Pupping Phenology and Haul Out Patterns of Harbor Seals (*Phoca vitulina richardii)* in San Francisco, California

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by,

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TABLE OF CONTENTS

List of Tables viii

List of Figures ix

Introduction 1

Environmental System

Study Animal 7
Study Area 9
EL Nino Southern Oscillation and La Nina Events 13

Methods

Data Collection 15
Data Collection and Analysis Techniques 15
Pup Abundance and Parturition Date 16
Alternate Site Abundance 17
Environmental Variation 17
Haul Out Area Use 18
Pup Growth Rate 21
Pup Status – Estimated Lactation Length 25
Maternal Pelage Coloration 26

Results

Pupping Phenology and Abundance 29
Alternate Site Abundance 33
Environmental Variation 33
Haul Out Usage 36
Pup Growth Rate 39
Pup Status – Estimated Lactation Length 46
Maternal Pelage Variation 51

Discussion 59

References 69

LIST OF TABLES

Tables		Page
1.	Growth Class Criteria	24
2.	Field Effort	30
3.	Pupping Phenology Statistics	31
4.	Environmental Variation Analysis	35
5.	Haul out usage at Castro Rocks	37
6.	Haul out usage on A	38
7.	Results of Repeated Measures ANOVA for growth class analysis	40
8.	Results of Kruskal Wallis Test with Growth Class	44
9.	Results of Repeated Measures ANOVA for paired and lone pup analysis	45
10.	Results of Kruskal Wallis Test with Paired and Lone Pups	47
11.	Test Statistics of Kruskal Wallis Tests	48
12.	Statistical Analysis of Maternal Pelage Coloration, 1999	52
13.	Statistical Analysis of Maternal Pelage Coloration, 2000	55
14.	Statistical Analysis of Maternal Pelage Coloration, 2001	56

LIST OF FIGURES

Figures		Page
1.	Map of Harbor Seal Haul Out Sites within the San Francisco Bay	10
2.	Aerial photograph of Castro Rocks haul out site and Richmond San Rafael Bridge	11
3.	Labeling of Castro Rocks haul out site	19
4.	Labeling of Castro Rocks haul out site	20
5.	Growth Class Criteria	22
6.	Red-pelaged Harbor Seals	27
7.	Maximum Number of Pups Observed on Castro Rocks During Pupping Season for years 1999, 2000, 2001	32
8.	Pup Abundance at Alternate Sites Within the San Francisco Bay	34
9.	Abundance of Pup Growth Classes Across Seasons	41
10.	Distribution of Pup Growth Classes Across Seasons	42
11.	Abundance of Pup Status Across Seasons	49
12.	Distribution of Pups Status Across Seasons	50
13.	Maternal Pelage Coloration (1999)	53
14.	Maternal Pelage Coloration (2000)	57
15.	Maternal Pelage Coloration (2001)	58

Introduction

Although the direct effects of El Nino Southern Oscillation (ENSO, *see Environmental Systems*) events have been well documented for many otariid species, few analyze the effects on harbor seal (*Phoca vitulina*) populations. ENSO events have been known to alter the population abundance and productivity of many pinniped species (Sydeman and Allen 1999; Guinet et al. 1994; Trillmich and Ono 1991; Trillmich and Limberger 1985). Most of these variations in pinniped population dynamics are related to increases in water temperature brought on by ENSO events and corresponding reduction in food supply, leading some species to shift in prey choices and increasing foraging time (Dellinger and Trillmich 1999). Reduction in abundance of all age classes of Galapagos fur seals (*Arctocephalus galapagoensis*) and younger class Galapagos sea lions (*Zalophus californianus wollebaeki*) were documented after the 1982-83 ENSO event as well as a lower pup production in Galapagos sea lions the following year (Trillmich and Limberger 1985). Reduction in Antarctic fur seal (*A. gazella*) pup production has also been noted in years following ENSO events since 1978 on Possession Island (Guinet et al. 1994). A reduction in pup condition was observed in New Zealand fur seals (*A. forsteri*) following the most recent, and strongest recorded ENSO in 1998

(Bradshaw et al. 2000). With continuous maternal foraging cycles for lactating harbor seals and otariid species (Boness et al. 1994), the effects of ENSO on harbor seal pup production, condition and survival are likely similar.

Low food resource and haul out availability associated with ENSO and La Nina can lead to variations in parturition date within the colony and reduction in pregnancy rates. Pinnipeds have a delayed implantation of the blastocyst, with some room for flexibility in timing in order to accommodate environmental changes. An increase in total gestation (time from mating to parturition) often occurs for many species in years of low food availability (Boyd 1996). Variation in total gestation can be caused by an increase in the amount of time between mating and implantation of the blastocyst. Two processes lead to implantation: (1) the detection of a critical photoperiod, which can synchronize births for the most advantageous time of year (Temte 1994), and (2) the attainment of a threshold body condition, e.g. the appropriate amount of fat within this time frame (Stewart et al. 1989). The threshold body condition is likely determined by food resource availability (Lunn et al. 1994; Lunn and Boyd 1993; Lunn et al. 1993; Boyd 1984). Limitations in food resource and haul out availability can ultimately extend the time of implantation, if

implantation occurs at all. Pregnancy rates are reduced after years in which feeding conditions were poor, likely due to the mothers failing to attain the appropriate amount of fat within the critical time period (Jemison and Kelly 2001; Boyd 1996; Lunn and Boyd 1993; Lunn et al. 1993).

Compromised maternal condition due to decreases in food and haul out availability can also affect pupping success. In female harbor seals of intermediate age classes, compromised maternal condition will affect the developmental stage of the pup at birth. Low maternal weight may lead to decreases in pup weight at birth, and subsequent decreases in survival (Ellis et al. 2000). Even with adequate maternal weight, maternal size of harbor seals constrains the amount of stored energy females carry into pupping (Bowen et al. 1994). In a study conducted with Antarctic fur seals (*Arctocephalus gazella)*, mothers left their pups for longer periods of time because of low food availability due to ENSO events (Lunn et al. 1994; Lunn and Boyd 1993; Lunn et al. 1993). This increase in time needed for foraging not only led to a later average birth date the following year, but also slowed the growth rate of those years' pups.

Availability of suitable haul out space is especially important for pinniped pup growth and survival. Mother-pup pairs use terrestrial sites to

bond with each other, for resting and recovery from foraging trips, and for energy transference from mother to pup through lactation. Bonding between mother and pup is important to pup survival because the pair often travel together (Renouf et al. 1983). By mothers and pups ability to recognize each other through vocalizations and olfactory cues, the pup's chances for nursing and acquiring adequate amounts of energy after returning from foraging trips increase (Renouf 1984).

Increases in harbor seal mother-pup separation and the inability for those pairs to reunite can lead to increases in pup mortality. In Washington, a high proportion of harbor seal pup mortality is caused by starvation in non-ENSO years (Steiger et al. 1989). Starvation in pups is mainly the result of mother and pup separation or abandonment (Boulva and McLaren 1979; Bonner 1975). In Nova Scotia, major causes of separation between harbor seal mothers and pups appear to be storms, which produce strong currents, large ocean swells near shore, high winds and increased noise levels (Boness et al. 1992), similar to those brought by ENSO and La Nina events.

If maternal condition is impaired during periods with high levels of energy expenditure or decreases in food supply, post-lactation pup survival may also decrease. Once pups are weaned they are not proficient

foragers and feed infrequently for 15-17 days. Pups survive the postweaning period by utilizing the energy stored during the lactation period. The condition of their mother before birth, and foraging success during lactation determine the amount of energy transferred to the pup. The amount of net energy remaining post weaning greatly affects pup survival (Muelbert and Bowen 1993). Therefore, increases in energetic costs of mothers and pups before, during and after lactation will have a significant effect on pup abundance, growth rate and post-weaning survival.

My study presents information concerning residual effects of recent ENSO and La Nina events on a Pacific harbor seal (*Phoca vitulina richardii*) population within the San Francisco Bay (SFB). I analyzed pupping phenology at the 2nd largest year round haul out site within this bay, Castro Rocks (CR). I compared overall pup abundance, haul out patterns, apparent pup growth rate, estimated length of lactation, and possible correlations between maternal coat discoloration and parturition date. The three years of the study include three different environmental conditions, a La Nina/post-ENSO year (1999), post-La Nina (2000), and the first recovery year (2001) from these previous extreme environmental events in SFB.

My objectives were to test four main hypotheses concerning the effects of La Nina events or residual effects of ENSO on pupping abundance, phenology and pup haul out patterns at CR. (1) There is no variation in total pup abundance or parturition date during the years after the last ENSO event, (2) the Castro Rocks haul out site will be used equally by mother pup pairs each year, (3) there is no difference in abundance and phenology of paired pups, lone pups and pups of different growth classes between years, and (4) there is no difference between the occurrence of red and normally pelaged harbor seal mothers between these years.

Environmental System

Study Animal

Harbor seals (*Phoca vitulina*) are found on a variety of substrates ranging from intertidal ledges and rocky islets to mudflats and beaches. These seals inhabit temperate to sub-arctic areas and are restricted to the Northern Hemisphere (Reeves et al. 1992). Along with this wide geographic variation, parturition date also varies greatly, dependant upon location (Temte et al. 1991; Bigg 1969). In Baja California, Pacific harbor seal (*Phoca vitulina richardii*) pups appear as early as February (Scheffer 1974), but date of parturition occurs later moving up the coast with pupping in Central California occurring late in March and continuing through May (Allen et al. 1989; Stewart et al. 1988; Knudston 1977). In British Columbia and Washington, pups are born June through September (Olesiuk et al. 1990). The season once again moves to earlier dates (June and July) as you move closer to the Pribolof Islands and the Aleutian Chain (Temte et al. 1991). There is similar variation in Northern Atlantic harbor seal (*Phoca vitulina vitulina*), with dates ranging from late-May in Great Britain (Thompson 1989) and Nova Scotia (Lucas and Stobo 2000) to June and July farther north (Harkonen and Heide-Jorgensen 1990).

Harbor seal pups are usually born in intertidal areas where pups must be able to swim at birth, sometimes in less than 20 minutes (pers. observ). The mother and pup will often leave the site together from the day of parturition until weaning, often departing with the rising tide (Knudston 1977; Lawson and Renouf 1985). To keep contact with each other, harbor seal mothers and pups bond with a combination of visual, olfactory and vocal cues. With low ambient noise, a mother can detect her pup's call up to 1 km away (Reiman and Terhune 1993). If the pup is not somehow bonded to its mother, the two can easily lose contact when in water where visibility is limited and ambient noise high (Boness et al. 1992; Renouf 1984).

Lactation period for harbor seals can range from 2 to 6 weeks, but averages around four (Muelbert and Bowen 1993). During this time, pups gain approximately 0.8 kg a day until they are weaned (Boness and Bowen 1996). The immune system in harbor seal pups is not fully developed at birth and newborns obtain temporary immunological protection from maternal antibodies mainly delivered through the colostrum (Ross et al. 1994). On Sable Island, weight at weaning is usually between 25 and 30 kg and mothers lose 37% of their postpartum mass during lactation (Bowen et al. 1992). Females may be foraging at a

reduced rate and in shallower areas during lactation. Hypotheses concerning why harbor seals exhibit this behavior center on their small size in comparison with other phocids (Bowen et al. 1994).

Study Area

Study areas were chosen based on historical usage by harbor seals and accessibility for researchers. Sites included were Castro Rocks (CR), Corte Madera (CR), Yerba Buena Island (YBI), and Mowry Slough (MS)(Figure 1). The main study site, Castro Rocks (CR; medium to low tide haul out site; Figure 2), is 10m from the southeastern edge of the Richmond-San Rafael Bridge at Pier 55. It is also about a quarter mile from the Chevron Long Pier (Kopec and Harvey 1995; Risebrough et al. 1979). This site is the largest haul out site in the northern bay and the second largest pupping site in SFB (Kopec and Harvey 1995). In recent non-ENSO years, the number of pups have averaged 20% of the population at ~25 pups annually (D. Kopec, Bar Harbor, Maine; S. Allen, National Park Service, pers. comm.).

The alternative sites that were monitored varied in location within the bay, use by seals and degree of disturbances. Corte Madera (CM; medium-high tide site) is located on the northeasterly point of the Corte

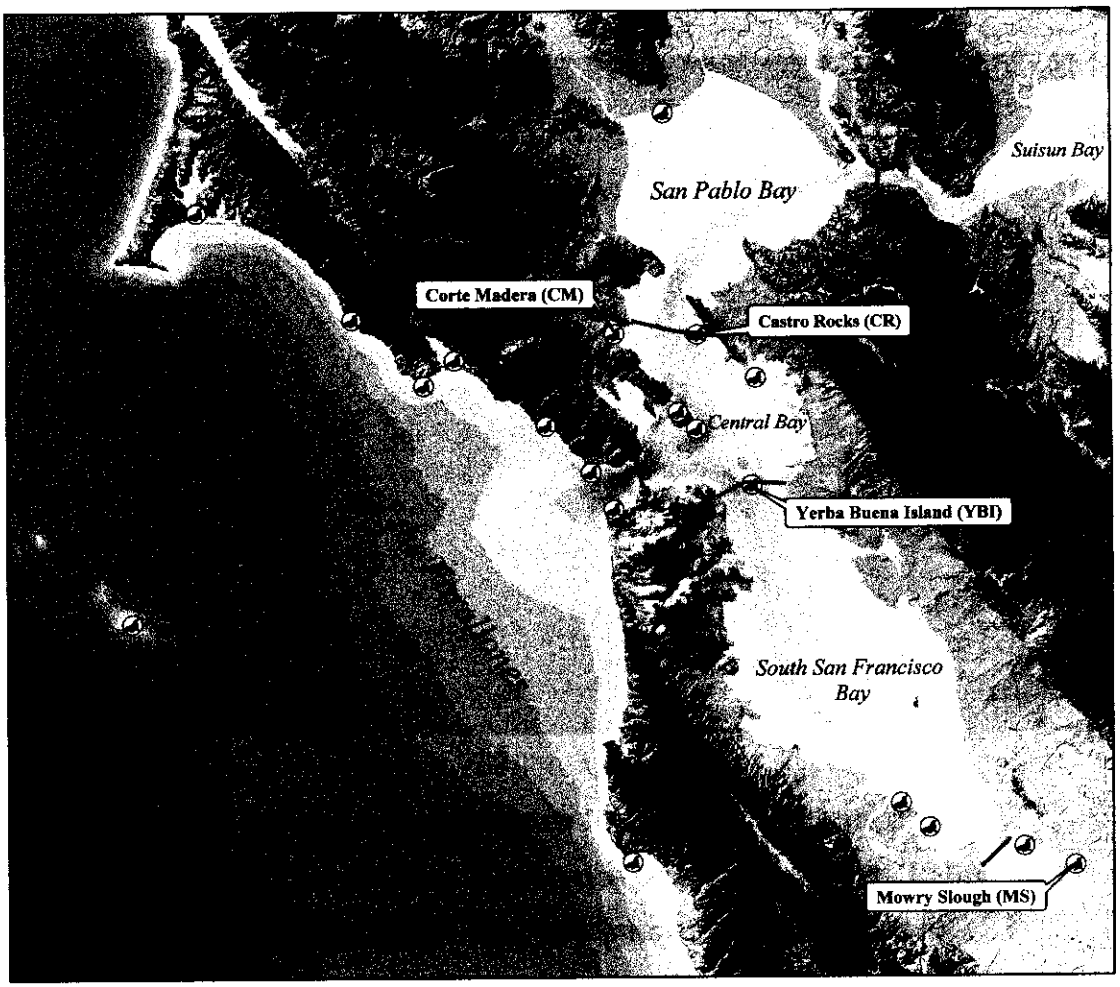


Figure 1. Map of harbor seal haul out sites within the San Francisco Bay. Four sites used in this study are labeled with names. Other sites are indicated with triangles. (Map courtesy of B. Nickel)

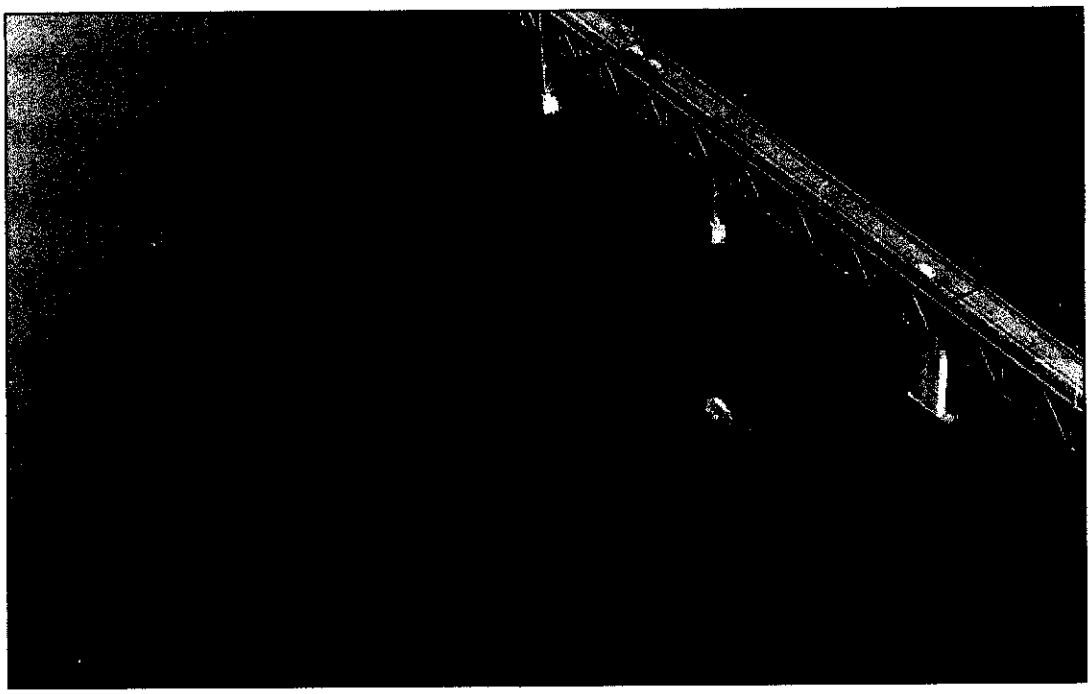


Figure 2. Aerial photograph of Castro Rocks haul out site and Richmond San Rafael Bridge. Note close proximity of bridge to haul out site. (Picture Courtesy of California Department of Transportation)

Madera Ecological Reserve and was established in the early 1980's (Josselyn and Buchholz 1984). Two breached dikes keep the location isolated from hikers when mud flats are flooded, limiting access to the site. Yerba Buena Island (YBI; low tide site) is located in the middle of the San Francisco-Oakland Bay Bridge, with the haul out site on the south side of the island. It is mainly utilized in the winter months during the Pacific herring spawn in SFB (Spencer 1997; Kopec and Harvey 1995; Risebrough et al. 1979). Pup abundance at this site is low with an average of three pups from 1995-1997 (D. Kopec, Bar Harbor, Maine; S. Allen, National Park Service, pers. comm.). Mowry Slough (MS) is a medium to high tide site located south of the Dumbarton Bridge (Alcorn and Fancher 1980; Fancher 1983). One side of the slough is part of the San Francisco National Wildlife Refuge, near Newark, California. The MS study site is a combination of six potential haul out sites within the slough that include Newark Slough, the north and south sides of two different sections of Mowry Slough, and the mud flats at the mouth of the slough. Pups number near 90 in the peak months constituting 40% of the population in non-ENSO years. (D. Kopec, Bar Harbor, Maine; S. Allen, National Park Service, pers. comm.). High counts were compared with data gathered by

the Richmond-San Rafael Bridge Harbor Seal Survey to verify maximum number at both YBI and MS.

EL Nino Southern Oscillation and La Nina Events

El Nino Southern Oscillation (ENSO) events are characterized by changes in barometric pressure across the equatorial zone in combination with changes in sea surface temperature. The normally low pressure above the largest bodies of warm water (northern Australia, the East Indies and New Guinea) area during the winter months are replaced by weak high pressure. The low pressure moves east, strengthening the equatorial trough, increasing rainfall in this area and shifting trade winds toward South America. This shift in pressure brings strong winds and heavy storms within the SFB from September to April. In 1997-1998, one of the strongest ENSO events since the 1950's was recorded. Seasonal rainfall during 1997-1998 increased in downtown San Francisco 230% (43.19") of normal seasonal rainfall (Wilkerson et al. 2000; Monteverdi and Null 1997; Wallace and Vogel 1994). The increase in rain and wind can bring large swells to the coastline.

The La Nina frequently follows ENSO events, as occurred in 1999. La Nina is characterized by increases in atmospheric flow over the eastern

north Pacific and North America. Unlike the increases in warm water around the equatorial plane associated with ENSO, La Nina events involve cold water along the eastern Pacific, reaching much further west than normal along the plane. A variable Pacific jet stream causes a high-pressure blockage in the Gulf of Alaska, pushing the polar jet stream over the continent, bringing cold weather along the coast of Alaska and western Canada. La Nina events bring drought to most of Southern California and Southern desert regions, yet the North Pacific sees increases in the average amount of rainfall (Null and Monteverdi 1999).

Methods

Data Collection –

Surveys conducted for this project were conducted under an Incidental Harassment Authorization (IHA) issued by the National Marine Fisheries Service to the California Department of Transportation. This IHA is issued under section 101 (a) (5) (D) of the Marine Mammal Protection Act (16 U.S.C. 1362 et seg.). Conditions of this IHA include limits in activity during the Work Closure Period (February 15 – July31) in area that surrounds the main site, Castro Rocks, creating an exclusion zone. This permit elevates the need for studies requiring separate scientific research permits issued under section 104 of the Marine Mammal Protection Act.

Data Collection and Analysis Techniques

Data for this study were gathered between March 24th and June 8th for the years 1999, 2000 and 2001. Estimates of the number of pups present after that date were not made, since pups are difficult to distinguish from yearlings by June. CR is completely submerged at high tide; therefore, surveys were conducted every 20 minutes in four-hour blocks of time around the low tide during daylight hours. Population data (e.g., pup status, growth class of pup, pelage color of mother) were

gathered at CR to estimate trends in usage and ranges in numbers during the pupping season. Observations were made on each pup in pre-determined quadrants and subsites (see *Haul Out Usage*).

Pup Abundance and Parturition Date

To estimate pup abundance within each season, I counted the number of pups observed on the haul out site on each day of observation. To compare date of parturition between years, I estimated the parturition date for each year estimated using the midpoint of the time interval between the date the first pup was born and the date on which the maximum number of pups was observed on the haul out site. In order to determine the relationship between the ENSO and La Nina events on the number of pups using the haul out and phenology, I compared differences in abundance of pups between the first half (March 24th - April 30th) and second half (May 1st – June 8th) of each season. I also compared differences in abundance and phenology between the years of study and between months and years. I compared totals between and within years by conducting an one-way ANOVA with repeated measures on date. Differences in phenology were determined by comparing median date of observation (Julian date) of each group by year using a Kruskal-Wallis

Test. Non-parametric tests were used to analyze phenology data because these data were not normal. Tests were accepted as significant for $p < 0.05$ (SPSS version 10.0 for Windows).

Alternate Site Abundance

To compare abundance trends throughout the SFB, data were gathered at three other sites within the bay. Methodology was the same as for Castro Rocks with surveys conducted every twenty minutes over a four-hour period. Numbers at Yerba Buena Island were verified with the Richmond Bridge Harbor Seal Survey.

Environmental Variation

Each day of observation, data were gathered concerning environmental variables. Tide levels were recorded at the time when the maximum number of pups was seen on the haul out site using Tides & Currents Pro 2.5. I also collected data on site including temperature, wind speed, wind direction and occurrences of rain using handheld equipment. Cloud cover was determined by visual estimation. All weather data were verified for the time period when the maximum number of pups was seen on the haul out site using data gathered by NOAA buoys within SFB.

Haul Out Area Use

In order to determine use of haul out site, I recorded the location of the pups on the site. The main rock labeling was consistent with that of Kopec (1998) and Markowitz and Allen (1997) (Figure 3). Each rock represents differences in topography, surface area and distance from the bridge. The main rock (A) was sectioned into 6 quadrants; B-F could not be broken into smaller areas due to the size of the rocks and due to distance to the observation site (Figure 4). Topographical changes were used to determine the quadrant lines since drawing the lines on the site was not possible. These quadrants also vary in topography, area and distance from the bridge as well as varying degrees of environmental protection.

I compared the percentage of pups observed within each subsite to determine if there was a variation in haul out site use between years. I compared combined totals observed in each quadrant for each day of observation as well as totals observed for the full season. I also compared haul out use on A rock using percentage of total pups observed in each quadrant on A per day and for the full season. Due to variation in date of parturition of pups, percentage of total pups observed on site was

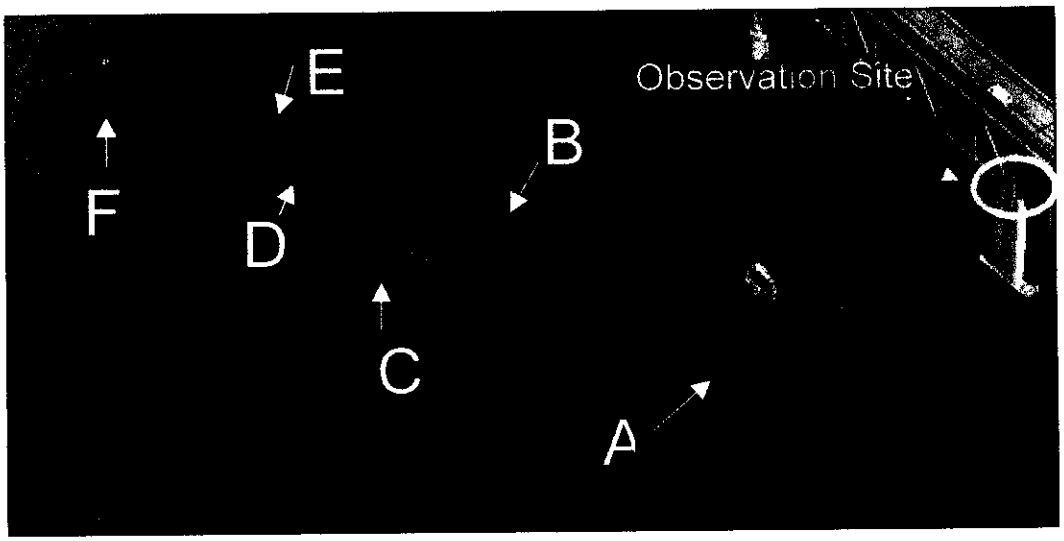


Figure 3. Labeling of Castro Rocks haul out site. The six main rocks used to show haul out pattern of mother-pup pairs.

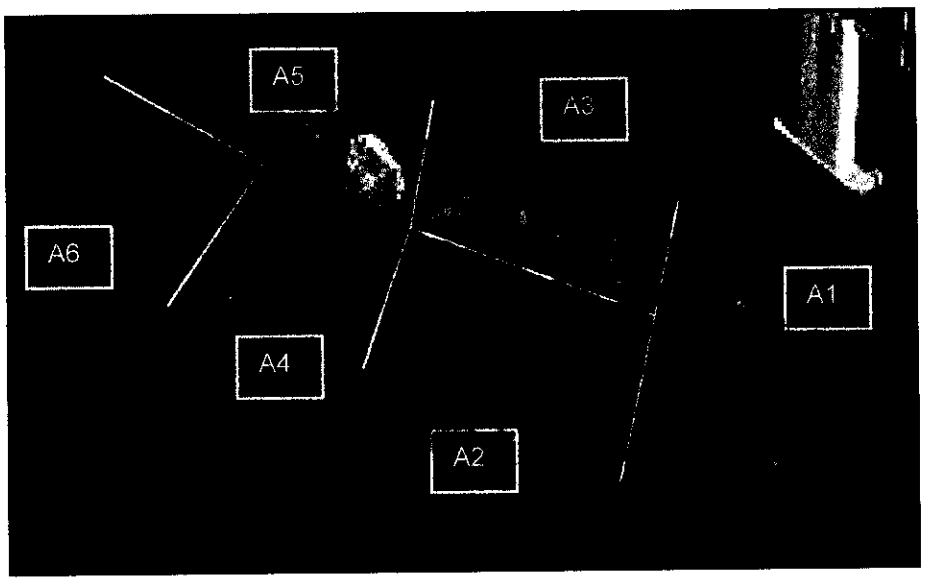


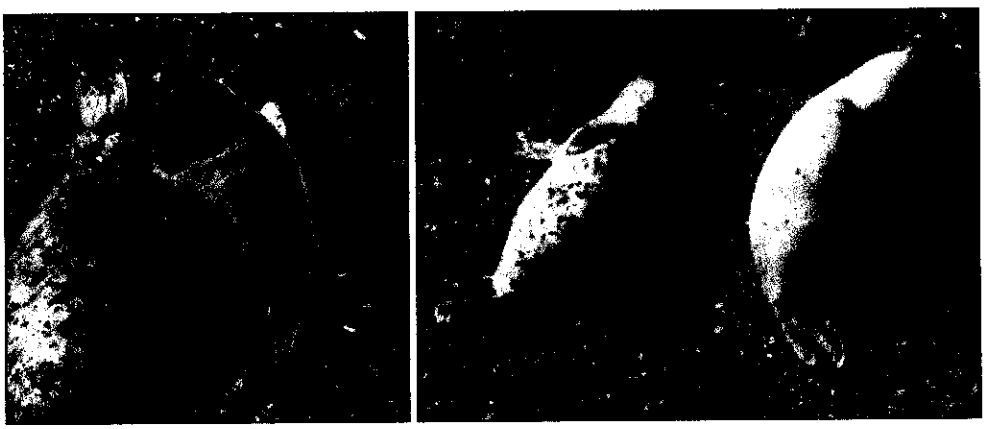
Figure 4. Labeling of Castro Rocks haul out site. The six main rocks used to show haul out pattern of mother-pup pairs.

considered more reliable than a comparison of number of pups observed to determine haul out use.

Pup Growth Rate

To estimate growth rate of the pups each season, I recorded the apparent growth stage of each pup on the site each day of observation. Each pup's approximate growth stage was recorded by ocular estimate by length, girth and relative overall size. If a pup still had its lanugo coat when born, it is indicative of a premature birth. If the pup did not have lanugo but an umbilicus was still present, the pup was noted as a newborn (~1-4 days old). Otherwise, pups were classified as early, middle or late growth classes, indicating the approximate number of weeks the pup had been alive (Figure 5).

Early growth class was determined by shortness in length when compared to size of flipper (high flipper to body ratio), width of head extending past body girth and the appearance of wrinkled skin. Middle growth class pups were distinguished by moderate flipper to body ratio. This is indicated by an increase in length, therefore the front flippers cover less of the main body area. Late age class pups were identified by low



Early Age Class **Middle Age Class** **Late Age Class**

Figure 5. Growth Class Criteria - Pictorial description of the age classes used to identify approximate growth class of pup.

flipper to body ratio and thick girth (the body girth extending past the width of the head).

Because wrinkled skin may also be indicative of malnutrition, I am not associating a definite age with each class. Relative age classes of each group are as follows: Early growth stage pups were grouped as approximately ~1-10 days old. Middle growth class pups were estimated at ~11-21 days old. Late growth class pups were estimated to be approximately 22-30 days old, and close to if not weaned (Table 1).

I compared abundance of pups in each growth class as well as the time period during which each growth class was observed to determine if there was any variation between years. I conducted a 3-Factor ANOVA with repeated measures on date to determine differences in the number of pups of each growth class between the first and second half of pupping season for each year. I also wanted to determine if there was a difference in the number of pups in each growth class between each year of study and if the differences found within each season varied between years using the same test. I compared differences in phenology by comparing median date of observation (Julian date) of each group by year using a Kruskal-Wallis Test. By testing the specific days of observation, variation

Age Class	Physical Characteristics	Approximate Age
Newborn	Presence of umbilicus	1 – 3 days
Early	Wrinkled skin, high flipper to body length ratio (short and wrinkled)	1 – 10 days
Middle	Fewer wrinkles observed, moderate flipper to body length ratio (long with wrinkles still present)	11 – 21 days
Late	No wrinkles observed, low flipper to body length ratio. Girth extends past width of head. (long and full bodied)	22 – 30 days Possibly weaned

Table 1. Growth Class Criteria – List of physical characteristics used to determine approximate pup growth class and related age correlate.

at a smaller scale maybe found. Non-parametric tests were used to analyze phenology data because these data were not normally distributed.

Pup Status – Estimated Lactation Length

To estimate differences in abundance and phenology of pups of different status, I recorded the number of pups on the site with their mothers (paired) at each 20-minute interval. I recorded the number of pups observed without their mother (lone) during the same interval. If the mother returned to the site during the observation period, the classification of the pup was considered paired for this analysis. If the mother was not seen throughout each day, these pups were assumed to be abandoned or weaned. I did not separate abandoned and weaned pups as both reflect an end to lactation and I did not feel capable of making an accurate distinction between them. Nursing bouts were also recorded if both the initiation and termination were observed.

I compared abundance of paired and lone pups and the time period during which paired and lone pups were observed to determine if there was variation between years. I conducted a 2-Factor ANOVA with repeated measures on date to determine differences in the number of pups of each status between the first and second half of pupping season

for each year. I also wanted to determine if there was a difference in number of paired and lone pups between each year of study and if the differences found within each season varied between years using the same test. I compared differences in phenology by comparing median date of observation (Julian date) of each group by year using a Kruskal-Wallis Test. Non-parametric tests were used to analyze phenology data because these data were not normally distributed.

Maternal Pelage Coloration

To determine if there was a difference in pup abundance and parturition date between mothers with the red discoloration of fur and mothers without, I recorded the coat coloration of the mother of each pup. Red pelage was defined as any red shaded discoloration of fur. The red coloration is associated with iron oxide deposition on the hair shaft of the seals (Allen et al. 1993). This red shade varied from an orange wash to bright red discoloration (Figure 6). Extent of red was recorded for future analysis. I compared differences in timing of observation of each maternal group to determine if there was variation between years that may be linked to the La Nina or ENSO events. I conducted a 2-Factor ANOVA to determine variation in observed number of mothers with both normal and

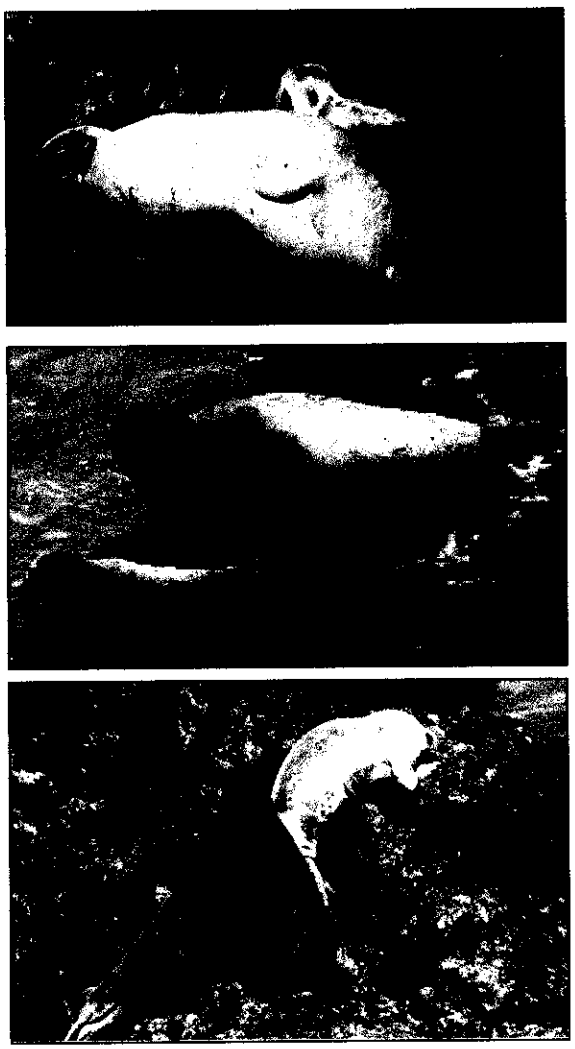


Figure 6. Red-pelaged harbor seals - Variation of red discoloration of fur found in harbor seals in SFB.

red pelage colorations between months for each year of study with repeated measures on coat color factor.

Results

Pupping Phenology and Abundance

Over the three years of study, a total of 368 hours of data were gathered over 62 days (Table 2). Analysis of pup abundance at Castro Rocks revealed a more consolidated pupping season in 2001, in comparison to 1999 and 2000 (Figure 7; Table 3). In 1999, the first viable pup was born on March 17th and the peak in pup numbers occurred on May 7th, with 23 pups observed on site, with estimated average parturition date as April 12th . May 7th was the only date when more than 20 pups were observed during the 1999 season. In both 2000 and 2001, the first pup was born on March 24th. In 2000, the peak in number occurred on April 22nd, with 24 pups observed, with average parturition date estimated as April 8th. In 2000, I observed over 20 pups on the haul out from April 22nd until the first week of May. The initial peak for 2001 occurred by April 14th, with 34 pups observed, with estimated average parturition date as April 4th. However, a second peak was noted on April 21st, with 33 pups observed. After a small decline, 33 pups were again observed on April 28th and 30th. The observed number of pups remained above 20 until the third week of May. The overall timing of pup observations occurred earlier in 2001 when compared to 1999 and 2000 ($H= 14.13$, $n=1153$, $p<0.01$).

	1999	2000	2001	Total
Number of field days	31	30	31	62
Number of observation hours	124	120	124	168

Table 2. Field Effort. Total number of days spent at Castro Rocks by year and grand total, total number of hours of observation by year and overall total.

Year	First Pup Observed	Peak Number of Pups Observed	Date of Peak	Estimated Parturition date	Number of Days in Interval	Daily Average of Pups
1999	03/17/99	23	5/7/99	4/12	51	8
2000	03/24/00	24	4/22/00	4/8	29	10
2001	03/24/01	34	4/14/01	4/4	21	14

Table 3. Pupping Phenology Statistics – General information concerning pupping dates, maximum number seen on the haul out site in one day, the date that number was seen and the average number of pups seen per day of observation. Number of days in interval refers to the number of days between the first pup observed and the date of peak numbers.

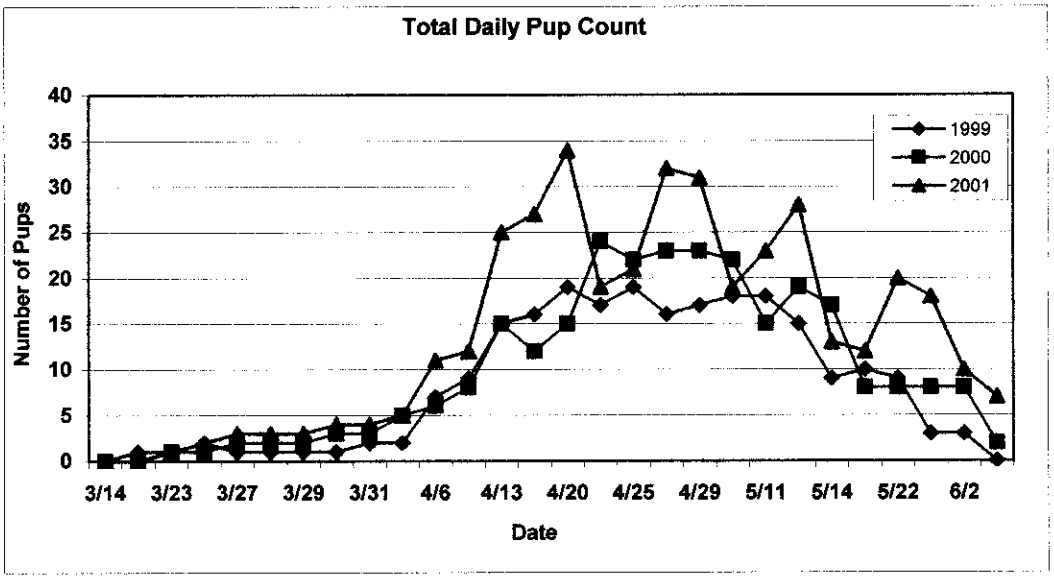


Figure 7. Maximum Number of Pups Observed on Castro Rocks During Pupping Season for years 1999, 2000, 2001. Each line represents the maximum number of pups observed each day of observation.

Alternate Site Abundance

The number of pups observed at MS, YBI and CM varied slightly over the three years of the study both within sites and between (Figure 8). At YBI, the highest number of pups seen occurred in 2001 with a high count of 9. At CM, pups did not exceed 2 pups total (1999, 2001). The numbers observed at MS exceeded those at all other sites across all three years. There was a peak in the number of pups observed at MS in 2001, with 98 pups at highest count.

Environmental Variation

Variation in environmental conditions occurred mainly with tide level at time of maximum count, however the variation was not statistically significant (Table 4). This time corresponded with low tide for each day of observation. Average tide height for all years was 0.7ft, and varied from 0.9ft in 1999 to 0.4ft in 2001. Variation in temperature, wind speed, wind direction and cloud cover was not statistically significant. Of the days surveys were taken, there were more days of rain in 1999 (5 d/28 total d of observation) than in 2000 (1 d/25 total d of observation) and 2001(2 d/29 total d of observation).

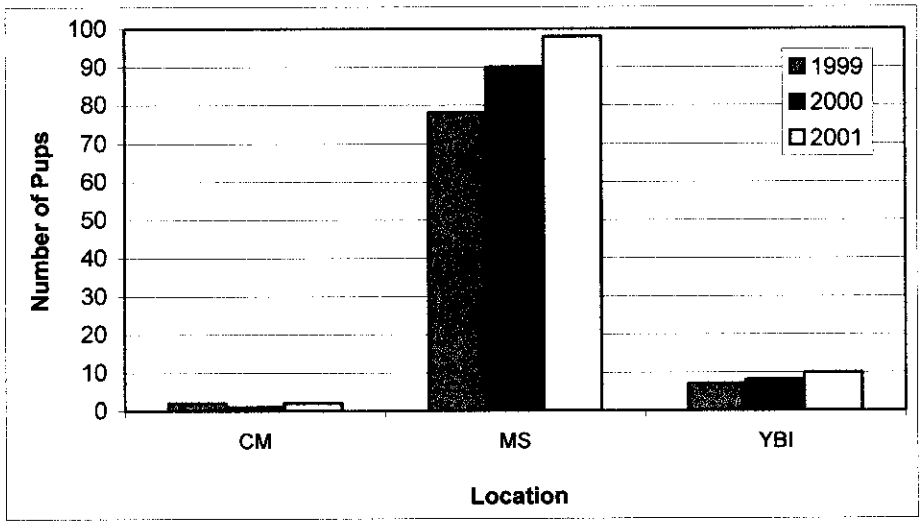


Figure 8. Pup Abundance at alternate sites within the San Francisco Bay. Numbers show increase in pup abundance at three alternate sites within San Francisco Bay. CM represents numbers seen at Corte Madera Marsh, MS, Mowry Slough and YBI, Yerba Buena Island. See Figure 1 for location of each site within SFB. Numbers at YBI courtesy of Richmond Bridge Harbor Seal Survey.

year	Tide Height (ft)	Temperature (F)	Cloud Cover (%)	Wind Speed (mph)	Wind Direction	Days of Rain
1999	0.9	59.2	59.2	5-9.9	SW	5
2000	0.7	65.1	65.1	5-9.9	WSW	1
2001	0.4	57.6	57.6	5-9.9	SE	2
Average	0.7	60.1	60.1	5-9.9	SE	3

Table 4. Environmental Variation Analysis. Variation in environmental factor data gathered on site for all years of study

Haul Out Usage

Analysis of haul out distribution shows a high usage of A rock all three years (83.9% of combine total; Table 5). Based on combined totals for each year, >80% of the pups were observed on A all three years (1999=86.3%; 2000=81.3%; 2001=86.1%). In comparing percentages on a daily basis, more than 70% of the pups were observed on A rock for 21 of the 24 data collection days. This consistent use of A in such high percentage was not seen for 2000 or 2001. There were no pups seen on E during both 1999 and 2000 and very limited usage of D in those years (0.4% for both). The highest percentage of pups seen on F occurred in 2000, with nearly 10% of total. In 2001, there was a more even distribution between usage of B and C (5.4% and 5.1%).

Analysis of haul out distribution on A rock also shows a preference for certain quadrants (Table 6). Combined totals show a preference for A3 with 30.3% of total pups observed in this quadrant regardless of year. In 1999, A3 was the most prominently used quadrant (34.6% of total), with >50% of pups observed in A3 on 11 out of 24 data collection days. Over 25% of total pups observed in 2000 were recorded in both A3 and A5. There was an increase in pups observed in quadrant A1 in 2001(30.3%)

year	A	B	C	D	E	F
1999	86.3	6.3	2.6	0.4	0.0	4.4
2000	81.3	6.9	1.5	0.4	0.0	9.9
2001	86.1	5.4	5.1	1.5	1.7	8.4
Overall	83.9	5.6	2.8	0.6	0.5	6.6

Table 5. Haul out usage at Castro Rocks - Percentage of pups observed on each of the six main rocks each day of observation.

year	A1	A2	A3	A4	A5	A6
1999	9.4	17.5	34.6	19.2	12.4	6.8
2000	9.4	3.8	25.4	15.5	27.7	18.3
2001	30.3	7.0	26.6	7.0	18.9	10.2
Overall	17.1	10.7	30.2	13.3	18.6	10.0

Table 6. Haul out usage on A - Percentage of pups observed within each quadrant on A rock each day of observation.

and a reduction in distribution of pups observed in all other quadrants except A3.

Pup Growth Rate

The number of pups observed varied by growth class within months ($F_{2,82}$ = 102.74, $p<0.01$) and within years ($F_{2,82}$= 6.46, $p<0.01$; Table 7, Figure 9). Abundance of early growth class pups was greater during the first half of pupping season than the second half of the season for all years. Abundance of the middle growth class varied between years with a low mean during the first half of the season of 1999 and greater abundance in second and similar means during both halves of the season in 2000. Nearly all observations of the middle growth class occurred in the first half of the season in 2001. The abundance of the late growth class was greater in the second half of the season than the first for all years. However, the mean number of pups in the late growth class in 2001 was twice that of 1999 and 2000.

Based on the daily maximum number of pups, I found a statistically significant difference between the median date of observation for the 'early' growth class between years (Table 8 & 11, Figure 10), yet the biological difference was small ($H=7.079$, $n=287$, $p<0.05$). The earliest

Tests of Within-Subjects Contrasts					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
GROWTH CLASS (GC)	182.11	1	182.11	9.43	0.00*
GC * YEAR	249.36	2	124.68	6.46	0.00*
GC * MONTH	1983.72	1	1983.72	102.74	0.00*
GC * YEAR * MONTH	124.44	2	62.22	3.22	0.05*
Error(AGE)	1467.44	76	19.31		
Tests of Between-Subjects Effects					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
YEAR	226.60	2	113.30	4.38	0.02*
MONTH	9.36	1	9.36	0.36	0.55
YEAR * MONTH	32.67	2	16.33	0.63	0.53
Error	1964.32	76	25.85		

Table 7. Results of Repeated Measures ANOVA for growth class analysis

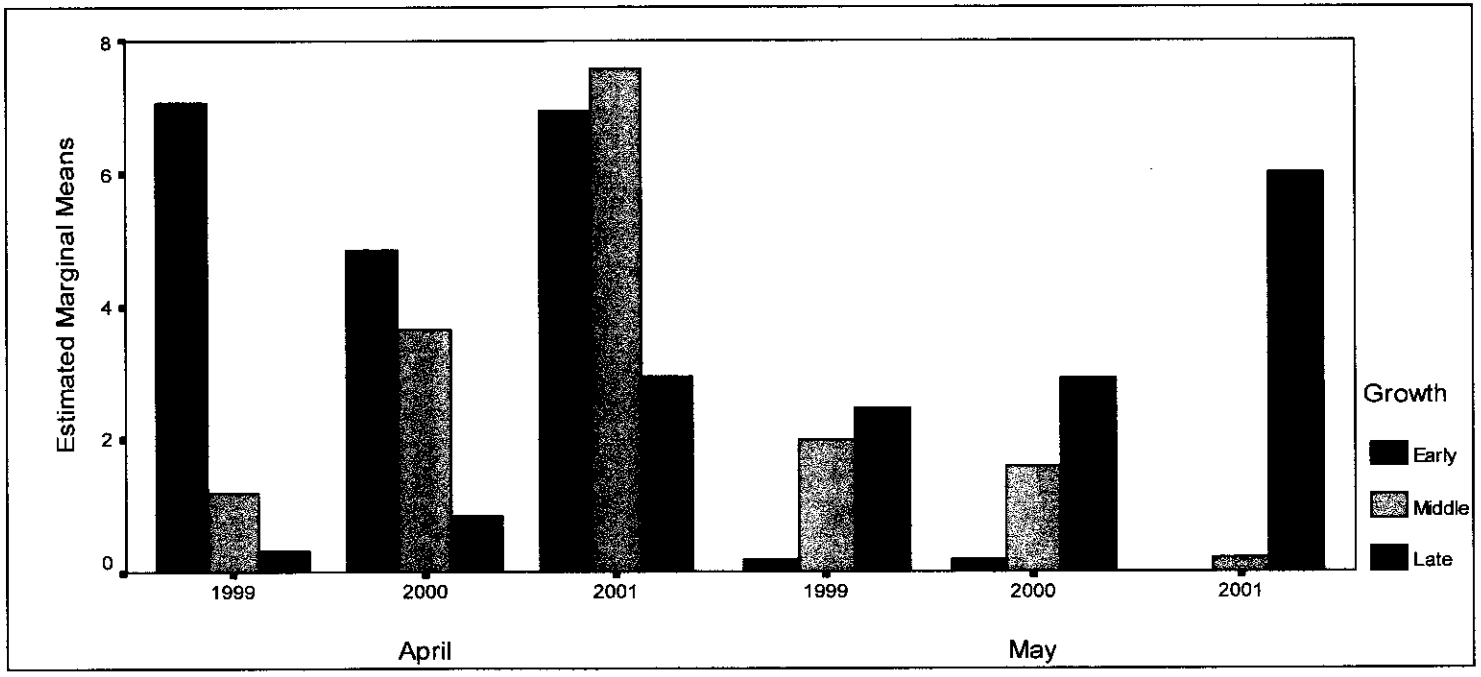


Figure 9. Abundance of Pup Growth Classes Across Seasons

Differences in pup abundance are shown for each growth class by year

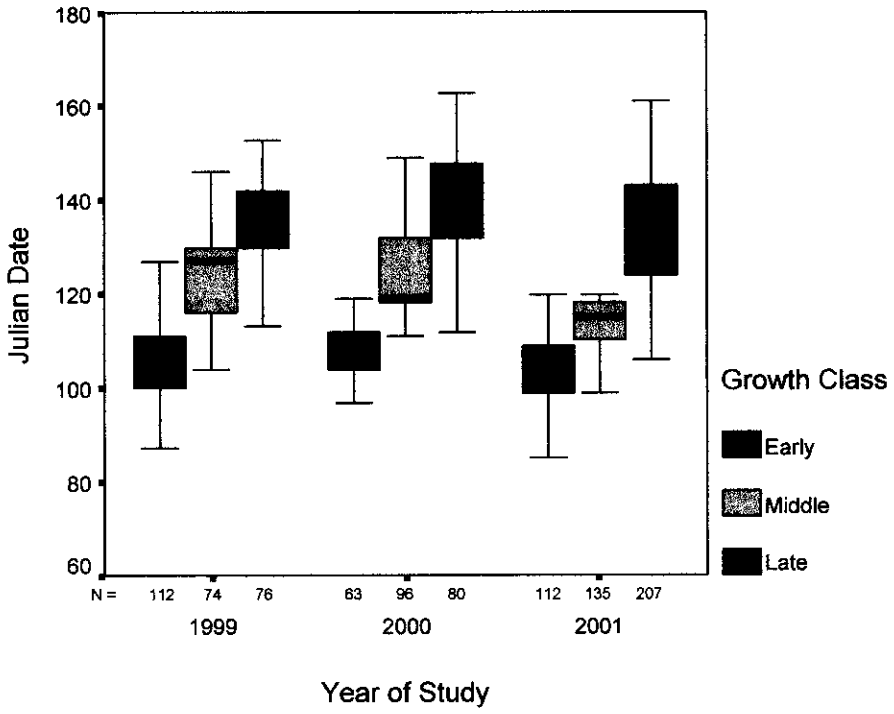


Figure 10. Distribution of Pup Growth Classes Across Seasons. The range of dates when each group of pups were observed are represented as boxes. Mean date of observation is shown as a black line within the box. Boxes represent 75% of data for each group. Whisker lines represent full data set of that group. N equals the number of pups observed in each growth class per year of study. Analysis based 30 survey days per year.

median date of observation was seen in 1999 and 2001 on April 14th. The difference in date is only three days between 1999, 2000 and 2001 (2000: April 17th).

I also found a statistically significant difference in the number of pups that fit the 'middle' growth class between years (Table 8 & 9). I had a higher number of pups fit the middle growth class characteristics earlier in the season in 2001 (April 23rd) when compared to 1999 (May 5th) and 2000 (April 27th) ($H=78.154$, $n=305$, $p<0.001$). There was also a drastic decrease in the number of pups seen in the middle growth class, when compared to the number of pups seen in the early growth class, for both 1999 and 2000.

Analysis revealed a similar pattern of possible growth rate for observed late growth class distribution (Table 8 & 9). A statistically significant difference in the median date of observation of 'late' growth class was seen between years. However, the variation occurred between the year 2000 and the years 1999 and 2001. The earliest median date of observation occurred in 2001 (May 12th), followed by 1999 (May 14th), then 2000 (May 18th) ($H=9.272$, $n=362$, $p<0.02$). In all three years, the number of pups in the late growth class was reduced from the initial number of early growth class pups. In 1999, I observed up to 15 pups in t

	EARLY				MIDDLE				LATE			
year	**N**	**Mean Rank**	**Mean Date**	**Std. Deviation**	**N**	**Mean Rank**	**Mean Date**	**Std. Deviation**	**N**	**Mean Rank**	**Mean Date**	**Std. Deviation**
1999	112	144.73	4/14	8.40	74	198.20	5/4	9.81	76	176.55	5/13	9.61
2000	63	165.67	4/16	10.89	96	188.19	5/3	9.78	80	212.67	5/18	12.98
2001	112	131.08	4/12	6.62	135	103.20	4/24	7.47	206	171.22	5/12	13.15
Total	287	--------	4/14	8.49	305	--------	4/29	10.07	362	--------	5/14	12.62

Table 8. Results of Kruskal Wallis Test with Growth Class. Ranking of mean value for each growth class and corresponding date of observation for each year of study.

Test Statistics						
	Abundance	**Paired**	**Lone**	**Early**	**Middle**	**Late**
H	14.13	19.504	4.523	7.079	78.15	9.272
degrees of freedom	2	2	2	2	2	2
Asymp.Sig	0.001*	0.00*	0.10	0.03*	0.00*	0.018*

Table 9. Test Statistics of Kruskal Wallis Tests. Results of analysis of tests of mean date of observation, (* indicates significance)

he early growth class, whereas at maximum I observed 10 pups in the late growth class in early May.

Pup Status – Estimated Lactation Length

Abundance of paired pups and lone pups varied within the first and second half of pupping season ($F_{2,83}$ = 35.15, $p<0.02$). There was no significant difference in abundance of pups overall within years of study ($F_{2,83}$ = 0.37, $p>0.05$; Table 10, Figures 11). However, when comparing abundance of pups of each status by year, abundance varied between the first and second half of pupping season between years ($F_{2,83}$ = 4.10, $p<0.02$; Table 10). Paired pups occurred in greater abundance during the first half of the pupping season and lone pups occurred in greater abundance during the second half of pupping season for all three years. There was a greater abundance of both groups in the year 2001, with the mean number of lone pups in 2001 during the second half of the season being double the mean number of lone pups observed in 1999.

Variation in timing of observation of pups also occurred within the three years of the study. A statistically significant difference in the date of paired pup observations was found (Tables 9 & 11, Figure 12; H=19.504, n=730, $p<0.001$). The earliest median date of observation of paired pups

Tests of Within-Subjects Contrasts					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
PUP STATUS	934.90	1	934.90	28.45	0.00*
PUP STATUS * YEAR	24.31	2	12.16	0.37	0.69
PUP STATUS * MONTH	1155.07	1	1155.07	35.15	0.00*
PUP STATUS * YEAR * MONTH	269.61	2	134.81	4.10	0.02*
Error(PUP STATUS)	2530.02	77	32.86		

Tests of Between-Subjects Effects					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
YEAR	343.02	2	171.51	4.47	0.01*
MONTH	16.44	1	16.44	0.43	0.51
YEAR * MONTH	22.70	2	11.35	0.30	0.74
Error	2953.55	77	38.36		

Table 10. Results of Repeated Measures ANOVA for paired and lone pup analysis. (* indicates significance)

	Paired (Pups With Mother)				Lone (Pups Without Mother)			
year	**N**	**Mean Rank**	**Mean Date**	**Std. Deviation**	**N**	**Mean Rank**	**Mean Date**	**Std. Deviation**
1999	207	352.81	4/23	14	58	117.09	5/14	11
2000	185	424.01	4/27	15	79	140.66	5/17	13
2001	338	341.25	4/22	11	135	142.40	5/17	14
Total	730	--------	4/23	13	272	--------	5/16	13

Table 11. Results of Kruskal Wallis Test with Paired and Lone Pups. Ranking of mean value and corresponding date of observation for each year of study.

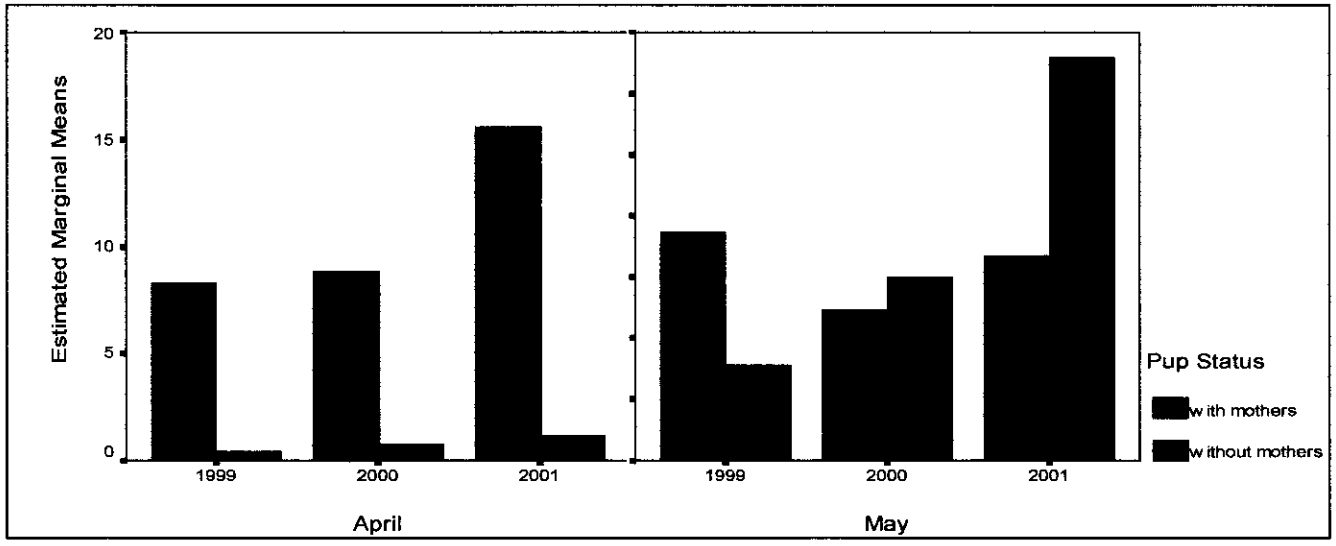


Figure 11. Abundance of Pups Status Across Seasons. Differences in pup abundance of pups observed with and without their mothers by month and year.

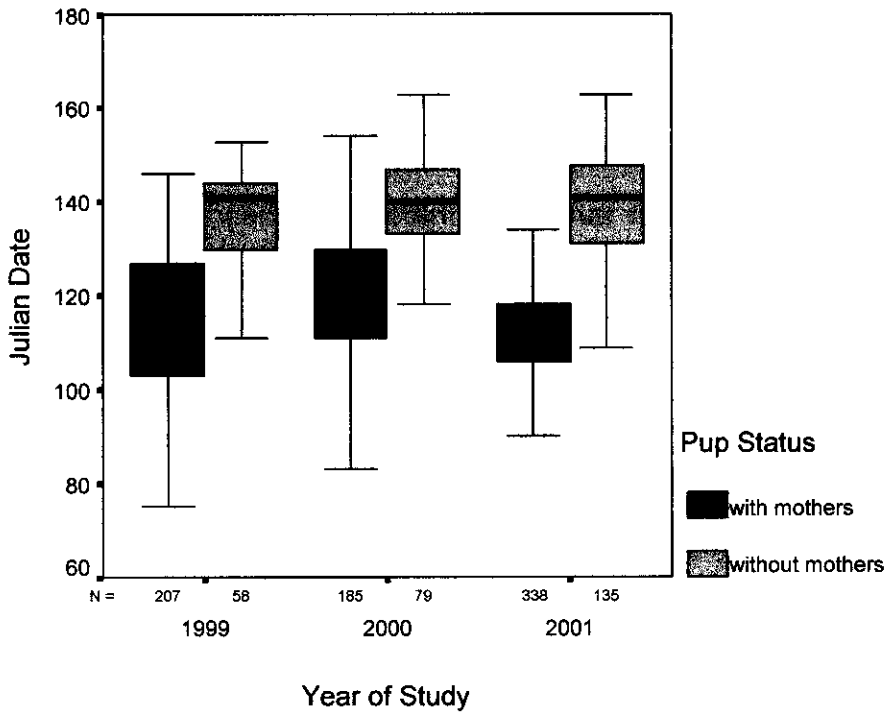


Figure 12. Distribution of Pups Status Across Seasons. The range of dates when each group of pups was observed is represented as boxes. Mean date of observation is shown as a black line within the box. Boxes represent 75% of data for each group. Whisker lines represent full data set of that group. N equals the number of pups observed in each growth class per year of study. Analysis based 30 survey days per year.

occurred in 2001 (April 21st) and the latest median date of observation in 2000 (April 28th). However, no statistically significant difference in the date of lone pup observations was found, with median date of May 20th for both 1999 and 2001, and May 21st for 2000 ($H=4.523$, $n=272$, $p>0.05$). In 2001, I also observed substantially higher number of lone pups on a daily basis at the end of the season. No statistically significant difference was found in nursing length. Average nursing bout length for all three years was approximately 8 minutes in length ($F_{2,103}=1.277$, $p>0.05$).

Maternal Pelage Variation

Analysis of the temporal distribution of maternal pelage coloration suggests abundance of mothers with red pelage declines during the second half of all three years. In the year 1999, significant differences found between the abundance of red and normal pelaged mothers occurred between April and May ($F_{1,22}=14.008$, $p<0.001$; Table 12, Figure 13). A greater number of red-pelaged mothers was observed in the month of April when compared to the number observed in the month of May. The reverse was found for normal pelaged mothers in 1999, with an increase in abundance found from April to May. In 2000, the variation in abundance of red-pelaged mothers also varied with month. The same temporal

1999						
	Tests of Within-Subjects Contrasts					
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	COAT	2.84	1	2.84	0.65	0.43
	COAT * MONTH	61.57	1	61.57	14.01	0.00*
	Error(COAT)	87.91	20	4.40		
	Tests of Between-Subjects Effects					
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	MONTH	6.09	1	6.09	0.32	0.58
	Error	384.85	20	19.24		

Table 12. Statistical Analysis of Maternal Pelage Coloration. Results from repeated measures ANOVA comparing pup abundance among red pelaged and non-red pelaged mothers for 1999,
(* indicates significance).

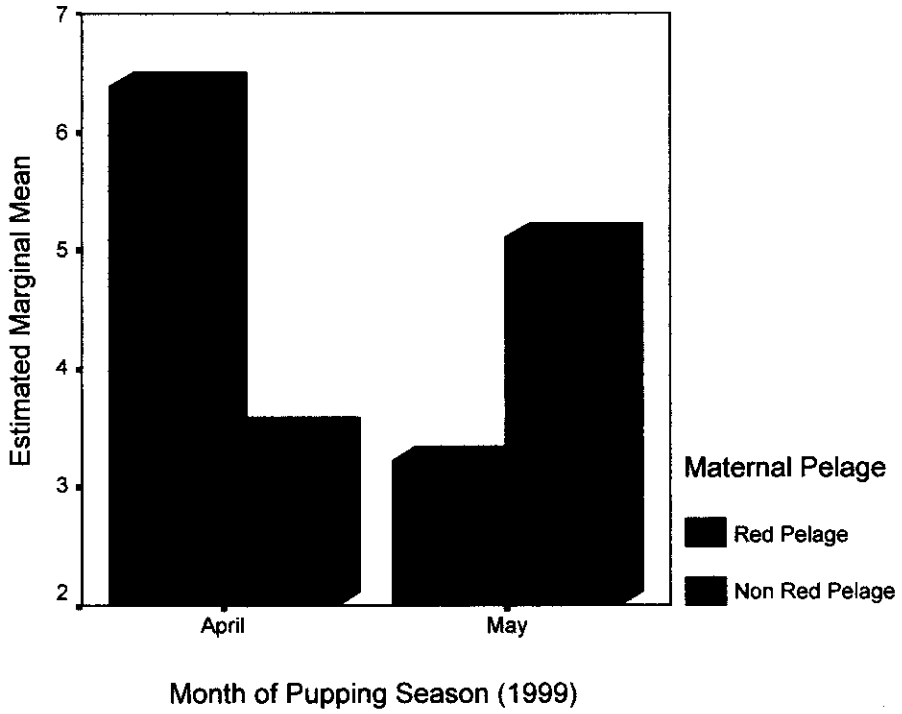


Figure 13. Maternal Pelage Coloration (1999). Graphical presentation of results from repeated measures ANOVA test comparing pup abundance among red pelaged and non-red pelaged mothers for 1999.

pattern as observed for red-pelaged mothers in 2000 as was observed for 1999 ($F_{1,19}$=3.288, p>0.05; Table 13, Figure 14). However, the increase in normal-pelaged mothers seen in 1999 was not observed in 2000 ($F_{1,19}$=1.490 p>0.05). A similar temporal pattern for red-pelaged mothers was observed in 2001 ($F_{1,23}$=5.808, p<0.025; Table 14, Figure 15). In 2001, the pattern seen for normal-pelaged mothers was more similar to the pattern seen for red-pelaged mothers in 1999 and 2000. In 2001, there were higher number of mothers with both pelage colorations observed in April and a steep decrease in abundance of mothers with both pelage colorations was observed in May ($F_{1,23}$=15.289, p<0.001).

2000	Tests of Within-Subjects Contrasts					
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	COAT	24.29	1	24.29	2.83	0.11
	COAT * MONTH	28.18	1	28.18	3.29	0.09
	Error(COAT)	145.71	17	8.57		
	Tests of Between-Subjects Effects					
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	MONTH	39.40	1	39.40	1.49	0.24
	Error	449.44	17	26.44		

Table 13. Statistical Analysis of Maternal Pelage Coloration. Results from repeated measures ANOVA comparing pup abundance among red pelaged and non-red pelaged mothers for 2000, (* indicates significance).

2001	Tests of Within-Subjects Contrasts					
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	COAT	55.60	1	55.60	12.74	0.00*
	COAT * MONTH	25.34	1	25.34	5.81	0.03*
	Error(COAT)	91.62	21	4.36		
	Tests of Between-Subjects Effects					
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	MONTH	499.20	1	499.20	15.29	0.00*
	Error	685.67	21	32.65		

Table 14. **Statistical Analysis of Maternal Pelage Coloration**. Results from repeated measures ANOVA comparing pup abundance among red pelaged and non-red pelaged mothers for 2001, (* indicates significance).

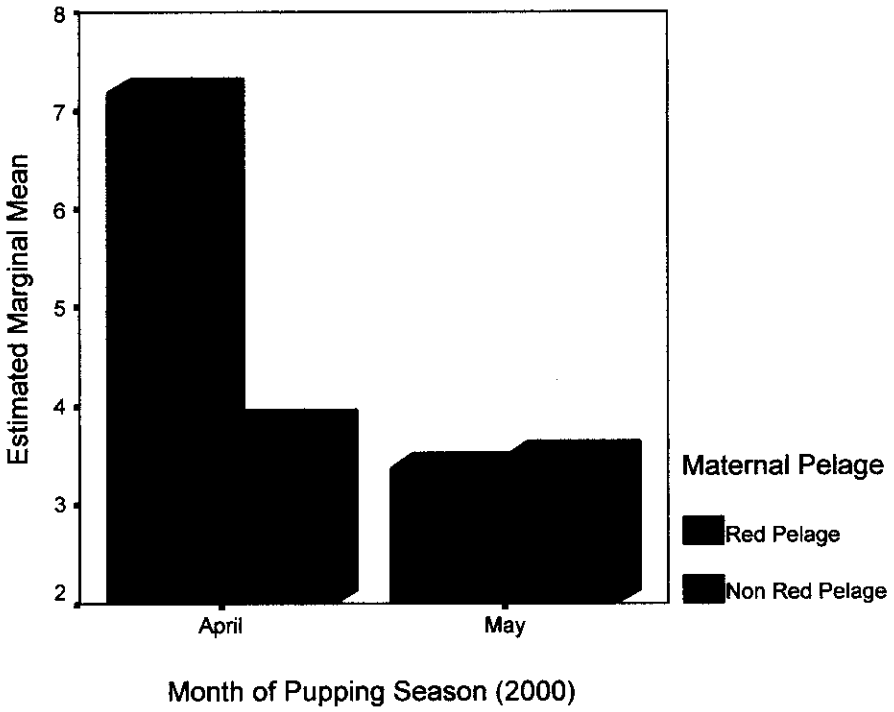


Figure 14. Maternal Pelage Coloration (2000). Graphical presentation of results from repeated measures ANOVA test comparing pup abundance among red pelaged and non-red pelaged mothers for 2000.

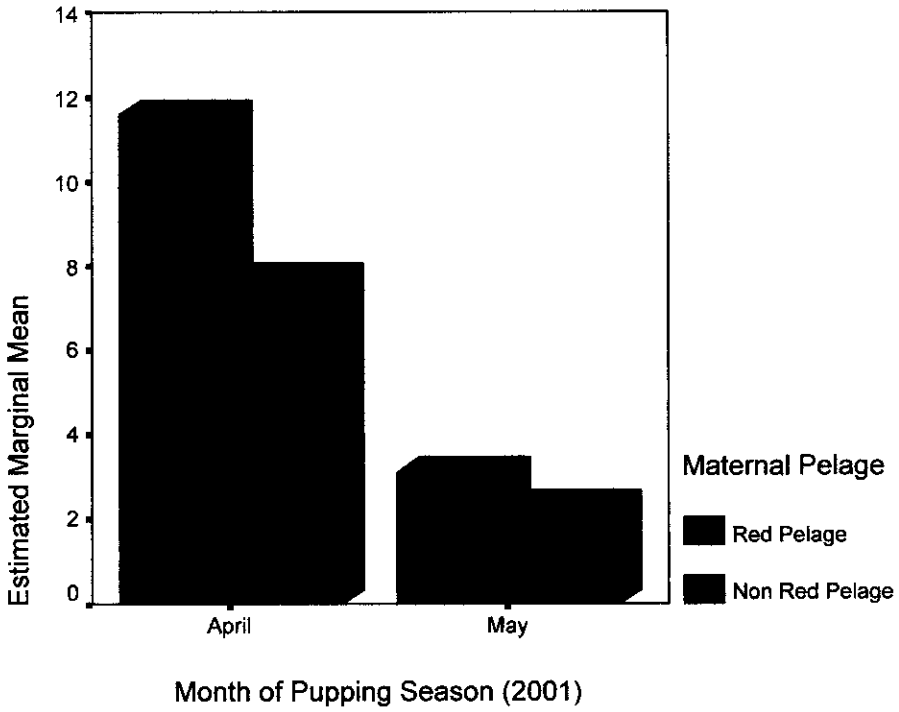


Figure 15. Maternal Pelage Coloration (2001). Graphical presentation of results from repeated measures ANOVA comparing pup abundance among red pelaged and non-red pelaged mothers for 2001.

Discussion

Within the San Francisco Bay, there was wide variation in pup abundance, lactation length and growth rate between 1999 and 2001. Since the last recorded ENSO event in 1998, an overall increase in the number of pups was observed at all sites within SFB except Corte Madera. Variation in numbers seen over the three years of this study may be explained in part by the effects of environmental constraints on the physiology of pinniped pregnancy.

Although photoperiod was consistent over the 3 study years, the maternal condition may have varied with drastic environmental variation from the 1998 ENSO and 1999 La Nina events. A reduction or alteration in food supply may have lead to an increase in the amount of time needed to attain the threshold body condition, a subsequent delay in implantation, and therefore, delay of parturition in the subsequent year (Boyd 1996). This may explain the larger variation in parturition date in 1999 and 2000 and the more punctuated parturition date in 2001 at Castro Rocks (CR). It is not uncommon to see a reduced pregnancy rate, indicative of low pup abundance in 1999 and 2000, as pregnancy rates are reduced after years in which feeding conditions were poor (Jemison and Kelly 2001; Boyd 1996; Lunn and Boyd 1993; Lunn et al. 1993; Allen, 1989).

Variation in food abundance was a likely cause of a shift in harbor seal pup phenology at Tugidak Island, Alaska (Jemison and Kelly 2001). The reduction in food availability may be the result of competition by a shift in the diet of Stellar sea lions (*Eumetopias jubatus*) in response to a dietary shift to wall-eyed pollock (*Theragra chalcogramma*) and other low-calorie, low-fat fish that are more common to harbor seal diets. This shift in diet of the Stellar Sea Lions increased the existing overlap of prey choices between the two species, leading to a decrease in food availability for harbor seals. It was suggested that the decline in food available for harbor seals was the cause of the pup decline and shift in parturition dates in recent years.

An increased tide level and increases in rainfall in April and May reported during the La Nina event (Null and Monteverdi 1999) may have led to a decrease in haul out availability. This decrease in haul out availability may explain the variation in haul out patterns of mother-pup pairs between each year of the study. At CR, the majority of pups were continuously observed on the main rock (A). However in the La Nina year (1999), a higher percentage of mother-pup pairs used A on a daily basis, which is the rock first exposed with the falling tide, therefore more accessible with a higher tide level. The variation in haul out use on A rock

may also be related to availability of haul out. Quadrant A3 is easy to access with the falling tide, containing the most sand and least rock, and appears to have a fairly gentle slope. This may explain why more mothers and pups were observed in A3 all years.

At CR, decrease in food availability in the fall of 1998, 1999 and spring of 2000 may have led to the decrease in growth rate during the 1999 and 2000 pupping season. Increases in energy expenditure leave less energy available to transfer to the pup. Typically, a slower pup growth rate is seen in years when mothers spend long periods of time searching for food because of low availability (Lunn and Boyd 1993; Lunn et al. 1993). Differences in abundance and timing of observed growth class at CR may imply variation in growth rate. In 2001, pups fit the physical characteristics of 'middle age class' and 'late age class' earlier and in greater abundance than in 1999 or 2000. A reduction in the mean number of pups was observed between growth classes for 1999. In 2001, the number of pups observed in each growth class increased throughout the season. The increase in growth rate and number seen in 2001 could be a result of increased nursing bout length, frequency or increase in milk energy transfer rate due to more accessible food supply and/or more favorable environmental conditions in 2001.

In 2001, there were a greater number of mother-pup pairs seen on the site earlier in the season than in 1999 and 2000. With this, it is not surprising that I saw a greater number of pups with their mothers earlier in the season in 2001, when compared to 1999 and 2000. Yet, in analysis of the dates when pups were observed without their mothers, I found no significant difference in date. It appears that, on average, pups stayed with their mothers for a longer period of time in 2001. This change in lactation length may be related to a decrease in food abundance during the fall and winter during post ENSO/La Nina years. If the mothers were more fit entering lactation, they could presumably nurse their pups for longer periods. If they are energetically constrained, they are more likely to abandon their pups after a shorter period of time (DeLong et al. 1999; Sydeman and Allen 1999).

The variation in environmental conditions of 1999 and 2000 may have led not only led to decreases in the amount of time the pairs stayed together, but may have led to decreases in nursing bout length and energy transfer rate. Analysis of these data did not show a significant difference in the length of nursing bout length, however, decreases in the amount of time spent on land as a result of increased tide level may have led to decreases in the frequency of nursing bouts in 1999.

Lactation in harbor seals is not only important in regard to mass transfer and overall weight gain, but for the strength of the immune system as well. The number of lone pups seen on the haul out site at the end of pupping was higher in 2001, when compared to 1999 and 2000. Susceptibility to infection by viral and bacterial agents is of great concern for harbor seal mothers and pups. There may be a correlation between high pollution and the incidence of phocine distemper due to pollution-induced immunosuppression, as was found in Washington (Ross et al. 1993). In the SFB, cases of brucellosis and herpes within our harbor seal population have been documented (F. Gulland, Sausalito, CA; pers. comm.), however, no direct study has been conducted on the link between these viruses and pollution. With the possible link shown in Washington, strong immune systems are extremely important for harbor seal populations exposed to high levels of human development and, therefore, high pollution as we see in SFB.

Due to the numerous hours mothers and pups spend in the water, mortality rate is nearly impossible to quantify (Johnson 1977). However, it is unlikely that the pups not observed had left the area during the pupping season because the majority of pups do not venture more than ~30 km during lactation (Bekkby and Bjorge 2000). The majority of pups remain

within the vicinity of their natal site even after weaning (Bekkby and Bjorge 2000; Thompson et al. 1994). The low number of pups seen at the end of pupping season may imply a low rate of survival in 1999 and 2000 when compared to 2001.

Evidence for a link between these variations and foraging behavior may be seen in the differences in parturition and growth rate within two distinct groups within the colony, female seals with red pelage and female seals with normal pelage. The effects of this discoloration of fur on pup survival have not been quantified; however, variation in temporal distribution occurred within each season. In 1999, there was a significant difference in occurrences of mothers with red vs. normal pelage in the first full month of pupping season. Red pelaged mothers appeared to give birth earlier in the season than normal pelaged mothers. I suggest that this difference in observation represents a difference in parturition date. The high number of red-pelaged mothers observed in April, with a decrease in observation in May suggests that a higher proportion of these mothers gave birth in April and had weaned or abandoned their pups during May. The low number of normal pelaged mothers in April with an increase in observed numbers in May suggests that a large proportion of these mothers gave birth in May.

In 2000, similar trends in parturition date were seen for red pelaged mothers. Red pelaged mothers continued to pup in April, however, there was an overall decrease in the number of normal pelaged mothers throughout the season. The number of normal pelaged mothers was lower than red pelaged mothers in April; however there was no increase in May as there was in 1999. Therefore, analysis of these data suggests that red-pelaged mothers gave birth in April. Yet, the number of normal pelaged mothers remained constantly low in 2000; therefore, no significance was found in comparison of the two.

This variation in parturition date could be the result of differences in prey species by seals with the two pelage colors. Lydersen et al. (2001) explained the red discoloration in bearded seals (*Erignathini barbatus*) and ringed seal (*Phoca hispida)* through variations in foraging behavior. They proposed that the bearded seals, who forage on benthic prey, are rutting in the sediment with high metal content. The ringed seal population that inhabits the same area does not have as many members that have this red discoloration. The main behavioral difference between these two species is that ringed seals forage mainly on water column species, not benthic species. In SFB, members of this harbor seal population have also been shown to forage on both benthic species, including Yellowfin goby

(*Acnthogobious flavimanus)* and Pacific staghorn sculpin (*Leptocottus sculpin),* and many water column species (Harvey and Torok 1994). Analysis of the dietary aspects of red-pelaged versus normal pelaged seals needs to be conducted to determine if a similar link to pelage color occurs in SFB.

If pelage discoloration is related to foraging behavior, this relationship may explain the difference in birth date. If the ENSO event of 1998 and La Nina event of 1999 affected different prey species, it is possible that the food sources of the red pelaged mothers were not as greatly affected by these changes in weather pattern. This does not necessarily imply they are only foraging on different food sources, it may be a difference in foraging area. If the foraging areas of the normal-pelaged mothers were hit harder by the storms than the areas of the others, causing a reduction in local prey availability, we may still have seen a difference in date of parturition.

Although no significant difference in the occurrences of red versus normal pelaged mothers occurred in 2001, a difference was found between pelage color and month. With both pelaged colors, higher numbers were seen in April than in May. This analysis verifies that in 2001 more pups were born in the first month of the season than in the second to

both red and normal pelaged mothers. I believe this distribution in parturition date reflects a 'normal' year, with little effect from variation in prey abundance or environmental variables within the previous year adult.

Based on the dates of parturition during 2001, I do not believe that red pelaged mothers gave birth earlier due to overwhelming energetic constraints in 1999 and 2000. Using photographic evidence of 1999 and 2000, the average pup size born to red-pelaged mothers does not appear to be smaller in either year. However, there are other variables in photographic analysis that could have altered apparent size. Due to small sample size, analysis of growth rate of pups based on pelage coloration was not conducted, but is important for future research.

With future research, I can determine continued effects of environmental factors by establishing where SFB seals forage and what species they are foraging on. If we can establish a difference in foraging behavior and prey species, we can examine how the ENSO/La Nina events affected these prey species as well. With this, we can attempt to correlate food resource availability with attainment of the threshold body condition and possibly date of implantation.

Overall analysis of these data suggests that the attainment of the threshold body condition has a greater effect on pup abundance, date of

parturition and pup growth in years of environmental constraint. This makes the need for optimal haul out space of prime importance during years of extreme environmental variation.

With an extension retrofit construction project planned for the Richmond-San Rafael Bridge, it is important to use pup abundance during these years with caution. It would be inaccurate to compare the numbers gathered for this study with number in non-ENSO/La Nina years, without taking these environmental events into consideration.

Now that we have estimates on how ENSO and La Nina affect pupping phenology at Castro Rocks, we can compare phenology during the retrofit for years with varying environmental variations. With a forecasted ENSO event for the winter of 2002, it may be important to increase protection to ensure availability of haul out space for females to meet energetic requirements. Although protection of the site during the pupping season is beneficial, it is important to ensure the good health of the mother prior to giving birth as well as while the pup is nursing.

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