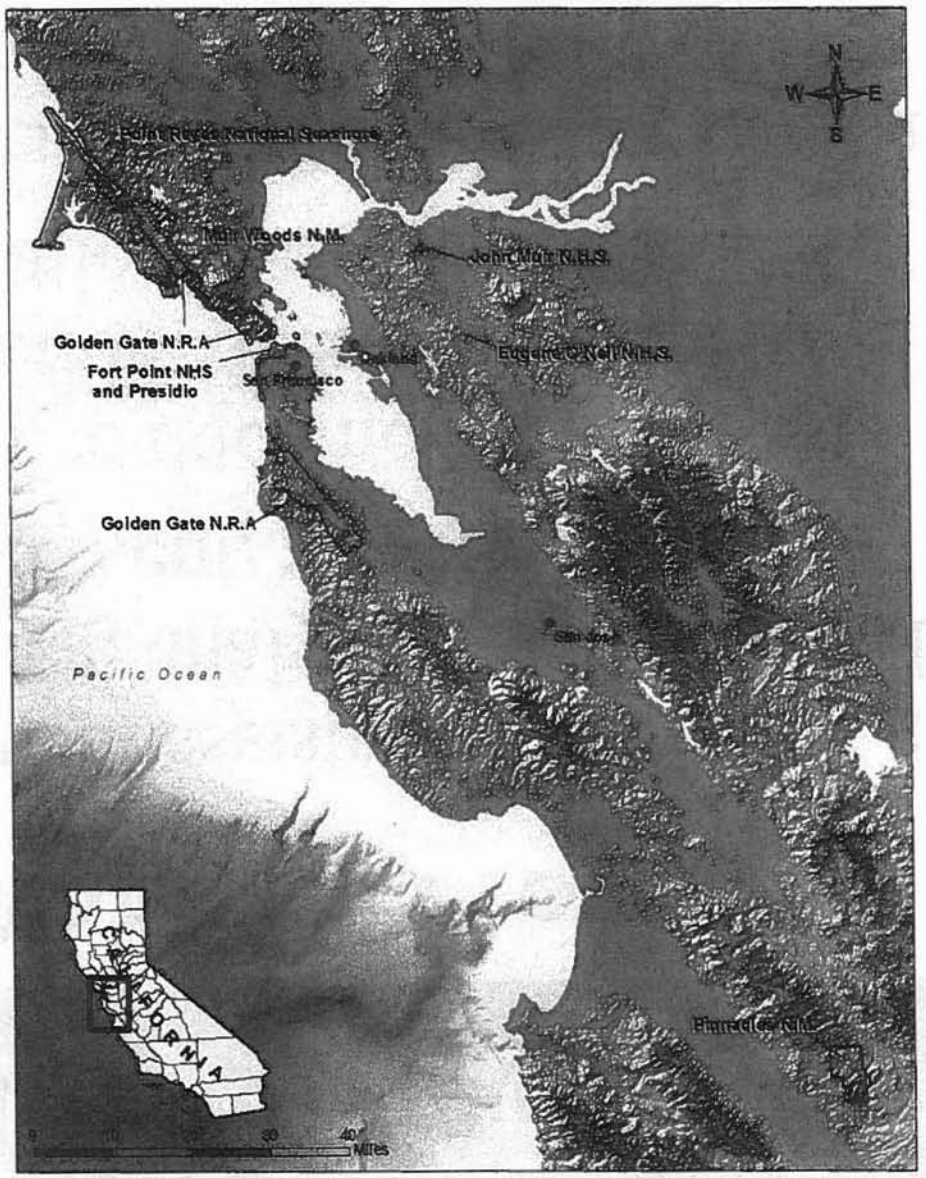

EXPERIENCE
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# SFAN Monitoring Plan

- Completed in 2005. Includes network data management plan.
- Identified and ranked 63 biotic and abiotic vital signs.
- 18 vital signs prioritized for initial funding.
- Budget restrictions likely to reduce funded programs to 10 vital signs

EXPERIENCE
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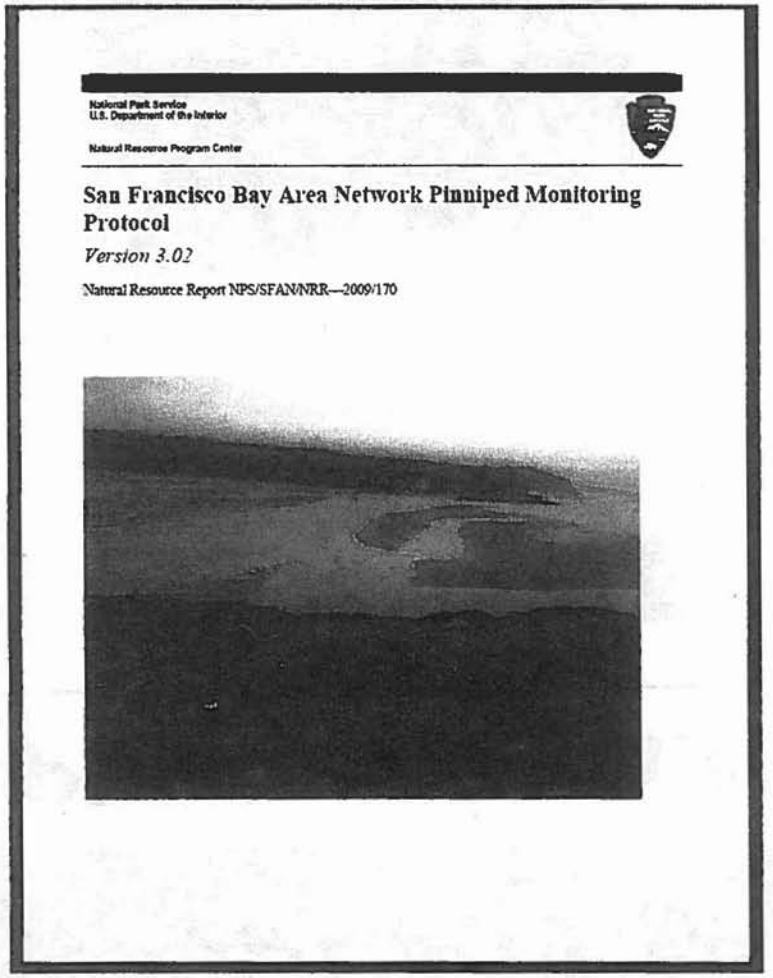
# SFAN Vital Signs

- Air Quality
- Amphibs/Reptiles
- Invasive Plants
- Salmonids
- Landbirds
- Landscape Dynamics
- Raptors (PINN)
- Pinnipeds
- Stream Flow
- Water Quality
- Wetlands
- Western Snowy Plovers
- Northern Spotted Owls
- Rocky Intertidal
- Stream Flow

EXPERIENCE YOUR AMERICA

# Pinniped Monitoring Protocol



National Park Service
U.S. Department of the Interior

Natural Resource Program Center

**San Francisco Bay Area Network Pinniped Monitoring Protocol**

*Version 3.02*

Natural Resource Report NPS/SFAN/NRR—2009/170

- Protocol approved December 2009.
- Harbor seals and northern elephant seals
- Open peer review 2004
- Dr. David Ainley, Dr. Jim Harvey

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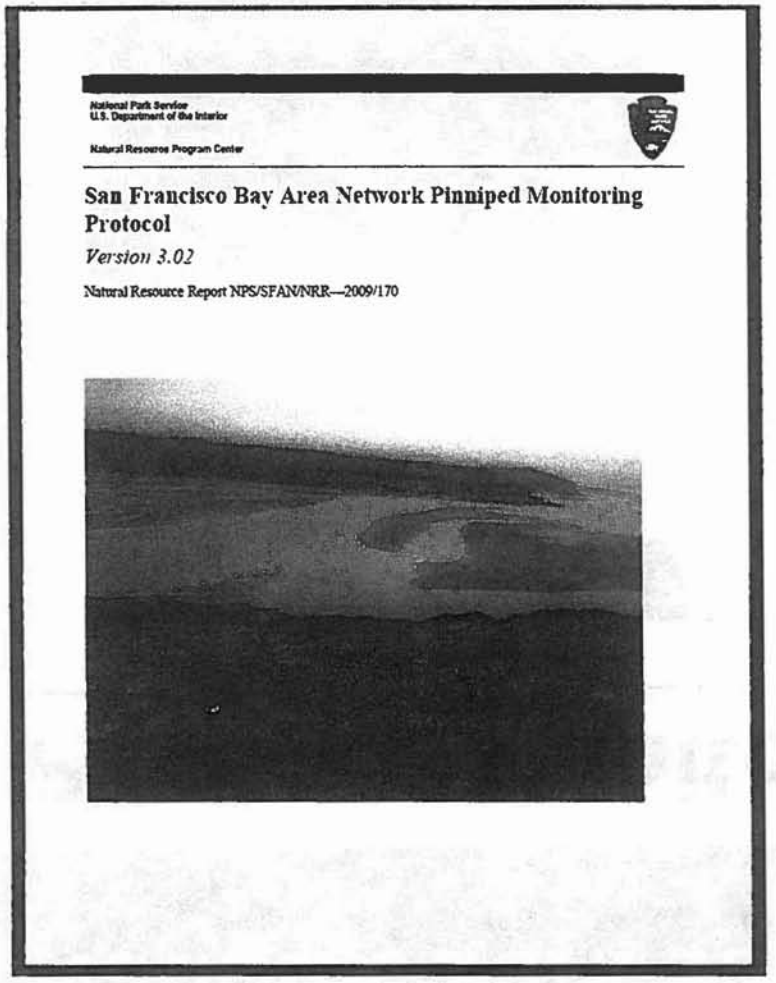
# Pinniped Monitoring Protocol


National Park Service
U.S. Department of the Interior

Natural Resource Program Center

**San Francisco Bay Area Network Pinniped Monitoring Protocol**

*Version 3.02*

Natural Resource Report NPS/SFAN/NRR—2009/170

- 2008 blind peer review coordinated by NPS and University of Washington
- 2 anonymous reviewers, Dr. Jim Agee (UW), Dr. Penny Latham (NPS)
- No modifications required to data collection or analytical methods.
- Protocol approved December 2009.

# Pinniped Monitoring Protocol



- Monitoring Objectives

1. Determine the long-term trends in population size and seasonal distribution of harbor seal populations at primary sites in the SFAN parks during the breeding and molt seasons.
2. Determine long-term trends in reproductive success of harbor seals through annual estimates of pup production at PORE and GOGA.
3. Determine the long-term trends in sources, frequency and level of effects of natural and anthropogenic disturbances on harbor seal haul out use and productivity.

# Pinniped Monitoring Protocol



- Power to Detect Trends

Adults: 90% power to detect 10% annual decline in the six major SFAN sites over 3 years.

Pups: 88% power to detect 10% annual decline in the six major SFAN sites over 4 years.

Drakes Estero: 80% power to detect 25% decline takes 21 years for adults and 15 years for pups

# Pinniped Monitoring Protocol



- Standard Operating Procedures

➢ Field Methods

➢ Data Management

➢ Data Analysis and Reporting

➢ Safety Procedures

# Field Methods

- Volunteers and NPS wildlife biotech
- 2009: 49 volunteers, 450 hours of monitoring March-July
- Eight monitoring locations.
- Breeding season: March 1 – May 31
- Molt Season: June 1 – July 31

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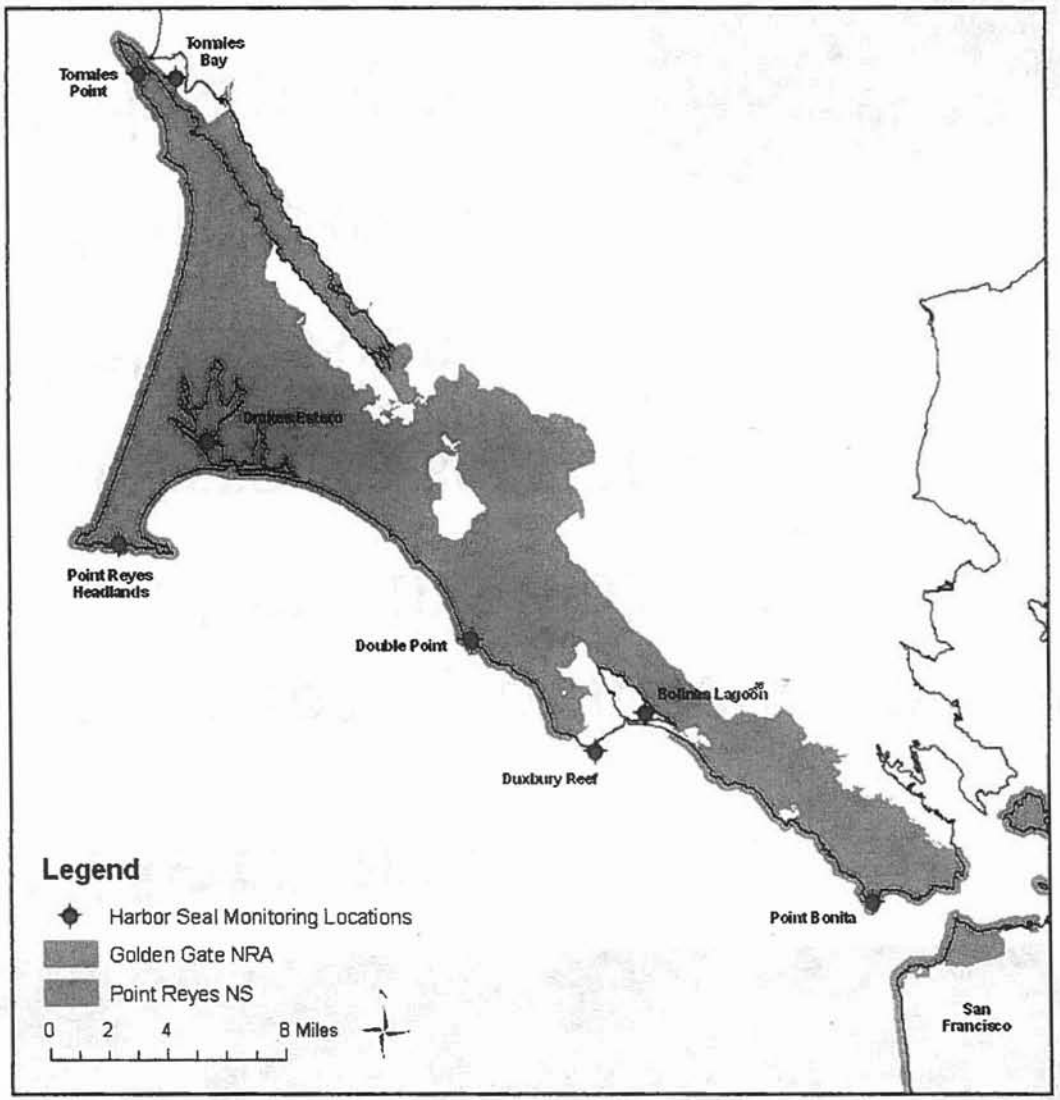

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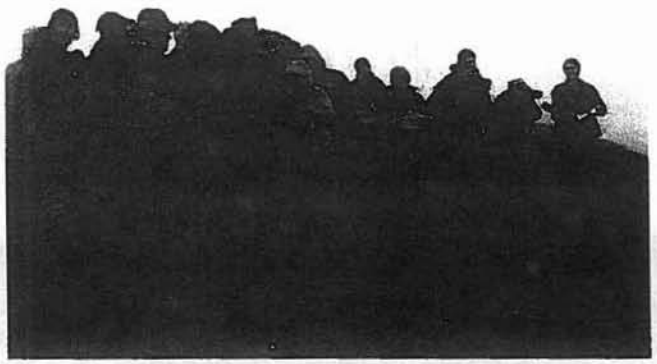
# Field Methods

- Data collected by trained volunteers and staff from fixed observation points.
- Two classroom sessions.
- One field session.
- Pup identification.
- Mentoring program.
- Quality certification.



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## Double Point

● Observation Point

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# Field Methods

## Census Data

- Adults / Immatures
- Pups (March 1 – May 31 only)
- Dead pups
- Red-pelaged seals
- Shark-bite seals
- Time / Subsite

## Disturbance Data

- Time / Subsite
- Source Category
- Specific Source
- Source number
- Response
- Flush numbers

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## POINT REYES NATIONAL SEASHORE HARBOR SEAL SURVEY

Page ___ of ___

Date:_____ Day of Week_____ Year_____ Location: _____

Start Time:_____ End Time_____ Observers:_____

Weather: Visibility (1,2 or 3)_____ Rain (Y/N)____ Low Tide Level closest to survey time _____

# of White Pelicans:_____ # of Brown Pelicans:_____ All subsites surveyed? (Y or N) _____

| Time (Survey every ½ hr) | Sub-Site* | # of Adults & Imm | # of Live and Dead Pups | Subsite Total | # of Dead Pups | # of Red Seals | # of Shark Bite | Disturb-ance Sources Y/N | Survey Total All subsites Each ½ hour | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
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**Visibility:** 1=clear, 2=slightly obscured but still able to count, 3=unable to conduct an accurate or full count

***SUBSITES:** **Drakes Estero** (A=A sandbar, A1=A1 sandbar, DEM=Drakes Estero Mouth, OB=Oyster Bar, UEF=Up Estero Far, UEN=Up Estero Near, L=Limantour Spit, DB=Drake's Beach) **Double Point** (SB= South Beach, NB=North Beach, NBR=North Beach Rock, TP=Tide Pools, SP=South Point, SS=Stormy Stack) **Tomales Point** (BR=Bird Rock, RB=Rope Beach, TRB=Two Rock Beach) **Tomales Bay** (SI=Seal Island, CI=Clam Island, HI=Hog Island) **Bolinas Lagoon** (KI=Kent Island, PWI=Pickleweed Island, HWY1= Highway 1 channel, other) **Duxbury Reef** (DUX=Duxbury Reef)

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## POINT REYES NATIONAL SEASHORE HARBOR SEAL DISTURBANCE SURVEY

Date:_____Year_____ Location: _____Observers: _____

| Time | Source * | Number | Sub-Site | Seal Behavior ** | No. Before Disturbance (Total Seals) | No. Adult Immature Seals Remain On site | No. pups Remain On site | No. Seals Flush Into Water | Seals Rehaul (Y/N) Time | Comments (vessel/aircraft identification) |
|---|---|---|---|---|---|---|---|---|---|---|
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*SUBSITES: Drakes Estero (A=A sandbar, A1=A1 sandbar, DEM=Drakes Estero Mouth, OB=Oyster Bar, UEF=Up Estero Far, UEN=Up Estero Near, L=Limantour Spit, DB=Drake's Beach) Double Point (SB= South Beach, NB=North Beach, NBR=North Beach Rock, TP=Tide Pools, SP=South Point, SS=Stormy Stack) Tomales Point (BR=Bird Rock, RB=Rope Beach, TRB=Two Rock Beach) Tomales Bay (SI=Seal Island, CI=Clam Island, HI=Hog Island) Bolinas Lagoon (KI=Kent Island, PWI=Pickleweed Island, HWY1= Highway 1 channel, other) Duxbury Reef (DUX=Duxbury Reef)

**SEAL BEHAVIOR: NR=no response; HA=head alert; F=flush; FW=flush into water. (Record Strongest Reaction)

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# Data Management

- Relational MS Access database
- Harbor seal and elephant seal monitoring data
- Data entry, QA/QC, data summaries.
- Complete user-interface
- Custom queries built for data summaries and QA/QC

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# Data Management

- Database modeled after national database template
- Spatial component of data built-into database
- Table relationships completely defined
- Definitions for all tables and fields

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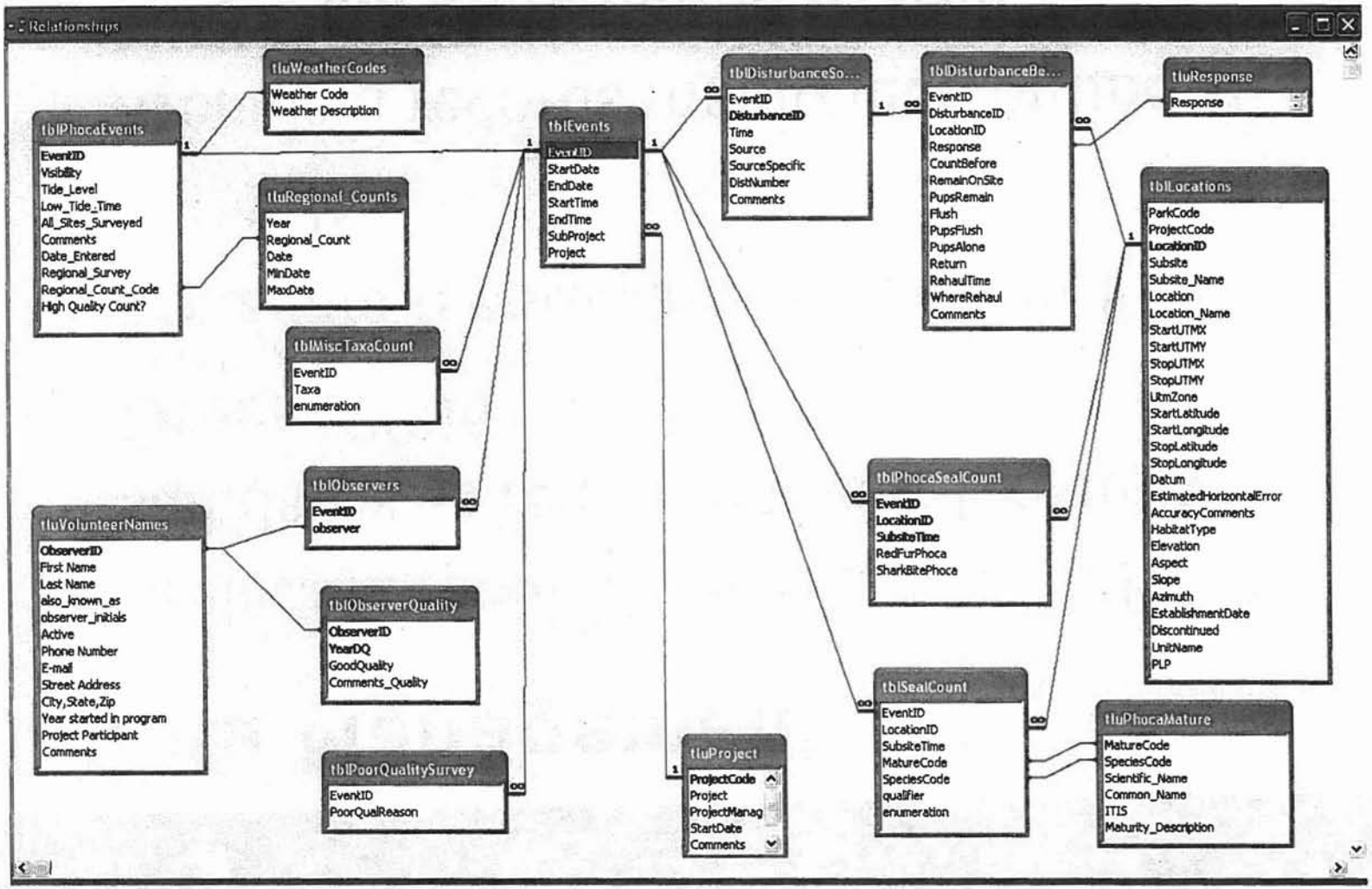

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# Data Management

- Metadata records compliant with FGDC standards as required under Executive Order 12906
- Metadata records accompany all FOIA requests
- Metadata records maintained online at NPS Data Store public website

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NR/GIS Metadata: Formal Metadata View - Windows Internet Explorer

http://science.nature.nps.gov/nrdata/metadata.cfm?ID=40523

File Edit View Favorites Tools Help

NR/GIS Metadata: Formal Metadata View

## NPS Data Store

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Application Home » | Search Results | Dataset Catalog View | Formal Metadata View

Login »

**Search**

Select Search Type: All Records

and NPS Unit: All NPS Units

Category: All Area Categories

or Subject: All Subjects

Word Search:
Keyword ☑
Title ☑
Abstract ☑

pinniped

Search

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Metadata Standards »
NPS Metadata Profile »

**Links**

Metadata Tools & Editor »
GIS/Metadata Tools »
NPS GIS Clearinghouse » (search by map)
NPSFocus »
NPS I&M Program »

## SFAŃ Pinniped Database

### Metadata:

- NPS_Information
- Identification_Information
- Data_Quality_Information
- Entity_and_Attribute_Information
- Distribution_Information
- Metadata_Reference_Information

*NPS_Information:*
*NPS Metadata Master ID:* 40523
*NPS Metadata Purpose:* NPS, DataCat
*NPS Unit and Type:* SFAN (Network)
*Data Store Information:*
*Data Category:* Wildlife
*Dataset Catalog Information:*
*Subject:*Mammals
*Priority:*Medium
*Data_Type:*ANADIG
*Data_At_Park:*Yes
*File_Location:*At originator SFAN network
*Dataset_Extent:*
*Extent_Description:*
Coverage: IN & OUT , LOCATION: Pacific Ocean and San Francisco Bay Beaches in Marin and San Francisco Counties. Bounding Rectangle is the default rectangle for SFAN network.
*UTM Bounding Coordinates:*
*UTM_West:*
*UTM_East:*
*UTM_North:*
*UTM_South:*
*UTM_Zone.* 17
*UTM_Datum:* Other

Back to Top

Local intranet | 100%

start

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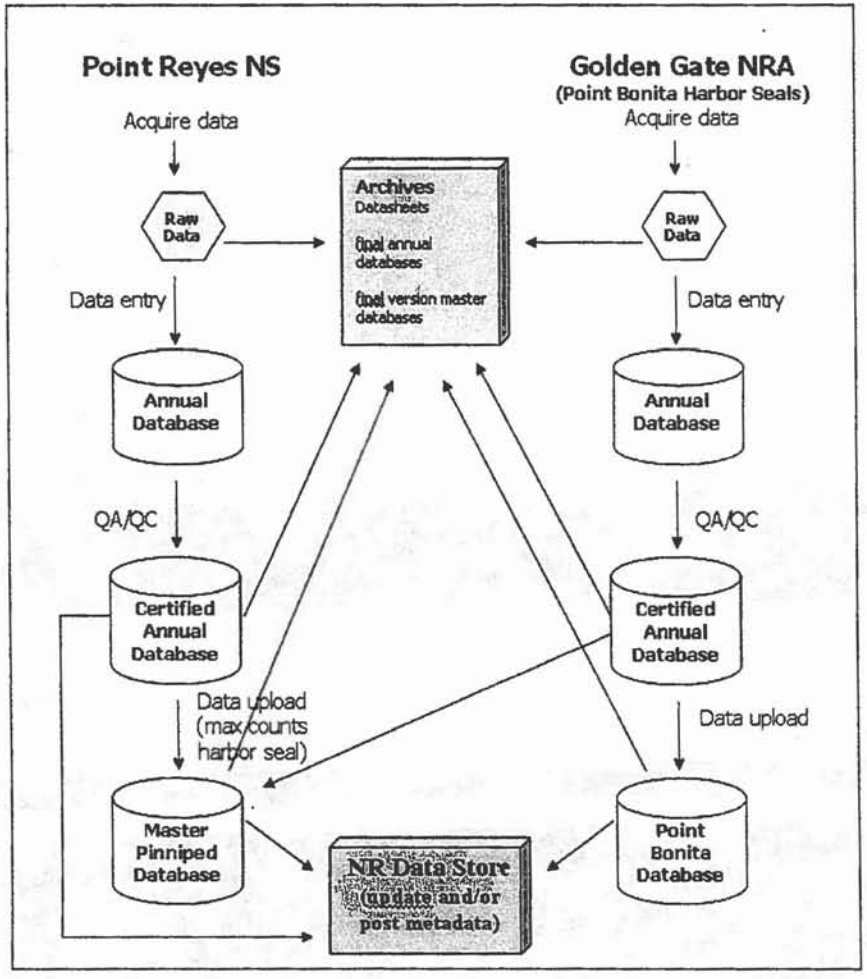
# Data Work Flow



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# Data Work Flow

- Annual Database – August to July of next year; all raw data entered
- Count data ranked as high vs. poor quality data.
- All data sheets error-checked against digital records
- 10% of data records randomly selected for additional error-checking by Data Manager
- Series of queries designed to check data for "logic" errors

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# Data Work Flow

- Merge annual dataset with master database.
- Harbor seal count data condensed to maximum count per survey.
- Disturbance data transferred as is.
- Archive data sets.
- Update database log - tracks significant database updates and data edits

# Data Reporting

- Annual monitoring report completed as soon as possible.
- Provides general overview of monitoring year. No subsite data.
- Maximum counts by location, comparisons with other monitoring years, disturbance counts by source, disturbance rates.
- Summaries based on maximum total count per location for breeding and molting seasons.
- Poor quality count data excluded from summaries
- Disturbance data not filtered for quality.

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# Data Reporting: Poor Quality Counts

- observer quality
- visibility
- other weather conditions (ie. wind, glare)
- incomplete survey

# Data Reporting: Disturbance Data

- Only "actual" disturbances included – head alert, flush, flush into water responses
- Disturbance data not filtered for quality based on observer experience, weather, tide, etc.

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**Photos courtesy of J. Thompson**

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# Data Reporting

- Annual report peer-review internal and external
- Reports approved by NPS Key Official
- Report posted to SFAN I&M website following approval

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NPS: Nature & Science - Networks: San Francisco Bay Area Network - Pinnipeds - Windows Internet Explorer

http://science.nature.nps.gov/im/units/sfan/vital_signs/pinnipeds/HarborSeals.cfm

File Edit View Favorites Tools Help

National Park Service
Inventory & Monitoring Program

Nature & Science NPS
Input Search Here Search
Advanced Search
Search A to Z

Nature & Science
Inventory & Monitoring

Network Home :
- About Us
- Inventories
- Monitoring
- Reports & Publications
- Network Contacts
- Data Liability Statement
- SFAN Intranet (NPS only)

Vital Signs
- Air Quality
- Amphibians and Reptiles
- Butterflies - T & E
- Fish
- Landbirds
- Landscape Dynamics
- Pinnipeds
- Plants - Communities
- Plants - Invasives
- Plants - Rare
- Raptors
- Riparian Habitat
- Snowy Plover, Western
- Spotted Owl, Northern
- Stream Flow
- Water Quality
- Weather and Climate
- Wetland Habitat

Parks: Nature & Science

## National Park Service Networks

NPS » Nature & Science » I & M » Networks » San Francisco Bay Area » Vital Signs » Harbor Seals

### San Francisco Bay Area Network
### Harbor Seals

Harbor seals (*Phoca vitulina richardii*) are the dominant and only year round resident pinniped in the San Francisco Bay Area, California. Within the San Francisco Bay Area, the population at Point Reyes represents the largest concentration of harbor seals in the State of California, other than the Channel Islands. Much of the Point Reyes coastal zone remains fairly pristine and provides excellent marine and terrestrial habitat for seals to rest, molt, feed, and breed where human encroachment is minimal. Long-term monitoring studies of harbor seals have been conducted at selected colonies for 30 years, and are currently conducted at 7 locations along the Point Reyes seashore and at Point Bonita in the Golden Gate National Recreation Area.

**Field Surveys**

- Surveys are conducted weekly at 12 sites during the breeding season (March - June) of each year.
- Bi-monthly surveys are conducted for all pinnipeds year-round.
  For more information on becoming a volunteer, contact the Harbor Seal Coordinator

**Project Updates 2009**

Harbor Seal Update and Summary Graphs - 8/3/2009
Harbor Seal Update and Summary Graphs - 7/8/2009

**Annual Reports**

Annual Report 2008

Annual Report 2007

Annual Report 2006

Local intranet 100%

# 80% decline at OB in 2007

- Sheltered Wilderness, public testimony
- 80% estimate of decline in use of OB in 2007 compared to 2004 was based on best professional judgment from previous years of study
- Peak pup count date at DE in 2007 was similar to other years but at OB it was later
- Count of April 23 used although actual peak later discovered to be May 4
- Actual decline at OB from 2004-2007 based on May 4 peak was 53% for adults, 65% for pups and 56% overall.

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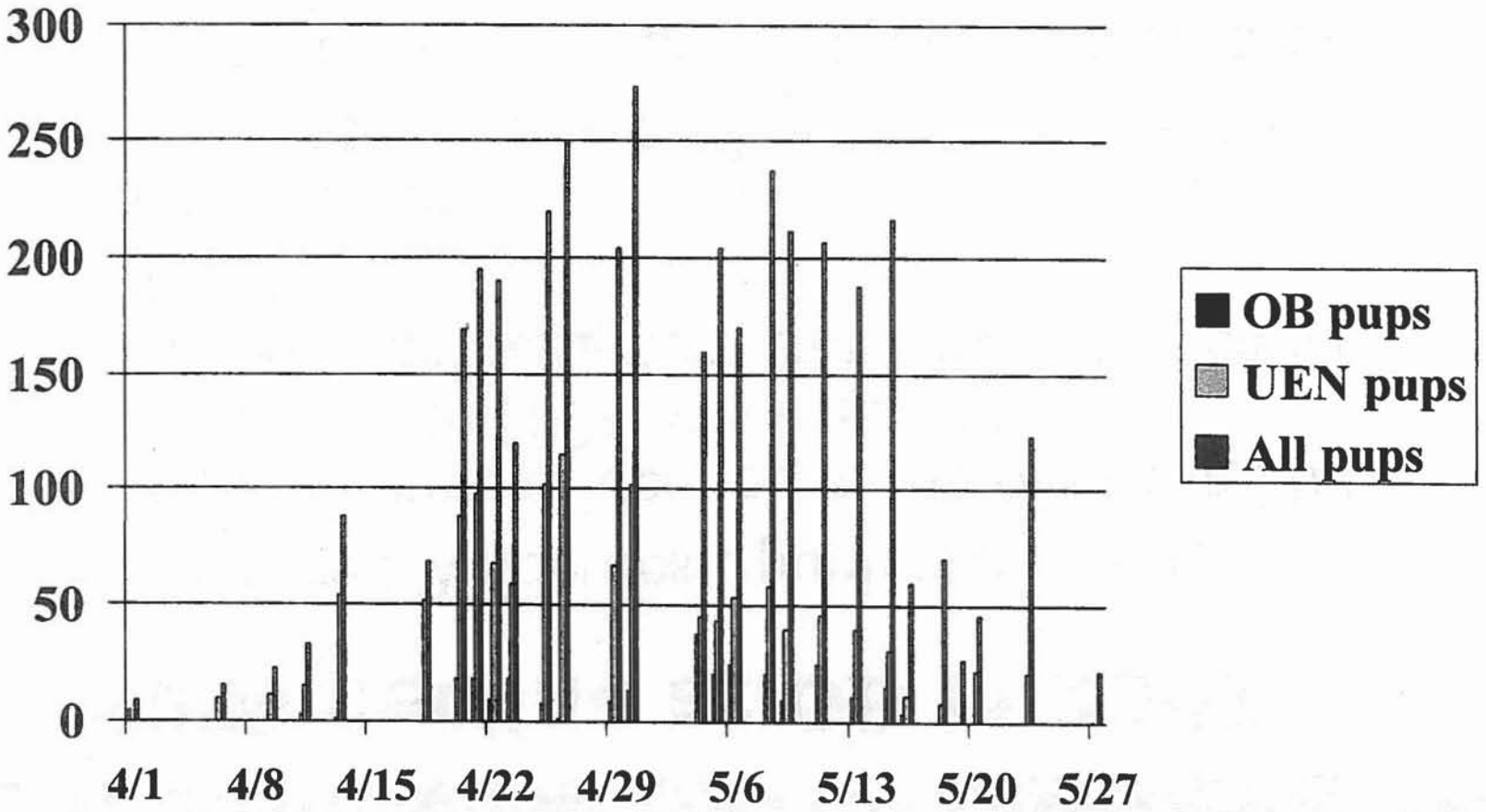

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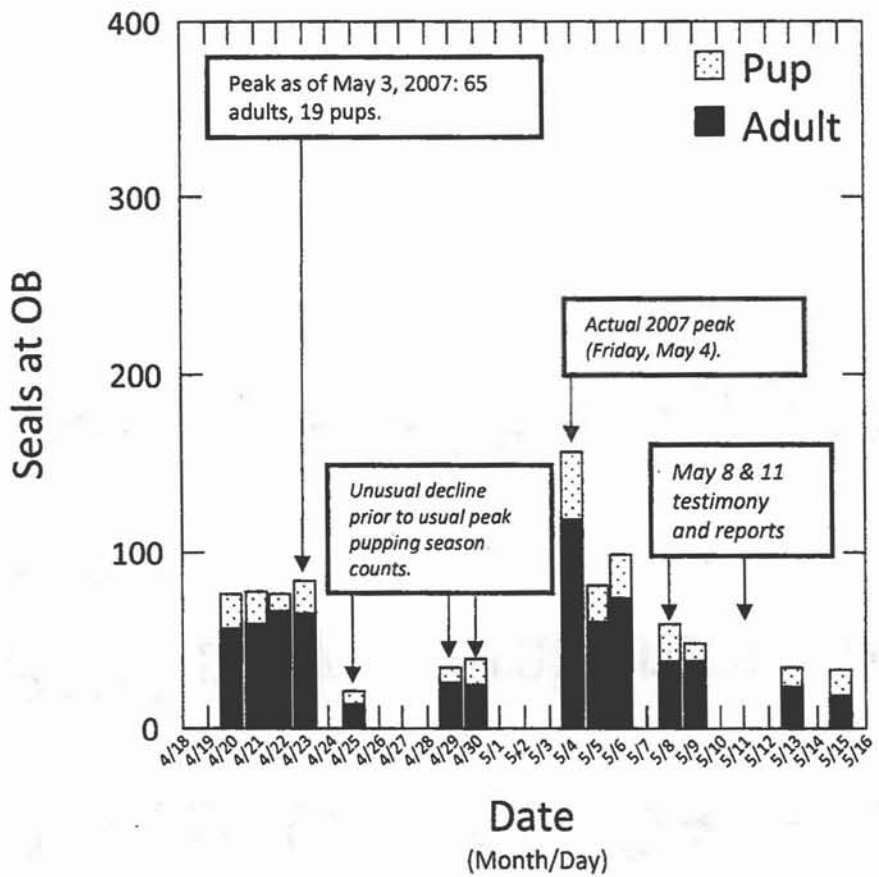


Figure 1. Harbor seal counts at Drakes Estero subsite OB in 2007. NPS used data available through May 3 to prepare May 8 and 11 testimony and reports. This is why the 80% decline was presented.

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# DBOC Disturbance Data

- Only DBOC may operate motorboats in Drakes Estero
- Harbor seal use sandbars at higher tides

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Sandbar OB on falling tide. 3 hours and 35 min prior to low tide of 0.89 ft (Golden Gate).

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Sandbar OB on falling tide. 2 hours and 45 min prior to low tide of 1.68 ft (Golden Gate).

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# DBOC Disturbance Data

- Only DBOC may operate motorboats in Drakes Estero
- Harbor seal use sandbars at higher tides
- Observer quality not related to disturbance data
- Sound travels
- Multiple subsites grouped under one disturbance source/time

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Photo courtesy of R. Campbell

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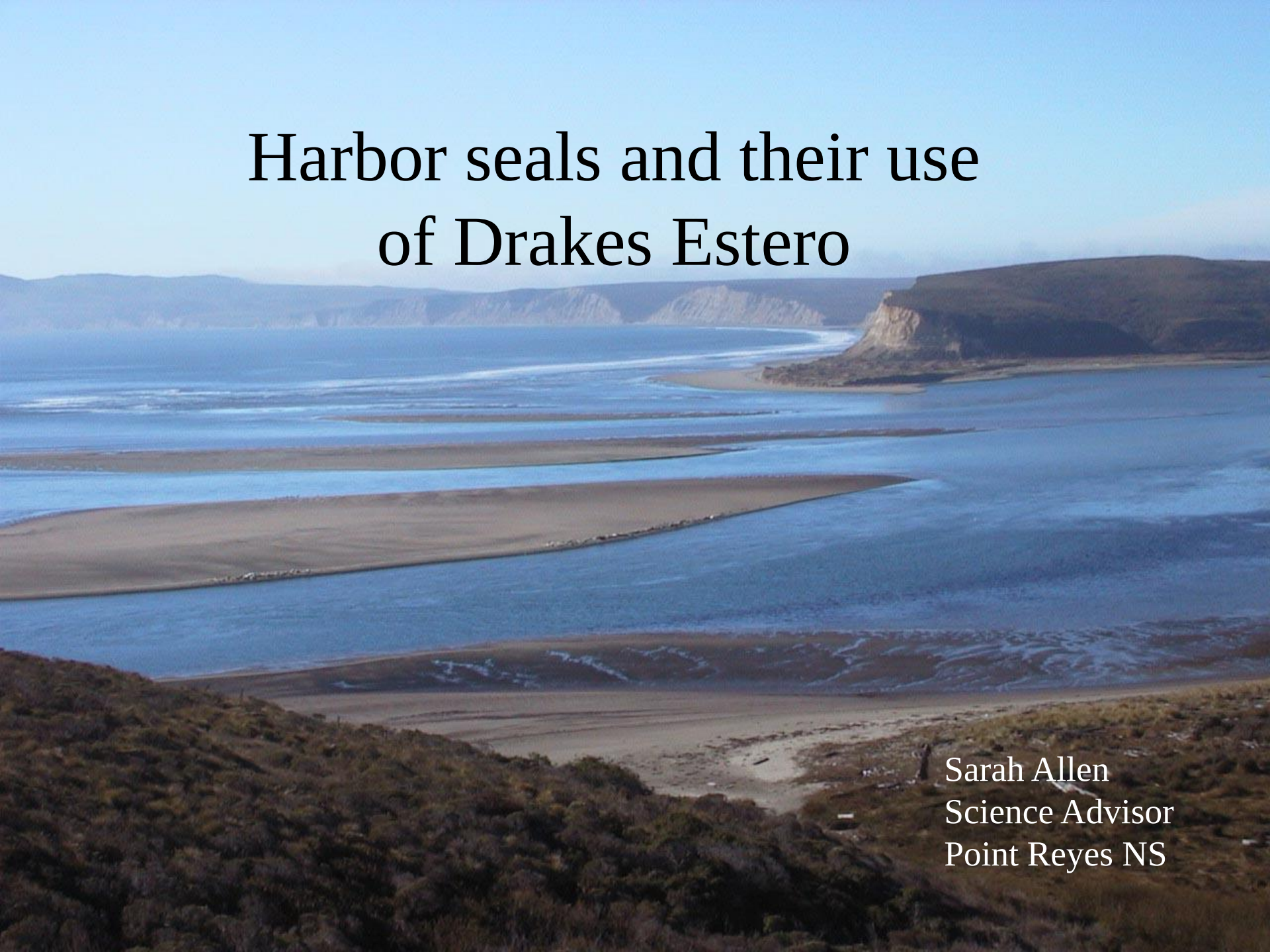
# DBOC Disturbance Data

- Only DBOC may operate motorboats in Drakes Estero
- Harbor seal use sandbars at higher tides
- Observer quality not related to disturbance data
- Sound travels
- Multiple subsites grouped under one disturbance source/time
- Data edits, additions
- Program organization, transition from PORE to I&M

# Harbor seals and their use of Drakes Estero



Sarah Allen
Science Advisor
Point Reyes NS

# Outline

- Regional significance
- Daily activity patterns
- Seasonal patterns
- Spatial use
- Population trend
- Disturbance

# Sources of information on Drakes Estero

- Baseline study of all haul outs in Point Reyes

  Allen and Huber 1982-83 and 1983-84

- Human interactions

  Allen and Huber 1983-84

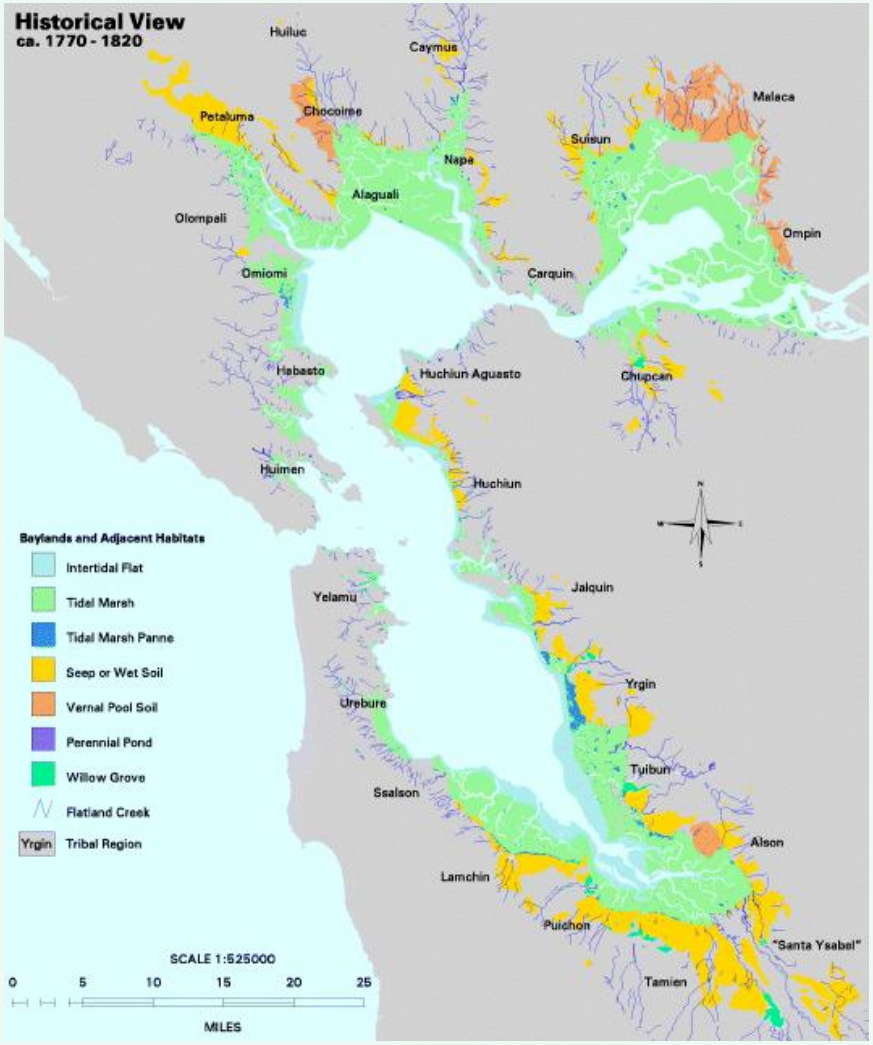
- Movement and activity pattern study 1985-88

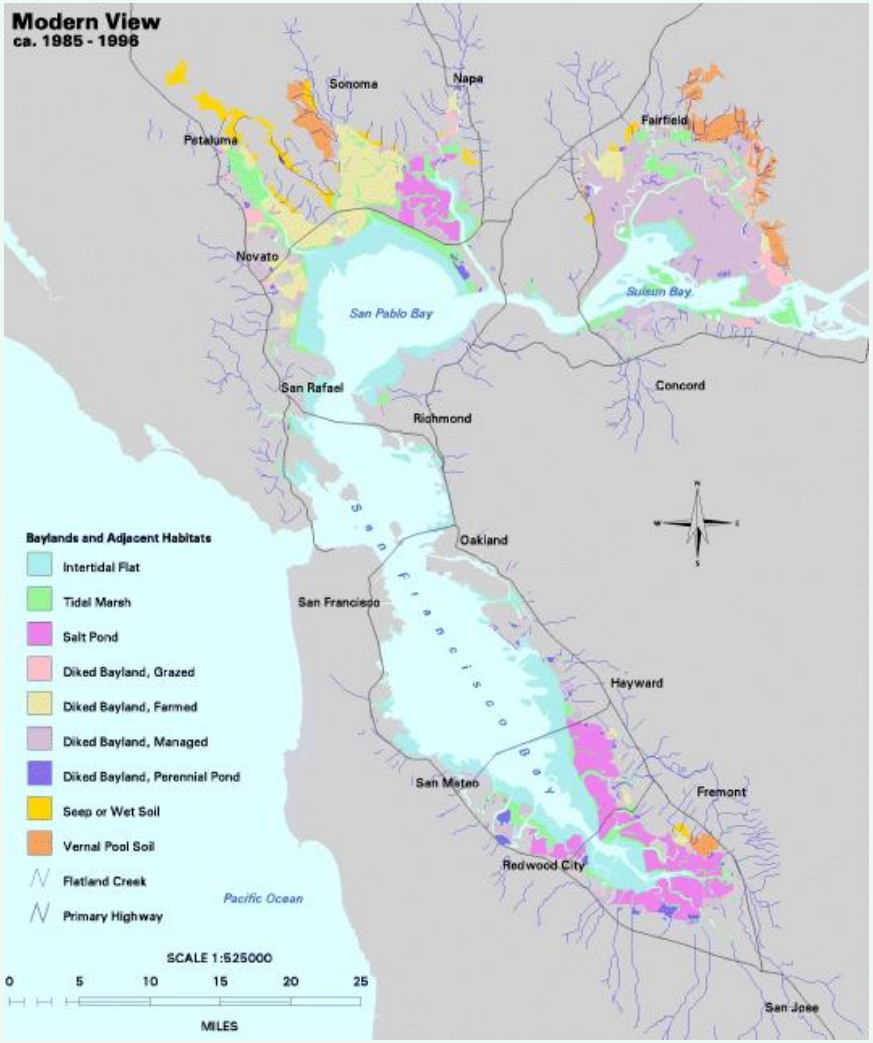
  Allen Miller 1988

- Monitoring 1996-2009

  NPS pinniped monitoring database

# Urbanization of San Francisco Bay

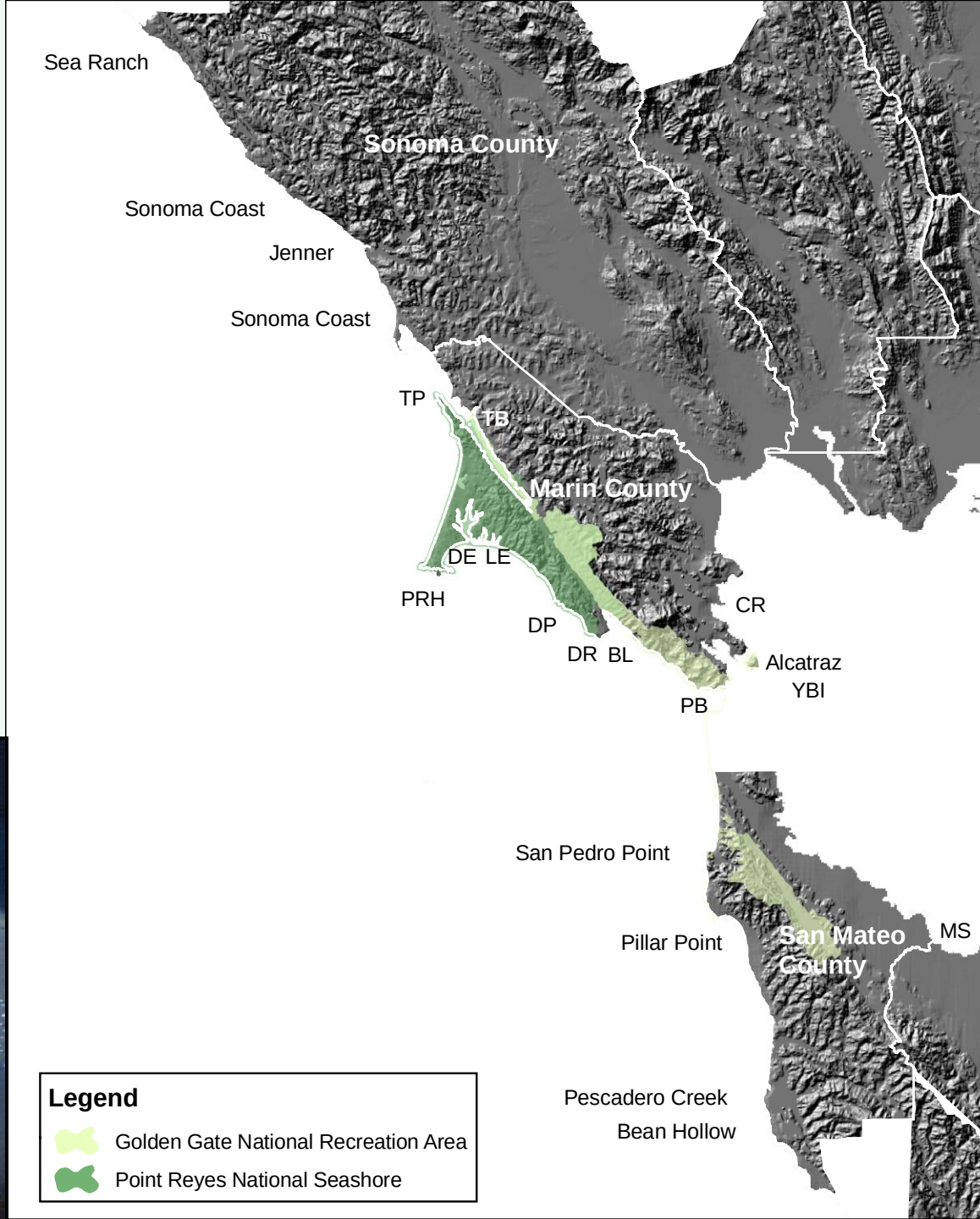



Maps from the San Francisco Estuary Institute

# Regional harbor seal haul out sites

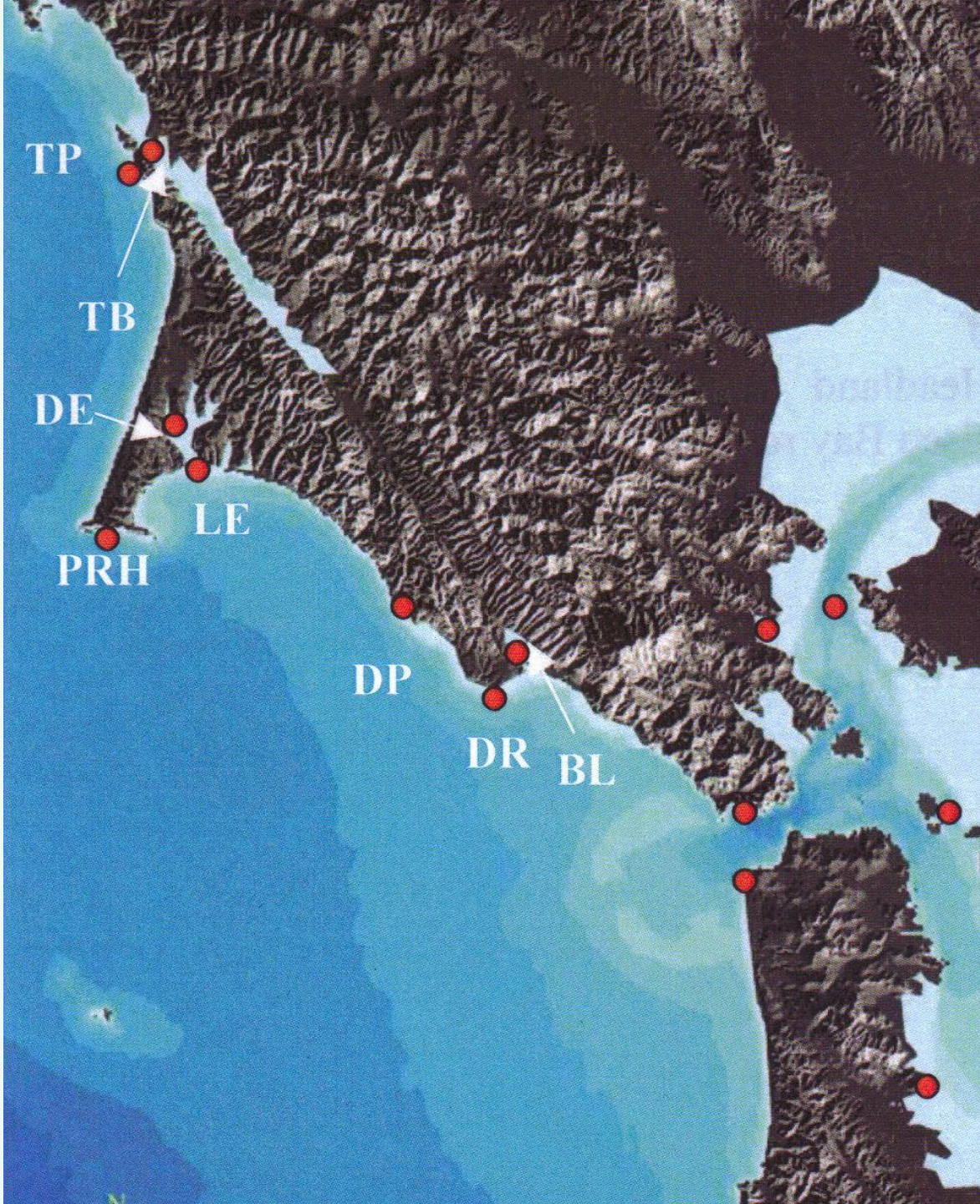
Marin County colonies = @ 20% of California mainland population (Lowry et al. 2005)



# Marin County Colonies

DE accounts for
24-30% of total seals
29-33% of total pups

(from NPS annual reports)



# Harbor seal activity patterns in Drakes Estero

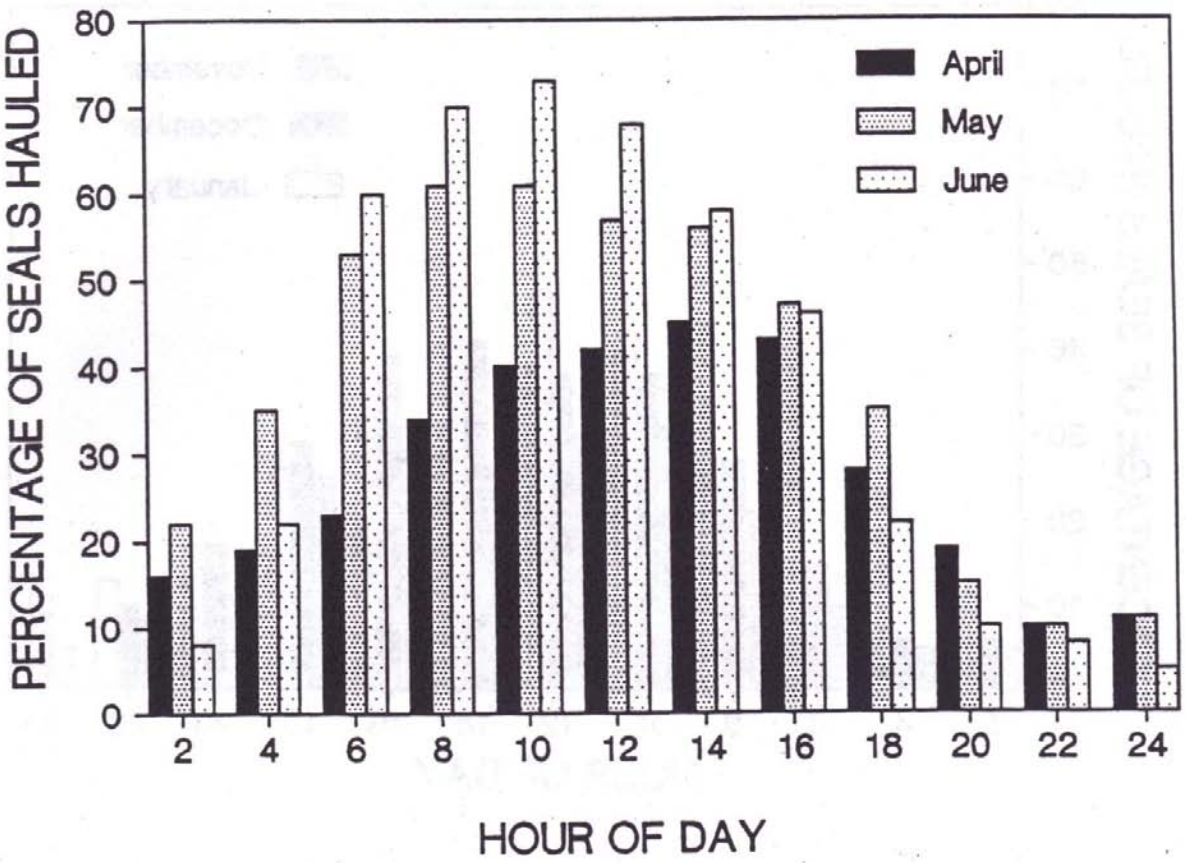
Many factors influence seal haul out patterns elsewhere: Loughlin 1978, Newby 1973, Slater and Markowitz 1983, Yochem et al. 1987, Jeffries 1986, Harvey 1987, Watts 1996, Thompson et al. 1997, Grigg et al. 2002, Lowry et al. 2005.

Daily Pattern
- Time of day
- Tide
- Hours per day

Seasonal Pattern
- Breeding (March-June)
- Molt (July-August)
- Non-breeding (Sept-Feb)

# Daily patterns



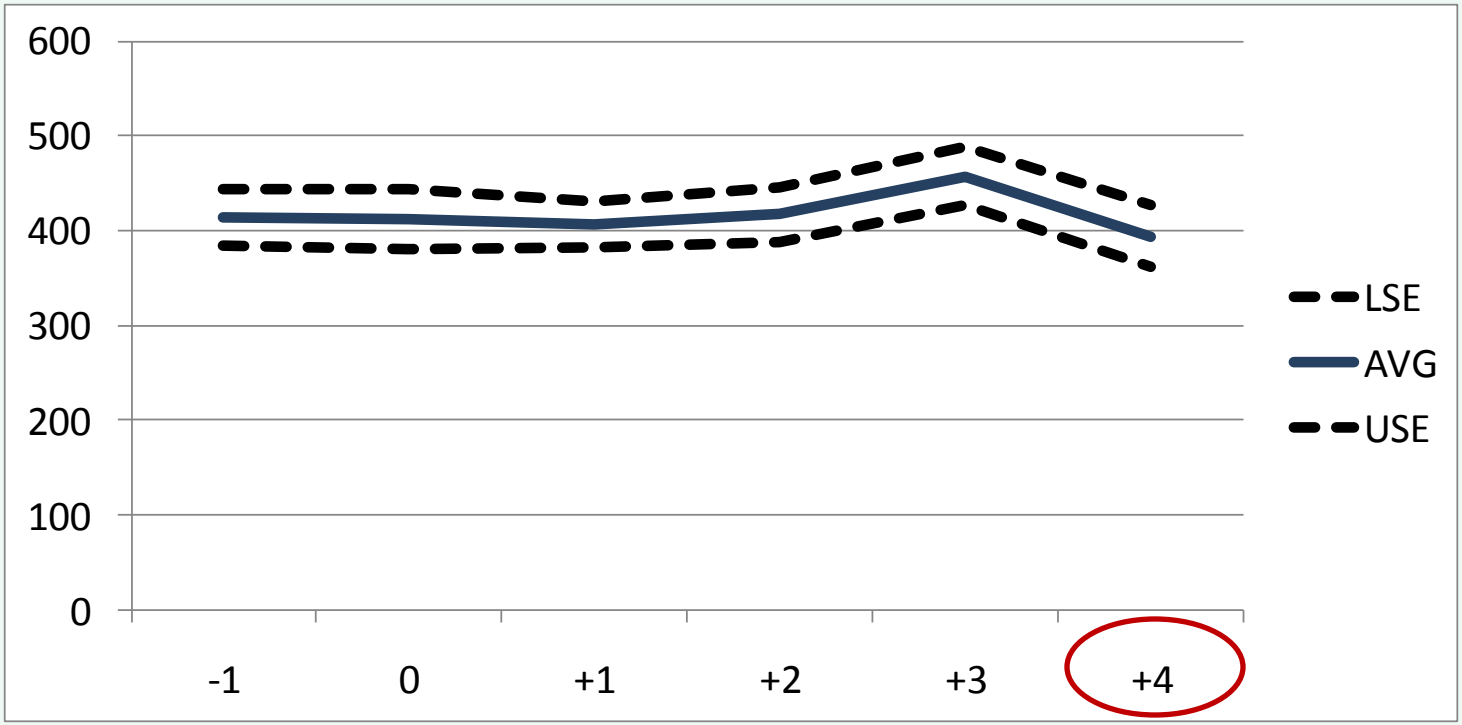



Percentage of radio-tagged seals hauled out by hour of day for the months April –June. Regardless of season, the largest number of seals hauled out from 0500-1600 hr. Similar patterns seen by Yochem et al 1987, Harvey 1987.

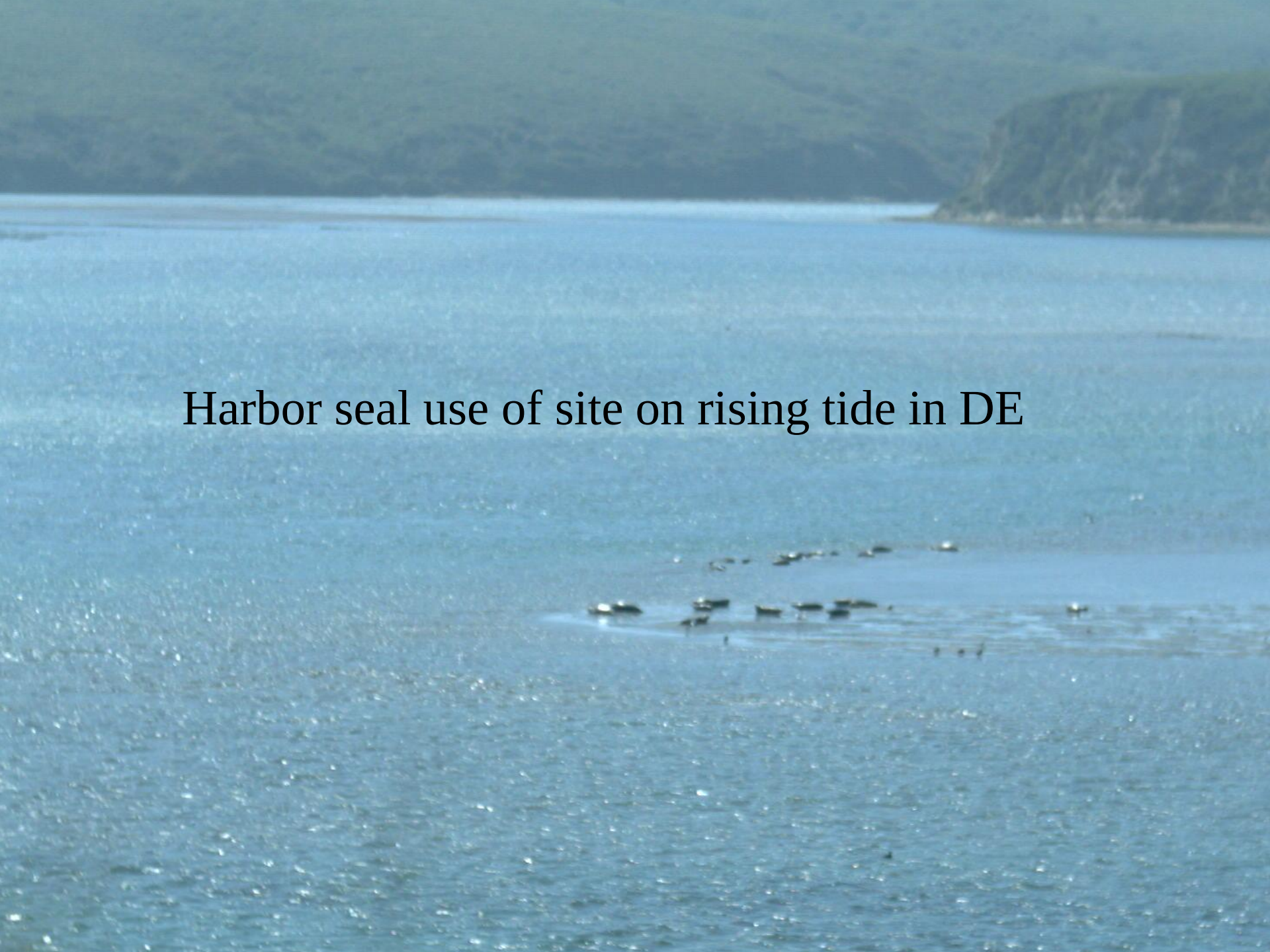
# Daily patterns

More seals hauled out relative to tide from -1 hr before to +4 hours after low tide. After +4 hours, numbers drop off. Similar pattern seen by Stein 1989, Harvey 1987.

Average number

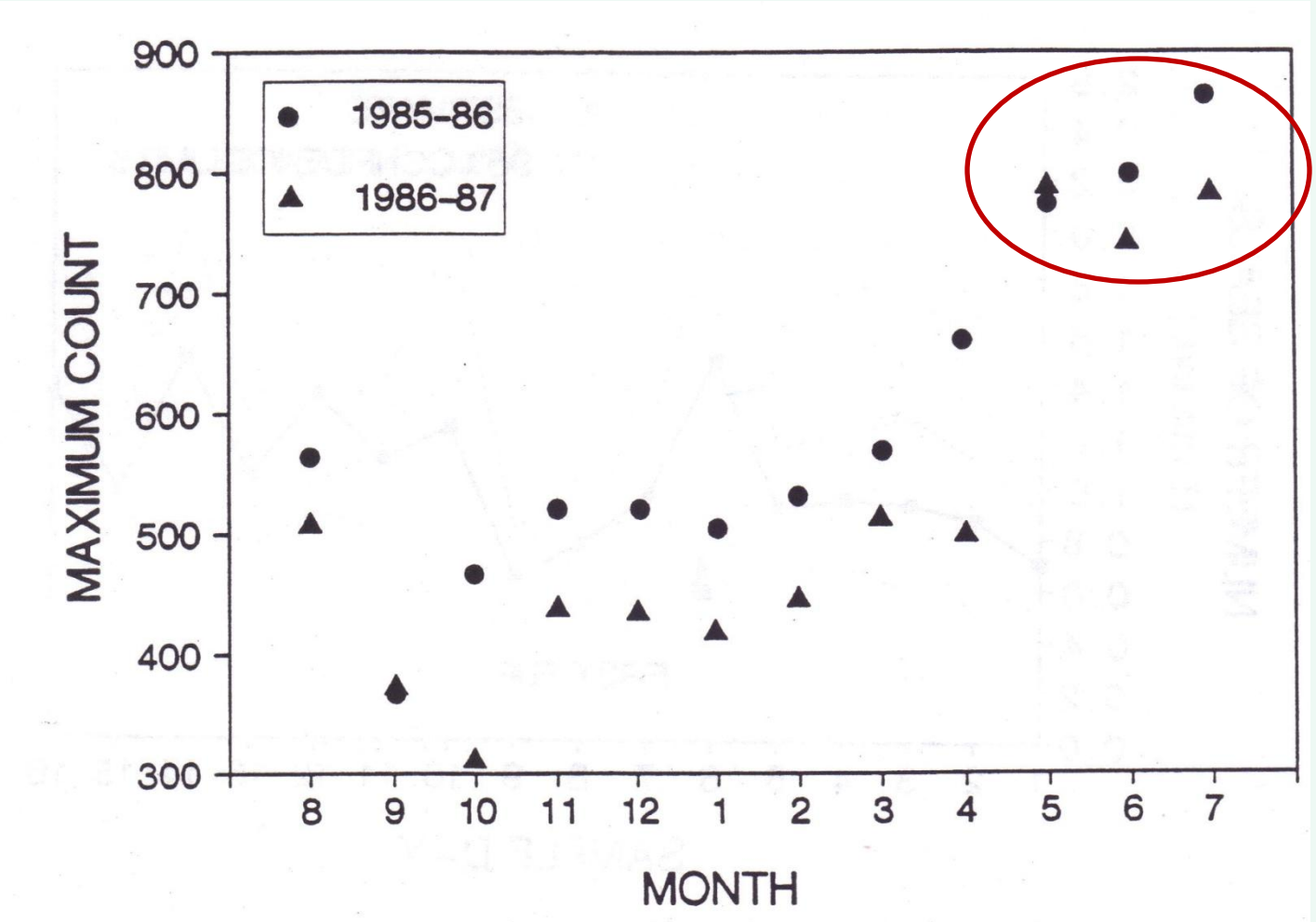



Hour from low tide


Harbor seal use of site on rising tide in DE

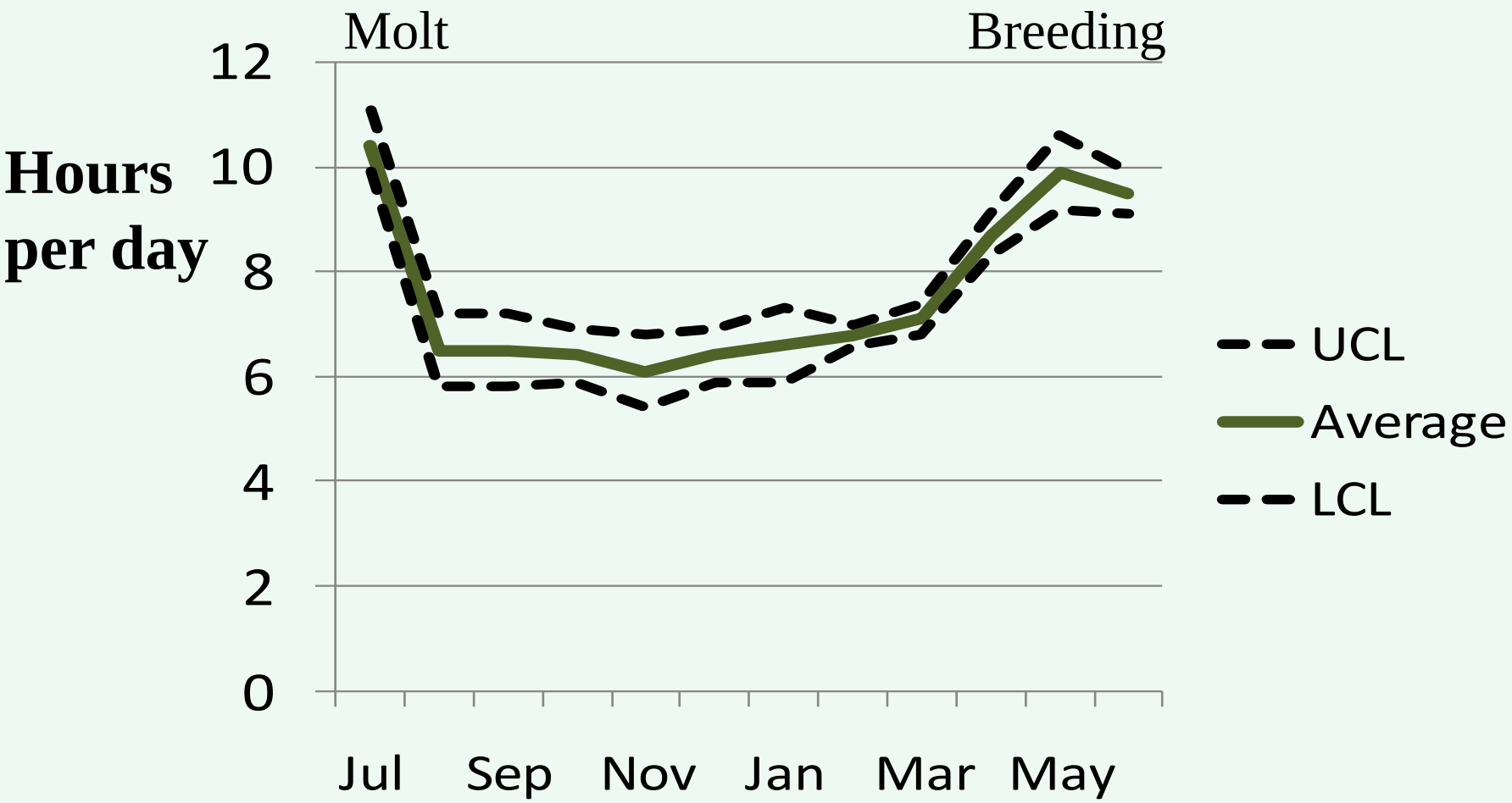
# Seasonal Patterns

Monthly maximum number of seals counted between August 1985 and July 1987. Similar to Yochem et al. 1987, Harvey 1987, Suryan and Harvey 1999)



# Seasonal Patterns

Average hours per day that radio-tagged female seals hauled out at Drakes Estero. Similar results to Stein 1989, Harvey 1987, Huber et al 2001.



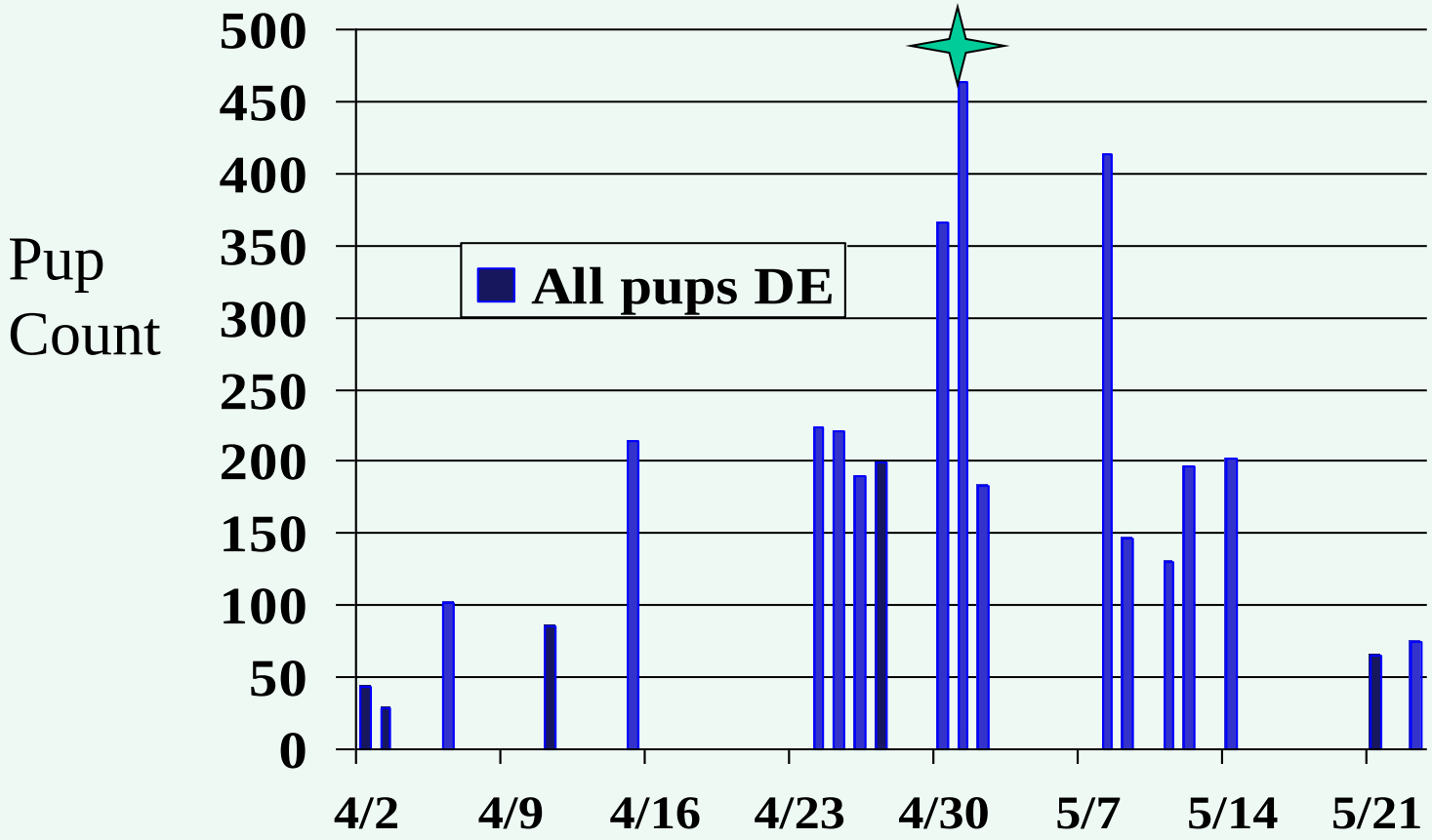
# First Pups

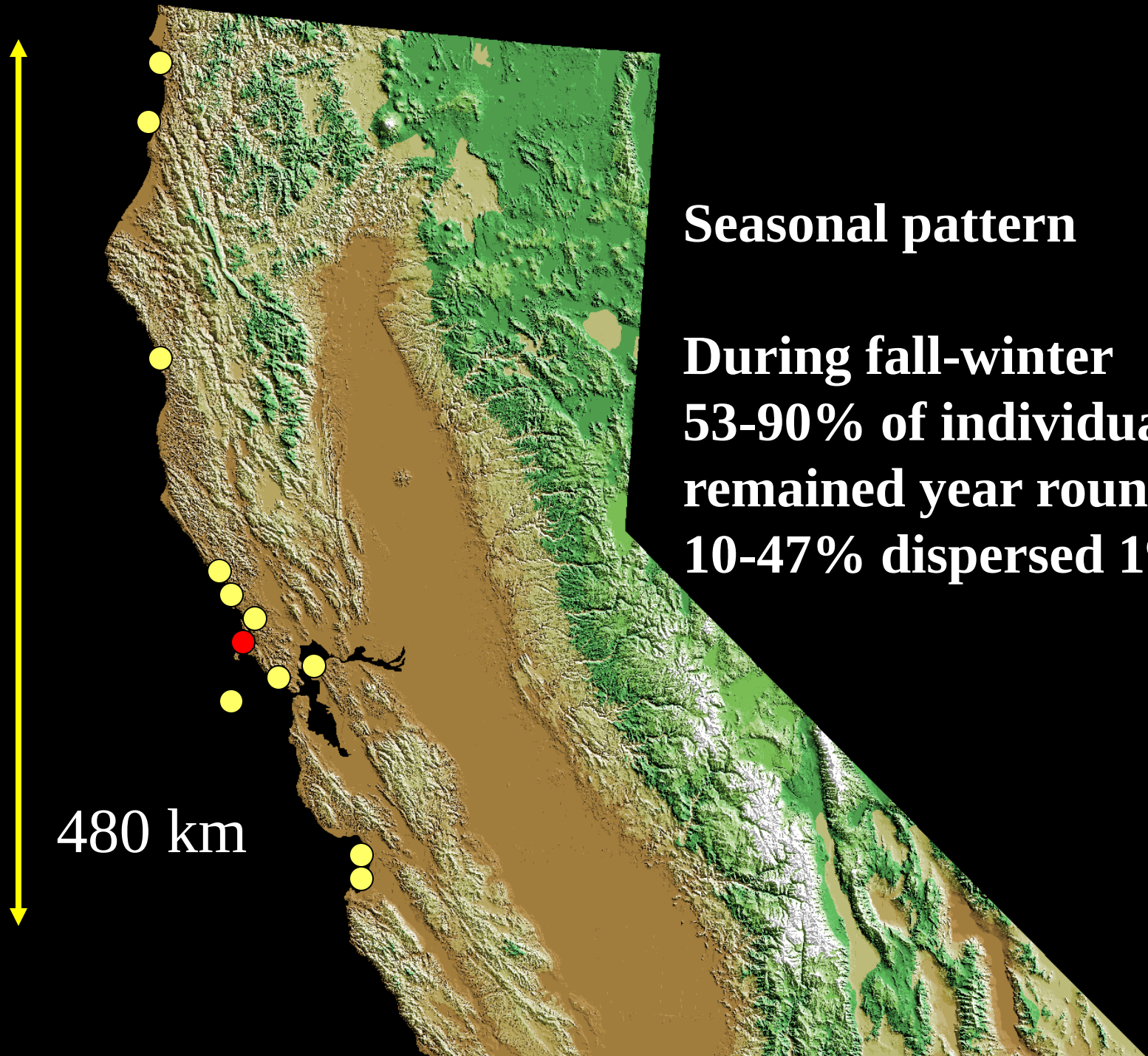
Date of first pup observed in the season by location, 2000–2008. (From NPS Annual Report 2009).

| **Year** | **Date** | **Location** |
|---|---|---|
| 2000 | March 14 | Point Reyes Headland |
| 2001 | March 16 | Tomales Bay |
| 2002 | March 3 | Drakes Estero |
| 2003 | March 27 | Bolinas Lagoon |
| 2004 | March 20 | Double Point |
| 2005 | March 6 | Drakes Estero |
| 2006 | March 9 | Double Point |
| 2007 | March 2 | Double Point |
| 2008 | March 16 | Bolinas Lagoon |

# Pupping Season

Regardless of year, peak pup count for DE and region is between last week of April and first week of May. Proportion of pups is @ 0.3 regardless of year. (Example from 2004 NPS database).






**Seasonal pattern**

**During fall-winter 53-90% of individual seals remained year round but 10-47% dispersed 1985-87**

# Spatial Patterns

**Upper** - UEN, OB, UEF
**Middle** -A, A1
**Lower** – DB, DEM, L

**Isolated sandbars**
A before 2003,
A1, UEN, OB, UEF, DEM

**Attached to mainland**
L, DB, A later after 2003

# Spatial Patterns

Females preferred isolated sand bars (A, A1 and U (includes UEF, OB and UEN) significantly more than sites attached to mainland (L). Segregation of sexes only occurred during the breeding season. This pattern persists to the present. Segregation seen at other sites by Knudtson 1977, Stein 1989, Slater and Markowitz 1983.

| | Breeding Location | | | |
|---|---|---|---|---|
| Sex | A | A1 | L | U |
| Female | 55 | 76 | 14 | 52 |
| Male | 20 | 9 | 21 | 14 |

$X^2 = 33.55$

$p < 0.0001$

# Spatial Patterns

Individual seals, particularly females, displayed strong within-site fidelity during the breeding season and remained entirely within DE for the first 2 weeks after birth.  Similar to other sites seen by Stein 1989, Thompson et al. 1994).

# Habitat change over time

Channel

Channel absent

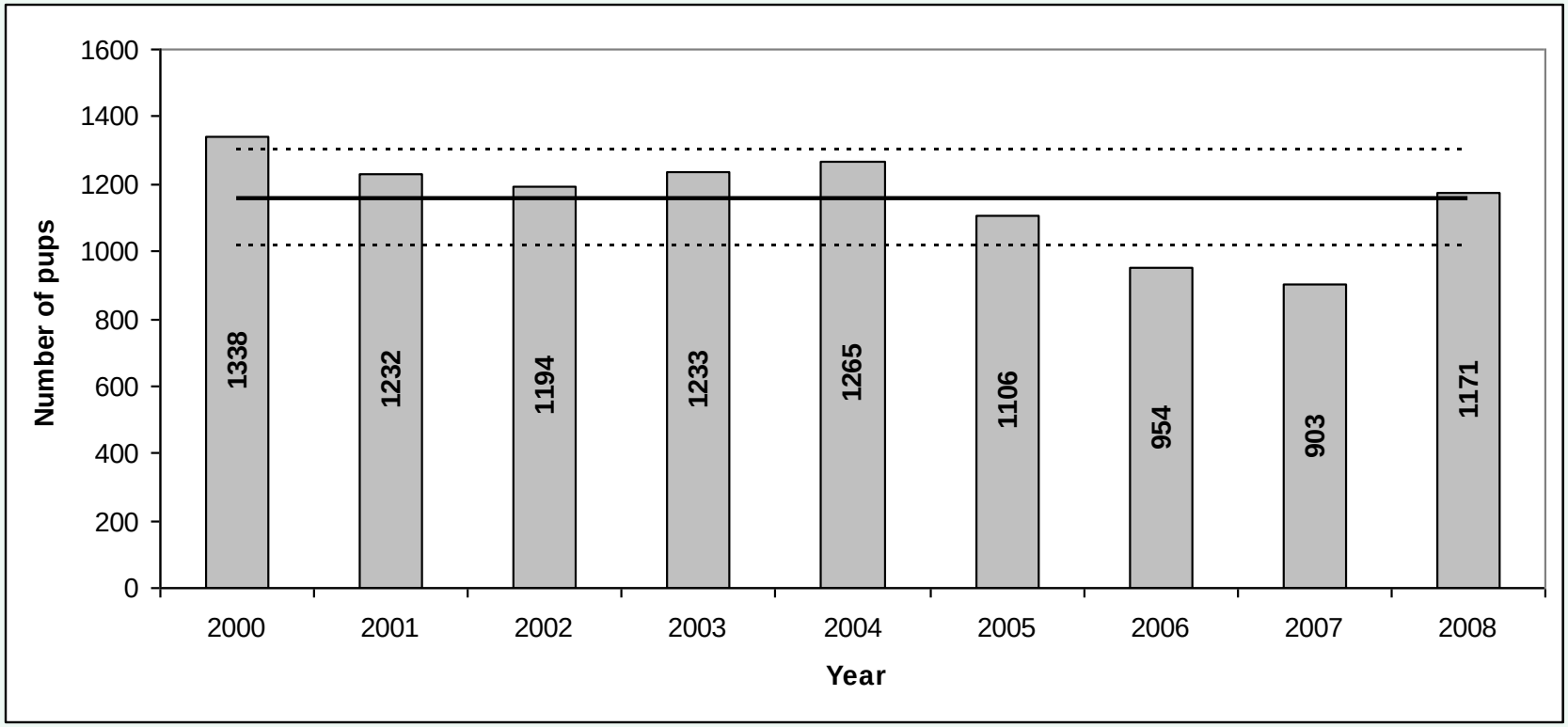
1986

2009

californiacoastline.org

# Population Trend

Maximum harbor seal pup counts for 2000–2008 at Marin County locations. The solid line on the graph represents the mean of the maximum pup counts from 2000-08 (mean = 1,155.1) and dashed lines represent one standard deviation from the mean (SD = 143.9; from NPS annual report 2009).



# Disturbance

## Defined by MMPA

The term “ harassment” means any act of pursuit, torment, or annoyance which—

(i) has the potential to injure a marine mammal or marine mammal stock in the wild. Level A Harassment

(ii) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering. Level B Harassment

## NMFS prohibits

The negligent or intentional operation of an aircraft or vessel, or the doing of any other negligent or intentional act which results in disturbing or molesting a marine mammal.

# Disturbance potential effects on pinnipeds

## Short-term – direct

•Disturb resting period by visual, sound or smell cues from human actions (Newby 1971, Johnson 1977, Allen et al. 1984, Suryan and Harvey 1999)

•Disrupt seals in water foraging or mating (NAS 2009)

•Pup separation and potential mortality (Johnson 1977, Kenyon 1972, Lawson&Renouf 1987, Jansen et al. 2003)

•Temporary displacement to subprime habitat (Ragen 1999, Stevens and Boness 2003)

## Long-term – indirect

•Reduced usage/abandonment (Bartholomew 1949, Newby 1971, Kenyon 1972, Schulmeister 1981, Allen&King 1991, Richardson 1995)

•Shift to nocturnal haul out (Paulbitski 1975, Grigg et al. 2002)

•Lower pup production (Slater&Markowitz 1983, Allen&Huber 1984, Ragen 1999)

•Reduced fitness from displacement from foraging areas, chronic stress, reduced nursing or resting of pups

•Permanent shift to subprime habitat leading to changes in demography and reduced population (Gerrodette and Gilmartin 1990)

# Seal responses to disturbance on land

- Head alert
- Flush to water
- Enter water

# Pinniped Response to Disturbance

## Head alerts – vigilance time in search of a predator

- Varies with sex, age, location (Sullivan 1979)
- Females with pups scan more often than other seals (Suryan & Harvey1999)
- Tomales Bay seals were disturbed more often and alerted significantly more times than other sites in Marin (Allen and Huber 1984)

## Distances triggering response on land

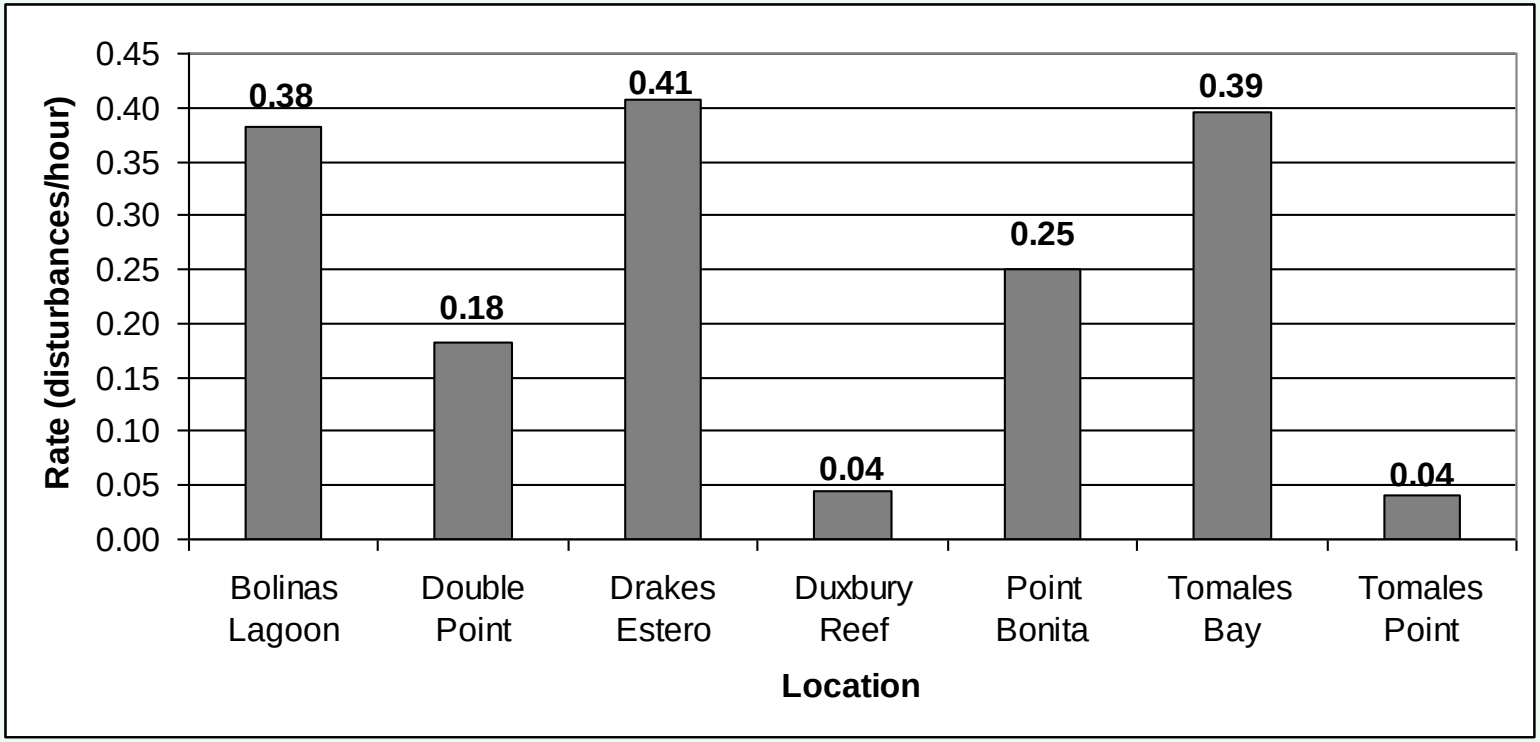
- Varies with species and population, and source
- NMFS guidelines = 300 ft (90 m)
- 50-600 ft (15-183 m) SF Bay (Alcorn and Fancher 1980)
- 80-500 m for small boats (Johnson and Acevedo-Gutierrez 2007)
- Within 200 m 75% of seals flushed (Jansen et al. 2003)
- 28-260 m seals flushed (Suryan and Harvey 1999)

## Recovery time

- Varies with species and location
- @ 28 min +/-21 for seals to rehaul in Bolinas (Allen et al. 1984)
- Counts typically do not return to pre-disturbance levels within the same tidal cycle – (Suryan and Harvey 1999)

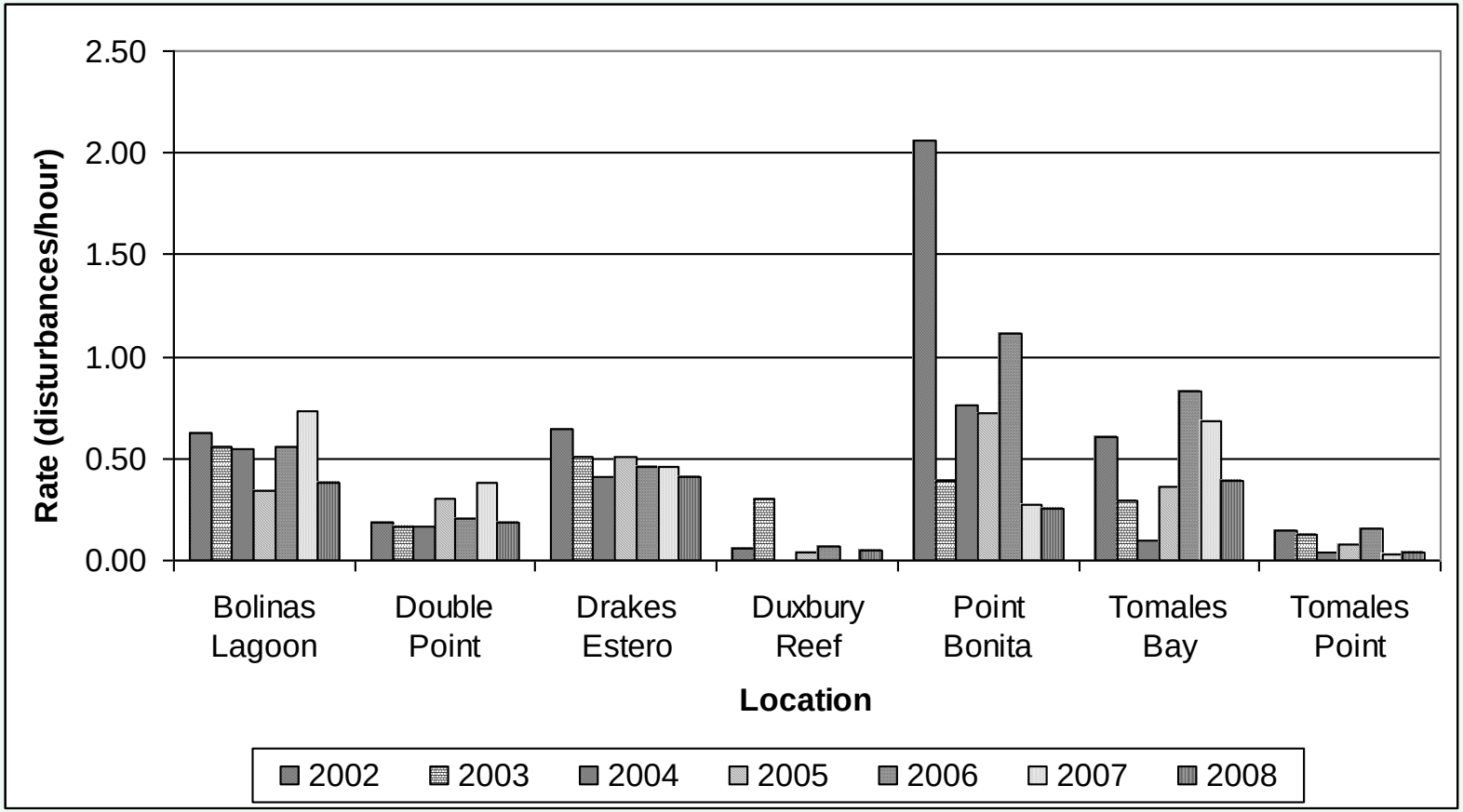
# Disturbance Rate

Rates of disturbances per hour at Marin County locations from March through July 2008. Only actual disturbances (head alert, flush, flush water) were used and survey time was based on observation time for all complete surveys (with or without disturbances). (From NPS Annual Report 2008).



# Disturbance Rate

Rates of disturbances per hour at Marin County locations 2002–2008. Only actual disturbances (head alert, flush, flush water) were used, and survey time was based on observation time for all complete surveys (with or without disturbances). (From NPS Annual Report 2008).



# Predators disturb seals

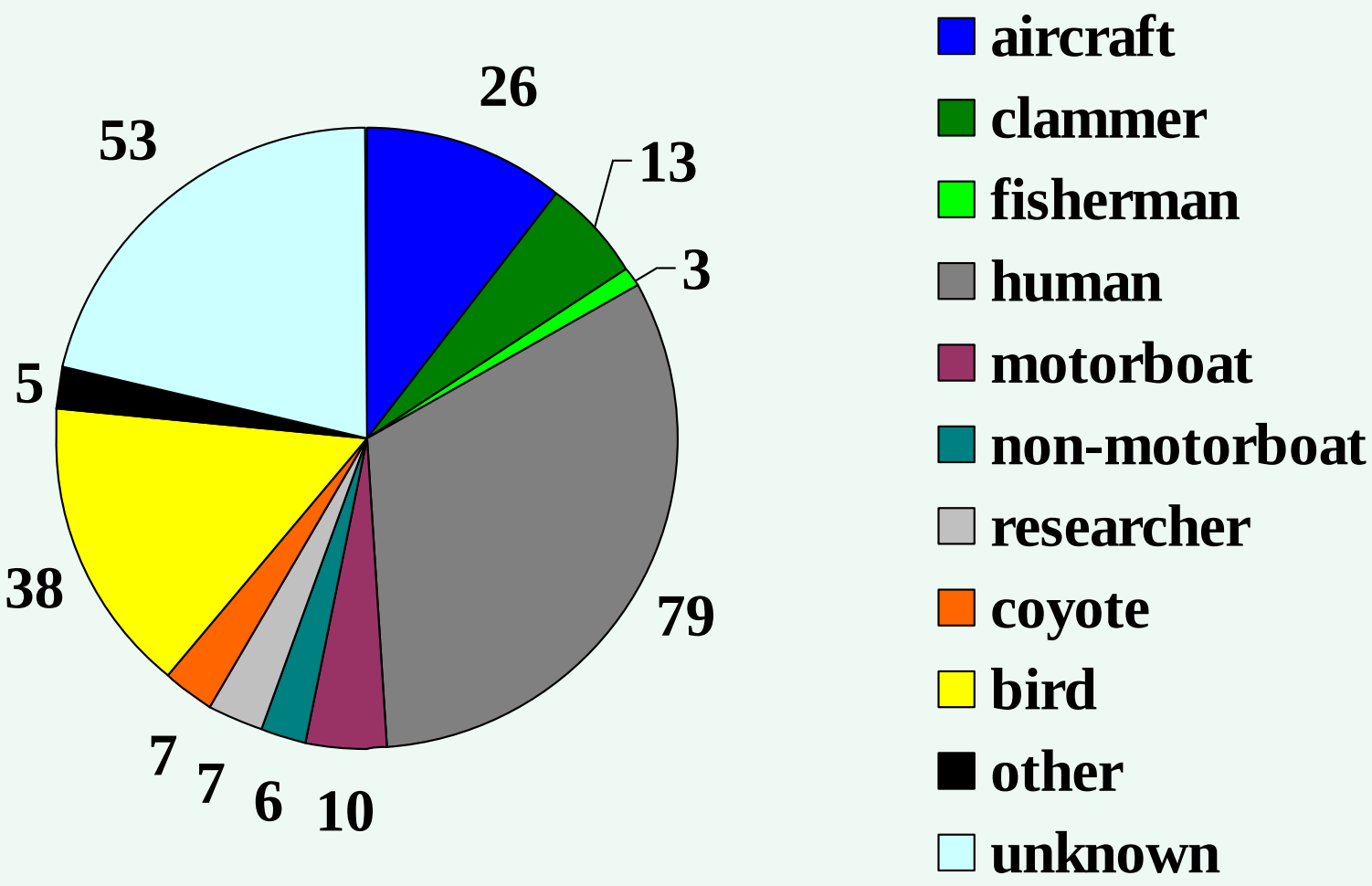
Photos NPS

# Human activities at Point Reyes disturb seals

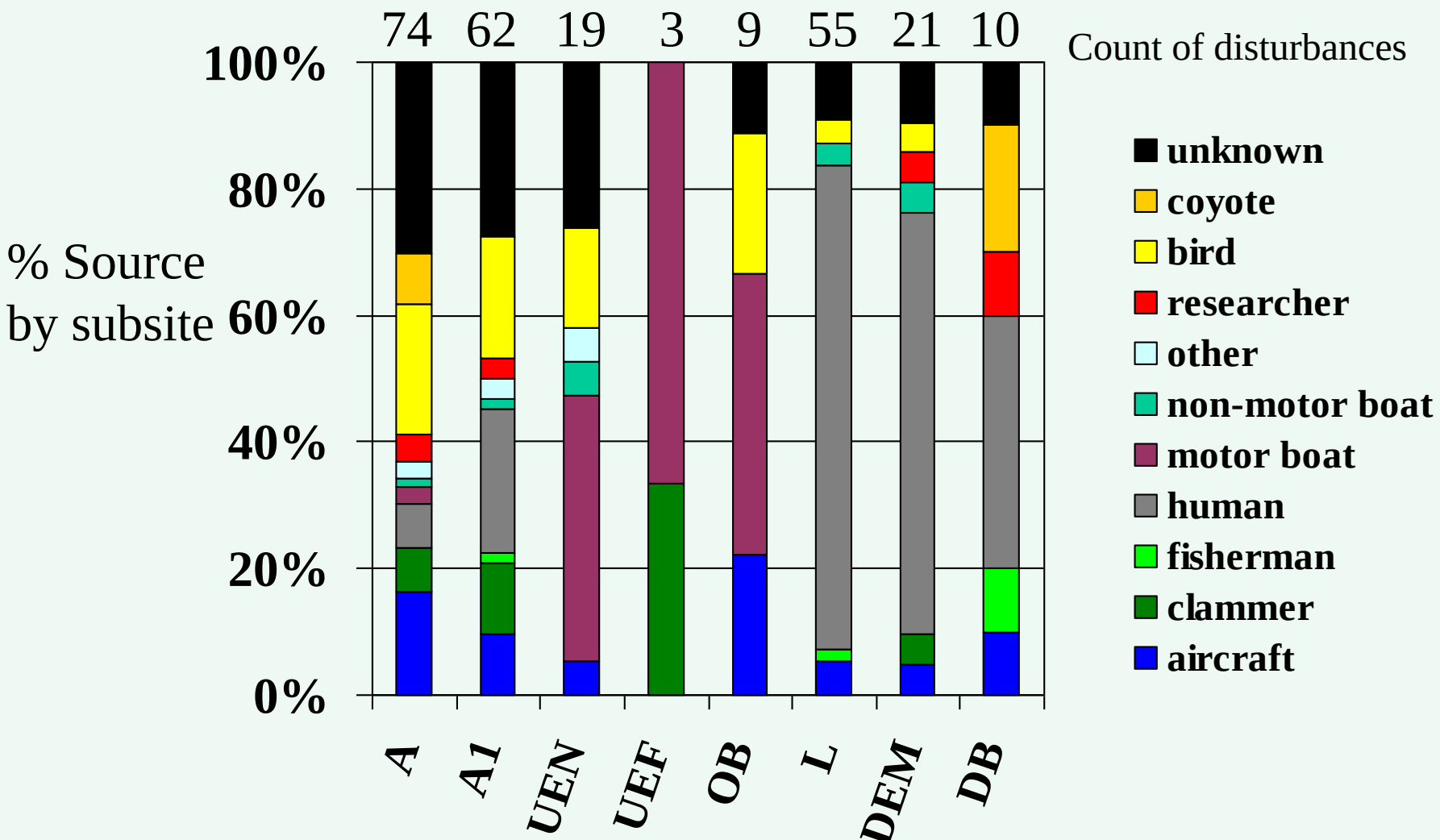
# Mariculture activities that disturb seals in DE

- Bags/equipment on or adjacent to haul outs
- Boat traffic
- People adjacent to haul outs tending equipment for extended periods

# Number of disturbances by source at Drakes Estero
# Breeding seasons 2000-2009



# Sources for disturbance by subsite for breeding seasons 2000-2009



# Summary

- DE is a significant colony in the state, largest in Marin County
- More seals are present during breeding season
- Seals haul out more hours per day during the breeding
- Peak pupping occurs the last week of April, first week of May
- Females prefer isolated sandbars for breeding
- Disturbance displaces seals
- More disturbances occur at Limantour – short duration
- Disturbances from mariculture at isolated sandbars – longer duration

# Acknowledgments

Farallones Marine Sanctuary Association
NOAA Fisheries
Gulf of Farallones National Marine Sanctuary
San Francisco State University students
Stewards of Coast and Redwoods
The Marine Mammal Center
Volunteers of Point Reyes Pinniped Monitoring

UEF
QB
UEN
A
A1
DB
DEM
L

**Inclusion of 2008 harbor seal data into the analysis presented in Becker et al. 2009**

Ben Becker, Dave Press, and Sarah Allen

## Introduction

The National Research Council (NRC 2009) concluded that the data analysis for 1997-2007 presented in Becker et al. 2009 may "serve as indicators of potential negative interactions between oyster harvest and seal attendance at these subsites" (NRC, p. 32). However, the NRC suggested that inclusion of the 2008 data could "call into question" the continued significance of the results. Here, we include the 2008 data in the model using more robust methods than those found in Becker et al. 2009, and show that the new data are fully consistent and supportive of the previously reported model with essentially no changes in model coefficients or significance. We extend the analysis to use an extension of Generalized Linear Models known as Generalized Estimating Equations (GEE) (Venables and Ripley 2002, Faraway 2006, Zuur et al. 2009) that explicitly model the temporal autocorrelation of multiple harbor seal counts taken during the breeding season within each year. The GEEs also allow flexible distributions for the entire dataset (which was overdispersed) and for the within year counts. GEEs are therefore a form of mixed-effects modeling.

## Dataset

Same as that used in Becker et al. 2009, with the addition of:

1. Oyster harvest for 2008 was 437,000 lbs (NRC 2009, p. 49).
2. Breeding/pupping season subsite counts at OB and for the entire lower estero (subsites A, A1, L, DBS, and DEM) for 2008 were included. These underwent the same QA/QC described in Becker et al. 2009 and are derived from the NPS harbor seal monitoring database (Table 1).
3. We modeled years since ENSO as a "log(years since ENSO+1)" because observational and theoretical evidence suggest that the ENSO effect should taper off and not be linear.
4. GEEs were run in R 2.9.0 using the "geeglm" function in the "geepack" library with year as the grouping variable to account for within year autocorrelation of counts at the same subsite (id = "fYear") and the correlation structure set as autoregressive ("ar1") since the counts were during a one month period and counts closer together should have higher correlation since the counts generally rise, peak, and fall during the April 15 – May 15 period. We used an initial data distribution of poisson, but the GEE is non-parametric and only uses this as a starting point.
5. Since the GEE functions in R do not allow for a negative binomial distribution, to control overdispersion we modeled the rounded square root of total counts at OB with a poisson distribution.

**Table 1.** Dates of 2008 surveys included in the new analysis and total counts (adults+pups) at subsite OB and for the Lower Estero (density-dependence control).

| Date | OB_Total | LowerTot |
|---|---|---|
| 4/15/2008 | 71 | 469 |
| 4/21/2008 | 98 | 372 |
| 4/25/2008 | 121 | 458 |
| 4/29/2008 | 86 | 456 |
| 4/30/2008 | 107 | 480 |
| 5/2/2008 | 97 | 616 |
| 5/9/2008 | 0 | 508 |
| 5/10/2008 | 81 | 434 |
| 5/13/2008 | 65 | 477 |

**Results**

Residual plots versus model predictions showed no issues with the model (Fig. 1). Overall, the results are similar to Becker et al. 2009, with both ENSO and Oyster harvest best explaining seal use at OB (Table 2). Lower estero total (density dependence) was not important and the P value ranged from ~ 0.26 - 0.42, depending on whether daily or annual density dependence was used. Overdispersion was 1.85, and 1-step within-year temporal autocorrelation was 0.43. Both of these parameters are incorporated into the model and used to correct the standard errors and P values. If an interaction between ENSO and oyster harvest is included, it is also highly significant (and oyster alone remains significant), but we do not report it here. The negative coefficient for oyster harvest of -0.45 is in this case a marginal estimate, meaning that the effects of multiple samples within each year have been removed. It therefore differs from the coefficient in Becker et al. 2009, which was conditional on all the samples within each year (Zuur et al. 2009). Further, the estimate is for the effect on the square root of OB counts, so for comparison with Becker et al. 2009, a fair comparison would be -2.10 (which is $-(1.45^2)$) for this conditional analysis versus -2.4 in the previous analysis.

Running the GEE without a transformation of counts at OB still results in similar significance of coefficients ($P < 0.03$ for oyster harvest), but overdispersion is quite large without the transform, and we therefore preferred the square root transform. See the Appendices for alternative forms of analysis that arrive at similar conclusions.

**Table 2:** Output from geeglm function in R. ENSO and Oyster harvest are both significant. Density dependence was not important and is therefore not presented in this model.

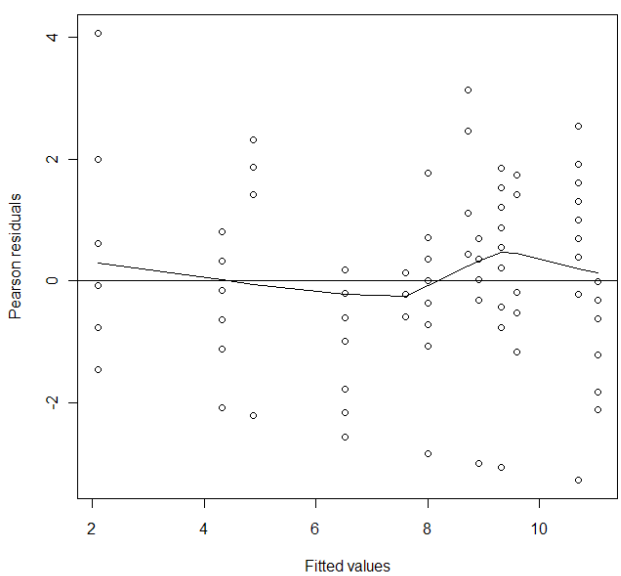
```
Call:
geeglm(formula = round(sqrt(OB.Total)) ~ log1p(ENSO.YRS) +
Oyster.new, family = poisson, data = may.08, subset = Year
< "2009", id = fYear, corstr = "ar1")

 Coefficients:
                 Estimate   Std.err  Wald Pr(>|W|)
(Intercept)      1.17e+00  2.36e-01 24.37  8.0e-07 ***
log1p(ENSO.YRS)  6.92e-01  1.42e-01 23.63  1.2e-06 ***
Oyster.new      -1.45e-06  4.99e-07  8.49   0.0036 **
---
Estimated Scale Parameters:
            Estimate Std.err
(Intercept)     1.85   0.239

Correlation: Structure = ar1  Link = identity

Estimated Correlation Parameters:
      Estimate Std.err
alpha    0.433  0.0984
Number of clusters:   12   Maximum cluster size: 15
```

**Figure 1.** Plot of residuals against model predictions for final GEE model. The model shows no structural issues with changes in variance or heteroscedasticity. Note that points are not jittered and thus many overlap, so actual n = 113.



**Discussion**

The additional year of data (2008) closely matches the patterns observed in the previously analyzed 1997 – 2007 dataset. In Becker et al. 2009, we suggested that a small increase in subsite use at OB in 2008 may have been associated with reduced disturbance at the subsite. However, it is now clear that in addition to fewer documented disturbances in 2008, harvest was also reduced in 2008 as well. The early oyster harvest predictions provided to us and used in the Becker et al 2009 paper estimated that the oyster harvest was increasing to ~497,000 lbs. in 2008). The reduction in actual harvest could conceivably be associated with less harvest activity near subsite OB. The updated model suggests that the 2008 seal count pattern at OB is similar to the 1997, and 2005-2007 years of higher oyster harvest levels (Table 2). This continued negative relationship in the model appears to be partially due to the fact that oyster harvest actually dropped slightly (by about 30,000 lbs) from 2007 to 2008 (NRC 2009).

Although the oyster harvest metric is certainly not fully representative of actual temporal and spatial mariculture activities in the Estero (NRC 2009), it nonetheless far improves the models presented in this report over ENSO and/or density dependence alone, suggesting a potential link between harvest activities and seal displacement at OB. As the NRC concluded for the data analysis for 1997- 2007 presented in Becker et al 2009, these models may "serve as indicators of potential negative interactions between oyster harvest and seal attendance at these subsites" (NRC, p. 32).

These results should be considered in light of the NRC's (2009) emphasis of Wursig and Gailey (2002) that there is a "need to consider potential loss of feeding and breeding habitat from shellfish and finfish farms, particularly given predicted increases in these facilities in nearshore environments."

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**Acknowledgements**

We thank the dedicated harbor seal monitoring volunteers and program managers.

**APPENDIX I: Comparison of Generalized Estimating Equations (GEE) results with generalized linear mixed model (GLMM) and generalized linear model (GLM).**

For comparison with the GEE presented above, we also used a generalized linear mixed model (GLMM), poisson distribution, with year as the grouping variable. The GLMM is less desirable than the GEE for this dataset, since the GLMM assumes within year count data are normal, and the within year autocorrelation is not autoregressive through the breeding season, but rather lumped together without regard for survey order. Nonetheless, it is useful to see if the conclusions from the GLMM and GEE generally agree. We used the glmmML package in R 2.9 for these calculations. We also show results from a simple negative binomial GLM which was used in Becker et al. 2009.

**GLMM MODEL 1**: Our first GLMM model looked at density dependence, ENSO, and Oyster harvest. Note that oyster harvest coefficient has a P ~ 0.05, while density dependence (LowerTot) has a P < 0.14.

```
Call:  glmmML(formula = round(sqrt(OB.Total)) ~
LowerTot + log1p(ENSO.YRS) + Oyster.new, family =
poisson, data = may.08, cluster = fYear, subset = Year
< "2009")

                     coef  se(coef)      z Pr(>|z|)
(Intercept)      9.943e-01 2.404e-01  4.136 3.53e-05
LowerTot         3.702e-04 2.495e-04  1.484 1.38e-01
log1p(ENSO.YRS)  6.082e-01 1.186e-01  5.127 2.94e-07
Oyster.new      -9.127e-07 4.725e-07 -1.932 5.34e-02

Scale parameter in mixing distribution:  0.2082
gaussian
Std. Error:                              0.05745

Residual deviance: 232.1 on 108 degrees of freedom
AIC: 242.1
```

**GLMM MODEL 2**: Dropping the Density Dependence (LowerTot) variable increases the significance of oyster harvest (to P ~ 0.04), while only penalizing AIC by 0.1, thus we would likely prefer this model over Model 1.

```
Call:  glmmML(formula = round(sqrt(OB.Total)) ~
log1p(ENSO.YRS) + Oyster.new,  family = poisson, data =
may.08, cluster = fYear, subset = Year < "2009")

                     coef  se(coef)      z Pr(>|z|)
(Intercept)      1.185e+00 2.093e-01  5.660 1.51e-08
log1p(ENSO.YRS)  6.295e-01 1.224e-01  5.142 2.72e-07
Oyster.new      -9.997e-07 4.897e-07 -2.041 4.12e-02

Scale parameter in mixing distribution:  0.2211
gaussian
Std. Error:                              0.06027

Residual deviance: 234.2 on 109 degrees of freedom
AIC: 242.2
```

**GLMM MODEL 3:** For completeness, we also remove oyster harvest from the model, leaving density dependence and ENSO. Density dependence is P < 0.12, and the AIC increases to 243.1, suggesting that Model 2 (which contains oyster harvest) is a better fit.

```
Call:  glmmML(formula = round(sqrt(OB.Total)) ~
LowerTot + log1p(ENSO.YRS), family = poisson, data =
may.08, cluster = fYear, subset = Year < "2009")


                    coef  se(coef)     z Pr(>|z|)
(Intercept)     0.8921362 0.2584712 3.452 5.57e-04
LowerTot        0.0004023 0.0002528 1.592 1.11e-01
log1p(ENSO.YRS) 0.5366083 0.1278604 4.197 2.71e-05

Scale parameter in mixing distribution:  0.2563
gaussian
Std. Error:                              0.06289

Residual deviance: 235.1 on 109 degrees of freedom
AIC: 243.1
```

We conclude that the GLMM and GEE provide similar results, but since the GEE better handles overdispersion, autoregressive within year correlation of counts, and non-normal within year counts, it is therefore the preferable analysis.

**Direct comparison to methods in Becker et al. 2009 (GLM).**
The final model presented in Becker et al. 2009 did not account for within year autocorrelation of counts (although random effects models were investigated in the paper). For comparison, we show these model results when including the 2008 count data. If we include density dependence on an annual rather than daily basis, the P value is <0.09, rather than >0.99 as shown below. The results indicate the same patterns as those reported for the 1997 – 2007 dataset in Becker et al. 2009. Note that the significance for oyster harvest is overestimated here (when compared with the GLMM or GEE) since we did not account for within year autocorrelation in the basic GLM model.

```
glm(formula = OB.Total ~ LowerTot + log1p(ENSO.YRS) +
Oyster.new, family = negative.binomial(1), data = may.08,
subset = Year < "2009")

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.1153  -0.7763  -0.2103   0.3253   2.4951

Coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)      2.943e+00  3.544e-01   8.305 3.00e-13 ***
LowerTot        -3.940e-06  5.344e-04  -0.007 0.994130
log1p(ENSO.YRS)  1.079e+00  1.324e-01   8.150 6.66e-13 ***
Oyster.new      -2.035e-06  5.641e-07  -3.607 0.000468 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '
' 1

(Dispersion parameter for Negative Binomial(1) family
taken to be 0.782268)

    Null deviance: 184.74  on 112  degrees of freedom
Residual deviance: 139.05  on 109  degrees of freedom
AIC: 1189.2

Number of Fisher Scoring iterations: 12
```

**APPENDIX II: Comment on decision not to use a multinomial model and presentation of model using proportions instead of counts.**

It was informally suggested to us by an NRC affiliated statistician that an alternative method might be to use a multinomial model (rather than the GLM, GLMM, or GEE) to ascertain proportion of seals using all 8 Drakes Estero subsites and testing if oyster harvest still explains the declines at upper estero sites (OB, UEN, UEF). At first glance, this could theoretically remove any confounding effects of ENSO and density dependence, isolating the oyster harvest effect (if any). However, we feel that the multinomial approach modeling proportions is not appropriate in this situation for several reasons:

1. Multinomial models do *not* account for random effects, in this case multiple counts within a year (that we are aware of).
2. Multinomial models do *not* allow for temporal autocorrelation in counts (that we are aware of).
3. Using proportion of seals (rather than counts) at each subsite without taking into account density dependence would obfuscate an important ecological mechanism. Directly modeling this is more statistically and ecologically sound.
4. Similarly, ENSO is an exogenous effect. If ENSO or density dependence explained all of the patterns, then failing to model these might result in simple oyster harvest-seal proportion correlations in a multinomial model with 8 subsites and one explanatory variable (oyster harvest).

Nonetheless, in an attempt to satisfy any concerns that using proportions is more appropriate than counts, while still using robust mixed-modeling methods with autoregression, we demonstrate below that a GEE model only using the proportion of seals in Drakes Estero that use subsite OB as a function of ENSO and Oyster harvest has similar results to the previous models relying on counts. Here we model ENSO with a diminishing $x/x^2$ function, but 1og(ENSO+1) provides similar results. Oyster harvest is significant at $P < 0.04$. Note that the data are underdispersed, but that using the square root of the proportion of seals approaches normality (although normality is not in any way required for a GEE).

```
Call:
geeglm(formula = sqrt(OB.pr) ~ ENSO.YRS/(ENSO.YRS *
ENSO.YRS) + Oyster.new, data = may.08.prop, subset =
Year < "2009", id = fYear, corstr = "ar1")

 Coefficients:
             Estimate   Std.err  Wald Pr(>|W|)
(Intercept)  2.03e-01  4.10e-02 24.47  7.6e-07 ***
ENSO.YRS     2.56e-02  6.08e-03 17.76  2.5e-05 ***
Oyster.new  -3.06e-07  1.45e-07  4.46    0.035 *
---
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1

Estimated Scale Parameters:
            Estimate Std.err
(Intercept)   0.0163 0.00253

Correlation: Structure = ar1  Link = identity

Estimated Correlation Parameters:
      Estimate Std.err
alpha    0.404   0.086
Number of clusters:   12   Maximum cluster size: 15
```

Thus, similar to the count data, we show that both ENSO and Oyster harvest explain the variation in the *proportion* of seals in Drakes Estero that use Subsite OB.

Here we have shown that there is broad agreement in the results whether using GEE, GLMM, and GLM on counts at subsite OB, as well as a GEE analyzing proportion of seals using the subsite. Further, similar patterns are seen regardless of transformations or interactions.

# Modeling the effects of El Niño, density dependence, and disturbance on harbor seal (*Phoca vitulina*) counts in Drakes Estero, California: 1997–2007

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Modeling the effects of El Niño, density dependence, and disturbance on harbor seal (*Phoca vitulina*) counts in Drakes Estero, California: 1997–2007

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ABSTRACT

Harbor seal (*Phoca vitulina*) haul-out site presence may be affected by natural or anthropogenic factors. Here, we use an (1-yr (1997–2007) study of a seal colony located near an oyster mariculture operation in Drakes Estero, California, to test for natural (El Niño-Southern Oscillation (ENSO), density dependence, long-term trends) and anthropogenic (disturbance related to oyster production activities) factors that may influence the use of haul-out subsites. During the study period there was a strong ENSO in 1998, a U-shaped pattern of oyster production, and increasing levels of disturbance related to oyster operations. Using generalized linear models

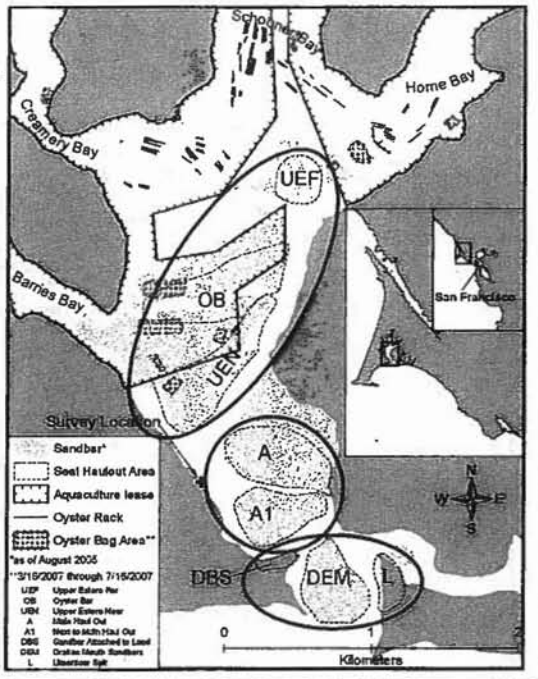
# Analysis Objectives

1. Determine if mariculture-related disturbance events are changing over time

2. Test competing hypotheses (natural and anthropogenic) that may be driving harbor seal counts during the peak pupping season (April 15 – May 15) at sandbars in upper Drakes Estero

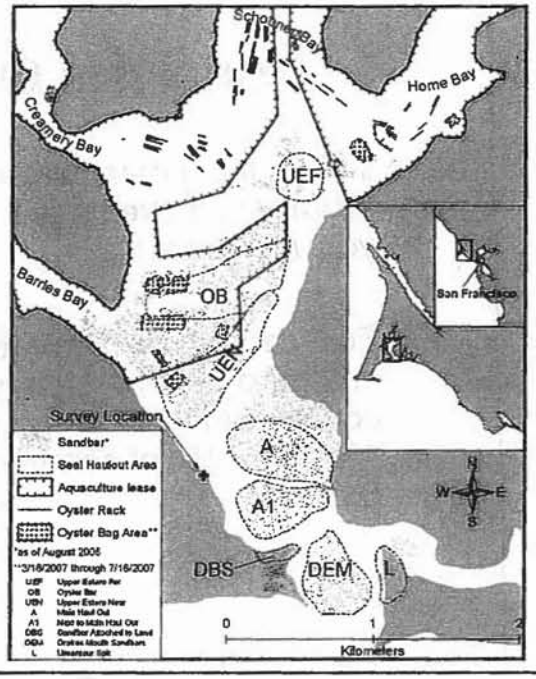
**Harbor seal subsites in Drakes Estero**

- Upper:
  - Primarily pupping/breeding
  - Islands
- Middle & Lower
  - Generally year-round
  - Human, predator access

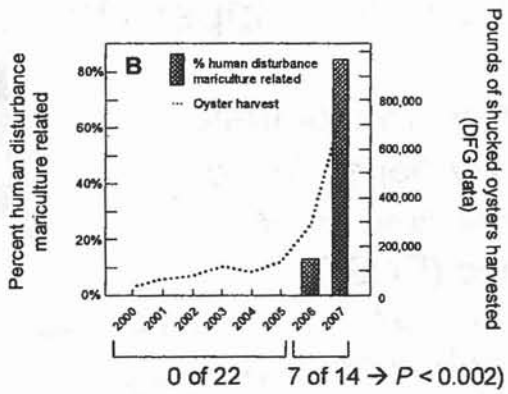


## Dataset – NPS Pinniped Database

- Disturbance surveys year round: 2000 – 2007
- Seal counts from peak pupping season: April 15 – May 15, 1997 – 2007. *(Full pupping season March-June.)*
- 9.5 ± 2.9 surveys/yr during peak pupping season. n = 104
- Removed count data with:
  - Tide > +2ft
  - First year observers
  - Wind, rain, fog, glare




## Increase in percentage of human-related disturbance in upper estero (OB, UEN, UEF) due to mariculture: 2000 - 2007




- High statistical power ($1-\beta > 0.91$ at $\alpha = 0.05$)
- No mariculture related disturbances in middle-lower estero
- Human disturbance is less frequent in upper estero (~1-2/subsite/yr) than the middle-lower estero (~5 subsite/yr)

# Analysis Objectives

1. Determine if mariculture-related human disturbance events are changing over time – *yes, increase*

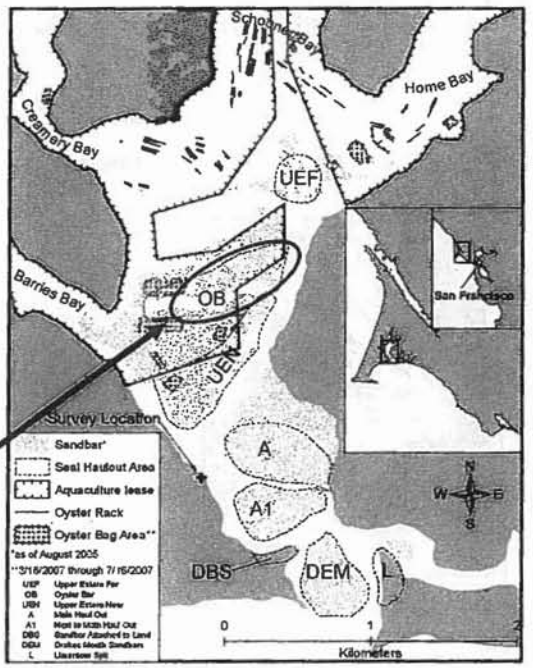
2. Test competing hypotheses (natural and anthropogenic) that may be driving harbor seal counts during the peak pupping season (April 15 – May 15) at sandbars in upper Drakes Estero

# *a priori* hypotheses to best explain seal counts in upper Drakes Estero

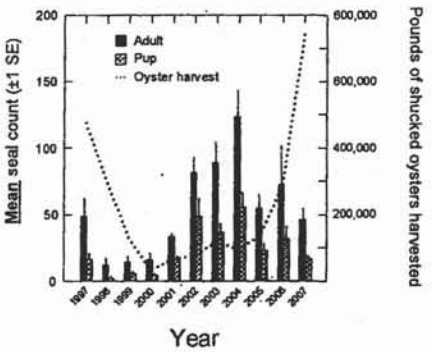
- Year as a linear trend
- Density-dependence
  - *"seals" in the rest of estero* *(Brown et al. 2005, Jeffries et al. 2005)*
- El Niño (ENSO)
  - *'91-'92 & '97-'98* *(Trillmich and Ono 1991, Sydeman and Allen 1999)*
- Oyster harvest *(Proxy for disturbance impacts: Suryan and Harvey 1999, Seuront and Prinzivalli 2005, Johnson and Acevedo-Gutierrez 2007).*
  - *DFG Data*
- Null model
  - *random*

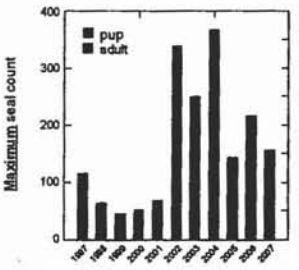
## Analyses

- Generalized linear models in *S-plus* and *R* software. Mixed models also tested.
- Seal counts at OB and UEN modeled with a negative binomial distribution
- Competing models (*a priori* hypotheses) ranked by $AIC_c$ and $r^2$
- Validate models with independent subsite counts (UEF)
- First Model: OB



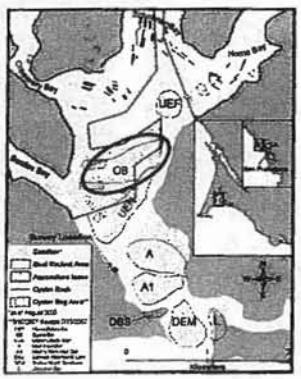

Mean peak pupping season (April 15 – May 15) seal counts at subsite **OB**



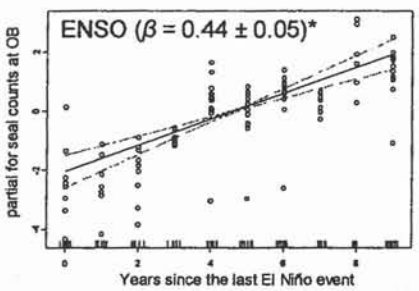



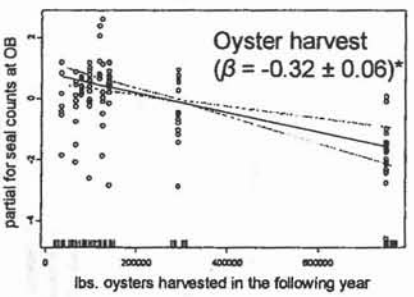
## ENSO and Oyster harvest best explain seal counts at **OB**

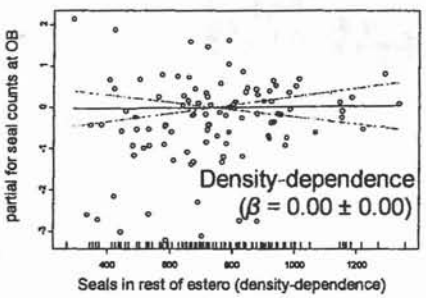
| Model | $AIC_c$ | $\Delta_i$ | $w_i$ | pseudo $r^2$ |
|---|---|---|---|---|
| **Subsite OB** | | | | |
| ENSO+Oyst | 321.84 | 0.00 | 0.75 | 0.48 |




## Best model at OB: *ENSO+Oyster* ($r^2$ = 0.48)



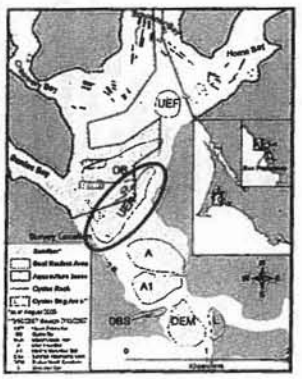



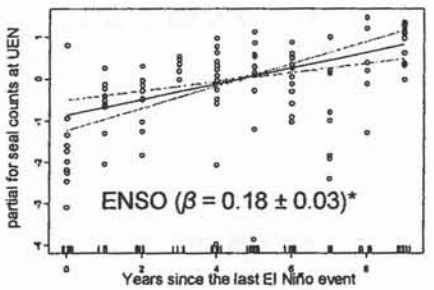

*$P$ << 0.05

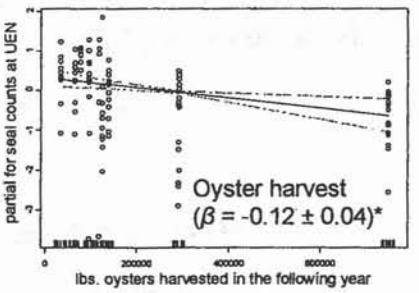
## ENSO and Oyster harvest also best explain seal counts at UEN

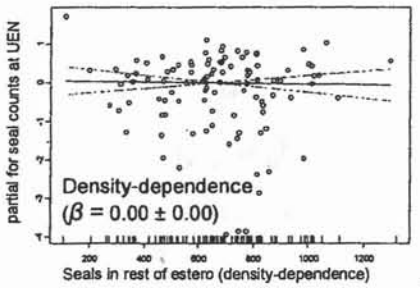
| Model | $AIC_c$ | $\Delta_i$ | $w_i$ | pseudo $r^2$ |
|---|---|---|---|---|
| Subsite UEN | | | | |
| ENSO+Oyst | 318.77 | 0.00 | 0.41 | 0.18 |

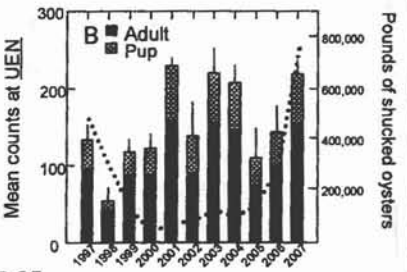



## Best model at UEN: *ENSO+Oyster* ($r^2$ = 0.18)



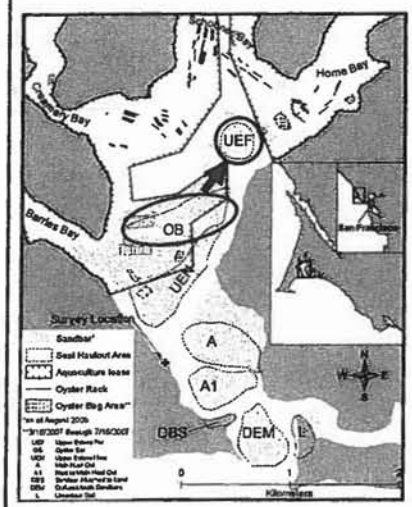



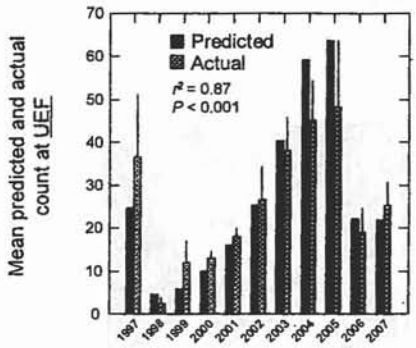




*$P$ << 0.05

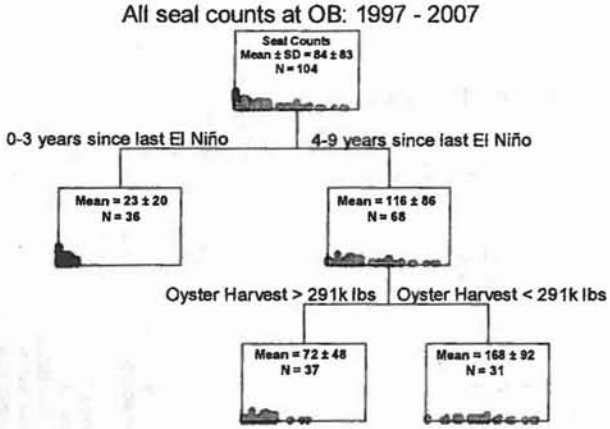
## Best model at OB (ENSO+Oyst) has high predictive power for subsite UEF



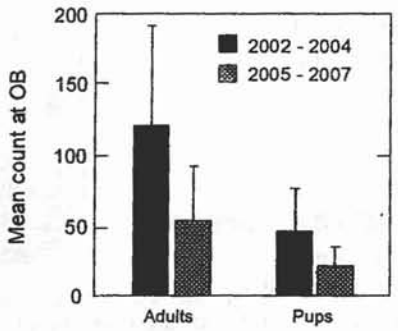




## Regression tree analysis illustrates and confirms GLM models. ENSO and Oyster harvest affects counts at **OB** (and therefore **UEF**)

All seal counts at OB: 1997 - 2007



Both adult and pup counts (during peak pupping season) at **OB** declined after ENSO effects tapered off and oyster harvest effects kicked in. Error bars indicate ±1SD




($t_{58} = 4.2$, $P < 0.001$)

## Conclusions:

- Significant increase in mariculture related disturbance in the upper estero during 2006 - 2007.
- ***+ENSO*** and ***–Oyster harvest*** explain seal counts very well at OB and UEF, and marginally at UEN.
- Ability of OB model to predict UEF indicates high confidence in modeling.
- Counts of adults (-57%) and pups (-54%) significantly declined at OB after 2004, and at UEF after 2005.

# Final notes on data quality

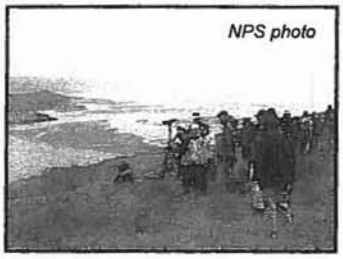
- Disturbance trends are minimally sensitive to sample size

  *(7 of 14 mariculture related in upper estero)*

  *IF 4 of 11 → P < 0.01*

  *3 of 10 → P < 0.05*

  *2 of 9 → P < 0.07*




- Seal count data by volunteers
  - Training, screening
  - If errors, they would likely result in a more variable (noisier) count dataset, making it <u>less</u> likely to detect a signal from ENSO and oysters *(Type II error – low power)*


## Acknowledgements

- Statistical review and advice
  - J. Laake (NOAA – National Marine Mammal Lab)
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- Harbor seal monitoring program volunteers