HARBOR SEAL, *PHOCA VITULINA RICHARDII*, POPULATION TRENDS IN THE SAN FRANCISCO BAY ESTUARY, 1970-2002

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Pacific harbor seals, *Phoca vitulina richardii*, have used the San Francisco Bay estuary in California as a nursery area and foraging site for thousands of years. Like other pinniped species, harbor seals in California were intensively hunted in the late 1800's and early 1900's, resulting in population declines obvious in the San Francisco Bay (SFB) by the 1920's. In 1972, the Marine Mammal Protection Act was passed, providing protection and management of harbor seal populations. We examined historical data (1970-1997) and our own ground counts at three primary SFB haulout sites (1998-2002) in order to understand the degree of recovery of the SFB harbor seal population. One of the largest estuaries on the west coast of the United States, SFB today is highly urbanized and heavily impacted by human activity. We documented a mixed response and recovery of harbor seals in SFB, likely due to a combination of factors, including habitat alteration, disturbance, pollution, and survey techniques. From 1970-2002, seal numbers at all three sites increased slightly during the fall/winter season, and increased at two sites during the pupping/molting season. At the largest SFB rookery site, however, no change was seen in seal numbers during the pupping/molting season.

INTRODUCTION

Along the west coast of North America, the Pacific harbor seal, *Phoca vitulina richardii*, ranges from Baja California to the Pribilof and Aleutian islands (Bigg 1969, Bigg 1981; Reeves et al. 1992). Periodically, harbor seals move onto offshore or intertidal rocks or reefs, sand bars, sandy beaches, or tidal mudflats in order to rest between

foraging trips, molt, thermoregulate or nurse their young (Bigg 1981, Allen[1] 1991, Watts et al. 1993). Seals tend to congregate at the same sites, called haulout sites, year after year (Fancher[2] 1979, Yochem et al. 1987, Harkonen 1987, Hanan[3] 1996). Such areas are characterized by ease of access to the water, proximity to food resources, and minimal disturbance levels (Scheffer and Slipp 1944, Loughlin[4] 1974, Allen[1] 1991). Although some haulout sites are used year-round by seals, others are used seasonally, for pupping, molting, or because of proximity to a seasonally-abundant prey resource (Risebrough et al.[5] 1980, Brown and Mate 1983, Slater and Markowitz 1986, Thompson 1989). Harbor seals often use haulout sites in bays and estuaries, particularly during the pupping and molting seasons, as estuaries provide sites protected from disturbance and sheltered from storms (Brown and Mate 1983, Harkonen 1987, Kopec and Harvey[6] 1995). Harbor seals generally feed on bottom-associated prey, in shallow waters of 30 to 50 m or less (Harkonen 1987; Harvey 1989, Tollit et al. 1998); estuaries provide large stretches of shallow bottom habitat, and can provide ample supplies of food (particularly small fish and crustaceans) for young seals (Bigg 1981, Harkonen 1987). In some areas, seals move seasonally and in large numbers into estuaries, following an abundant prey resource such as salmon or herring (Brown and Mate 1983, Allen[1] 1991, Greenstreet et al. 1993).

During pupping and molting seasons, harbor seals typically spend approximately 60% of their time on the haulout site (Yochem et al. 1987, Allen Miller[7] 1988, Harkonen and Heide-Jorgensen 1990; Thompson et al. 1997, Thompson et al. 1998). Counts of harbor seals made at haulout sites have been used to estimate population size, status and trends of harbor seals, often with correction factors derived from telemetry studies, designed to compensate for animals in the water at the time of survey and extrapolate haulout counts to population size (e.g. Hanan[3] 1996). Considerable research has been dedicated to determining the optimal time to survey haulout sites for maximum numbers

[1]Allen, S.G. 1991. Harbor seal habitat restoration at Strawberry Spit, San Francisco Bay. Report to the Marine Mammal Commission, Contract No. MM2910890-9, March 1991. 43 p.

[2]Fancher, L. 1979. The distribution, population dynamics and behavior of the harbor seal in South San Francisco Bay. M.S. Thesis. California State University, Hayward, CA. 109 p.

[3]Hanan, D. 1996. Dynamics of abundance and distribution for Pacific harbor seal (*Phoca vitulina richardsi*) on the coast of California. Ph.D. dissertation, University of California, Los Angeles. 158 pp.

[4]Loughlin, T.R. 1974. The distribution and ecology of the harbor seal in Humboldt Bay, California. M.S. Thesis, Humboldt State University, Humboldt, CA. 70 p.

[5]Risebrough, R.W., D. Alcorn, S.G. Allen, V.C. Anderlini, L. Booren, R.L. DeLong, L.W. Fancher, R.E. Jones, S.M. McGinnis, and T.T. Schmidt. 1980. Population biology of harbor seals in San Francisco Bay, California. Nat. Tech. Inf. Serv. Report No. MMC-76/19.

[6]Kopec, A.D. and J.T. Harvey. 1995. Toxic pollutants, health indices, and population dynamics of harbor seals in San Francisco Bay, 1989-1992. Moss Landing Marine Laboratories, P.O. Box 450, Moss Landing, CA USA 95039-0450

[7]Allen Miller, S. 1988. Movement and activity patterns of harbor seals at the Point Reyes Peninsula, California. M.S. Thesis, University of California at Berkeley (Wildland Resource Science), Berkeley, CA. 69 p.

(Fancher and Alcorn 1982, Allen et al. 1989, Thompson et al. 1989, Thompson et al. 1997, Frost et al. 1999). However, given the differences in seal site use by location, season, year, time of day, tide height, weather, and levels of disturbance (Paulbitski 1975, Stewart[8] 1981, Slater and Markowitz 1983, Allen et al. 1984, Pauli and Terhune 1987, Grellier et al. 1996, Frost et al. 1999), optimal survey time may vary from site to site (Thompson et al. 1997, Grigg et al. 2002). Generally, coastal sites are surveyed during the molt (Thompson et al. 1989), when seals tend to spend more time onshore, possibly to facilitate the molting process (Feltz and Fay 1966). To assess seal numbers in an estuarine habitat, haulout sites may be best surveyed during the pupping season (Thompson et al. 1997), given the apparent preference of estuarine sites for pupping (Harkonen 1987).

An observed decline in numbers of seals using a haulout site can be indicative of an actual population decline (for example, due to overhunting, decreased reproduction or survival) (Bartholomew and Boolootian 1960, Bonner et al. 1973). However, changes in haulout site numbers may be influenced by a number of factors, including seasonal differences in amount of time spent on the haulout site, or shifts away from one site to another. For example, adult female seals spend more time on the haulout site during the pupping season and, after molting, seals appear to spend more time in the water foraging (Thompson et al. 1989, Thompson et al. 1997). Seals have been reported to abandon a haulout site due to high levels of disturbance (Paulbitski 1975, Allen[1] 1991) or shift site use following shifts in prey abundance or location (Brown and Mate 1983, Thompson et al. 2001). Determining the cause or causes of observed shifts in seal numbers in a given area can be difficult, because such shifts can be due to a number of confounding factors.

The San Francisco estuary, more commonly called the San Francisco Bay (SFB), is the largest coastal embayment on the west coast of the United States (Conomos et al. 1985) (Fig. 1). Based on evidence from shellmounds found along the SFB shoreline, harbor seals have used this estuary for thousands of years (Nelson 1909, Broughton 1999). Limited data are available on seal numbers prior to the late 1800's (Scammon 1874, Bartholomew 1967), and reliable census data on harbor seals in SFB are almost non-existent prior to 1949 (Bartholomew 1949). The historical data suggest that seals were numerous in SFB prior to the late 1800's, but were hunted intensely in SFB and along the California coast during the late 1800's and early 1900's (Scammon 1874, Bonnot 1928, Bonnot 1951, Bartholomew and Boolootian 1960, Hildebrandt and Jones 1992), resulting in severe population declines that were obvious in SFB by the 1920's (Bonnot 1928). In the United States, marine mammals have been legally protected from hunting since 1972. Since that time, harbor seal numbers on the coast of California have increased markedly (Allen et al. 1989, Hanan[3] 1996, Sydeman and Allen 1999, Caretta et al.[9] 2001). Based on counts of harbor seals during aerial surveys of haulout sites conducted in May/June 1995, and a correction factor of 1.3, the California population

[8]Stewart, B.S. 1981. Seasonal abundance, distribution and ecology of the harbor seal (Phoca vitulina richardsi) on San Miguel Island, California. MS Thesis, San Diego State University, San Diego, CA. 66 p.

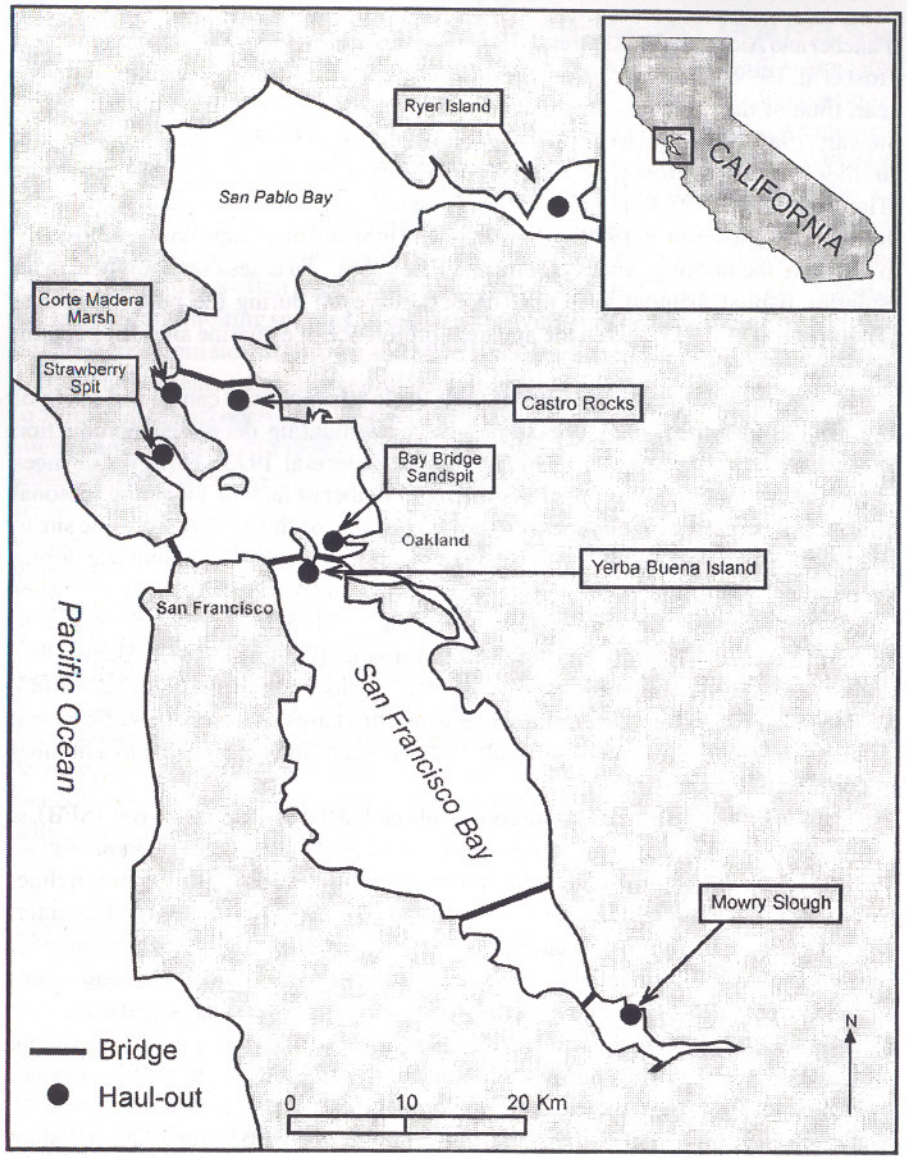

Figure 1: Map of San Francisco Bay harbor seal haulout sites. Shown are three primary haulout sites (Castro Rocks, Yerba Buena Island, and Mowry Slough), two smaller sites (Ryer Island, Corte Madera Marsh) and two historic sites (Strawberry Spit, Bay Bridge Sandspit).

is estimated at 30,293 (Caretta et al.[9] 2001).

Since the 1970's, considerable research has been conducted on harbor seals in SFB. The SFB population has been described as "stable" (Fancher[2] 1979, Risebrough et al.[5] 1980, Alcorn and Fancher[10] 1980, Fancher and Alcorn 1982), although some researchers have expressed concern about the loss of certain haulout sites, due primarily to disturbance (Bartholomew 1949, Paulbitski 1975, Allen[1] 1991). Since 1982, the California Department of Fish and Game (CDFG) has conducted statewide aerial surveys to assess population numbers of harbor seals in California; haulout sites in SFB are included in their surveys (Fluharty[11] 1999, Read and Sweetnam[12] 2002). Although the CDFG aerial surveys were not designed for evaluating population trends in SFB, their data for all SFB haulout sites have been cited as an indicator of lack of population increase in SFB (Kopec and Harvey[6] 1995). The CDFG aerial surveys support a population estimate of approximately 500 seals for SFB (R. Read, California Department of Fish and Game, personal communication). Recently, some SFB researchers have expressed concern about the lack of increase in harbor seal numbers in SFB, as these numbers do not appear to be rebounding compared to seal populations on the California coast (Kopec and Harvey[6] 1995). SFB is surrounded by three major urban areas and is home to a major west coast shipping port, with a rapidly expanding human population and a shoreline extensively altered by human activity. An estimated 94% of tidal marshes in SFB (i.e., estuarine habitat preferred by harbor seals) have been altered by filling or diking (Josselyn and Buchholz[13] 1984). Contaminant levels in the tissues of SFB seals have been found to be high (Risebrough et al.[5] 1980, Young et al. 1998, She et al. 2002), prompting concerns about possible negative effects on seal reproductive rates.

There are currently 20 active harbor seal haulout sites in SFB, although most are used sporadically or by small numbers of seals (<15) (Kopec and Harvey[6] 1995). We have been intensively surveying the three largest harbor seal haulout sites in SFB (Castro Rocks, Yerba Buena Island, and Mowry/Newark Sloughs) since 1998. This report:

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[9]Caretta, J.V., J. Barlow, K. A. Forney, M.M. Muto, and J. Baker. 2001. US Pacific Marine Mammal Stock Assessments: 2001. US Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-317.

[10]Alcorn, D.J. and L.E. Fancher. 1980. Report on the harbor seals of the San Francisco Bay National Wildlife Refuge, south San Francisco Bay, California. Final Report to the USFWS, SFBNWR. 30 April 1980.

[11]Fluharty, M.J. 1999. Summary of Pacific harbor seal, *Phoca vitulina richardsi*, surveys in California, 1982-1995. California Department of Fish and Game, Marine Region. Administrative Report 99-1. 49 p.

[12]Read, R. and D. Sweetnam. 2002. Final Report: Survey of Harbor Seals in California 2002. California Department of Fish and Game, Marine Region. 12 p.

[13]Josselyn, M. and J. Buchholz. 1984. Marsh restoration in San Francisco Bay: a guide to design and planning. Tiburon, CA: Romberg Tiburon Center for Environmental Studies. Technical Report no. 3. 103 p.

1. analyzes seasonal patterns of site use at these three important haulout sites, and
2. evaluates trends in harbor seal numbers at these three sites, in light of our data and available historical counts.

STUDY AREA AND METHODS

Castro Rocks (CR) is a rocky outcrop located in northern SFB, adjacent to the southeastern edge of the Richmond-San Rafael Bridge (Fig. 1). The rocks span approximately 265 m, beginning 17 m from the bridge and ending 75 m from the bridge. CR is the largest harbor seal colony in northern SFB (Fancher[14] 1987) and is the second largest pupping site in SFB (Kopec and Harvey[6] 1995). Seals haul out year-round on CR during medium to low tides, during the daytime and nighttime (Green et al.[15] 2002, Grigg et al. 2002).

Yerba Buena Island (YBI) is located at the midpoint of the San Francisco-Oakland Bay Bridge in central SFB (Fig. 1). The site is a cobblestone beach backed by a steep, 15-25 m high cliff. It is located on the south side of the island, approximately 3 km northeast of the San Francisco city shoreline, 2 km west of the Port of Oakland and approximately 650 m from the Bay Bridge. Harbor seals haul out on YBI year-round, under a wide range of tidal conditions, with maximum counts reported during the winter months when Pacific herring, *Clupea harengus pallasii*, spawn in SFB (Spencer16 1997, Green et al.[15] 2002). Although YBI is not historically known as a pupping site (Spencer[16] 1997), more recent data indicates that several pups are born here each year (Green et al.[15] 2002).

Mowry Slough (Fig. 1) and adjacent Newark Slough are located in the extreme south of SFB, on National Wildlife Refuge land. Given the proximity and similar seasonality of seal use of these two sloughs, seals counted at both were included in one total, and the area was treated as one site, Mowry/Newark sloughs (MNS). Seals at this site haul out at varying tides on sloping mud banks bordering the sloughs, backed by tidal marsh vegetation, and (at low tides) on mudflats at the slough mouths. MNS is the largest harbor seal rookery in SFB, and has a highly seasonal pattern of use, with high numbers during the pupping and molting seasons and markedly lower numbers of seals present during the fall and winter (Fancher[2] 1979, Alcorn and Fancher[10] 1980, Kopec and Harvey[6] 1995, Green et al.[15] 2002).

[14]Fancher, L. 1987. An update on the current status of the harbor seal in San Francisco Bay. The Bay Institute of San Francisco, Sausalito, CA. February 1987.

[15]Green, D.E., E. Grigg, S. Allen, and H. Markowitz. 2002. Monitoring the potential impact of the seismic retrofit construction activities at the Richmond-San Rafael Bridge on harbor seals (*Phoca vitulina*): May 1998-December 2002 (Final Draft Interim Report, December 2002). Richmond Bridge Harbor Seal Survey, San Francisco State University (Biology), San Francisco, CA.

[16]Spencer, C.L. 1997. Seasonal haul-out patterns of *Phoca vitulina richardsi* in San Francisco Bay. M.A. Thesis, San Francisco State University, San Francisco, CA. 98 p.

Survey Methods (1998-2002)

We surveyed all three sites from May 1998 through December 2002. Surveys were conducted 3-7 days/week at CR, and 2 days/week at YBI and MNS. Surveys at CR and YBI were centered around the low tide when possible, when maximum daily numbers of seals are recorded at these sites (Green et al.[15] 2002). Surveys at MNS were centered around the low tide during pupping/molting seasons, and approximately 3-4 hours after the high tide at other times of the year, in accordance with information from previous studies (Fancher[2] 1979, Fancher and Alcorn 1982) on timing of maximum seal numbers at MNS.

Statistical Analyses: Long-term Trends (1970-2002)

In order to minimize impacts on our counts by disturbances which caused seals to leave the site, we used maximum counts for all comparisons. For the trends analysis, in order to maximize comparability to previous studies in SFB, we examined maximum counts from two "seasons": pupping/molting season (March through July), and fall/winter season (August through February). The maximum count for the trends analysis was defined as the maximum count (i.e., the maximum number of seals present at one time on the haulout site) obtained at a given site during the season noted. We evaluated current data against historical harbor seal counts for the three largest SFB haulout sites, using only data from 1970 onwards (Paulbitski[17] 1972; Paulbitski and Maguire 1972; Paulbitski[18] 1976; Fancher[2] 1979; Risebrough et al.[5] 1980; Alcorn and Fancher[10] 1980; Fancher and Alcorn 1982; Fancher[14] 1987; Allen[1] 1991; Kopec and Harvey[6] 1995; D. Kopec, personal communication; Green et al.[15] 2002). Not enough information was available on counts made prior to 1970 to assess the reliability of those counts. Data for these three sites was the most consistent source of data for trends in SFB; other SFB sites were surveyed only infrequently and were not included in the historical analysis.

In order to look for trends in seal numbers in SFB, we ran regressions on the natural logarithm of maximum harbor seal count (1970–2002) versus year, for the two seasons, for all sites. As we were not attempting to obtain absolute estimates for the SFB population as a whole, no correction factor was used on counts data prior to trends analysis. We calculated mean annual finite growth rate, G, from the slope of the regression line, m, as follows (Olesiuk et al. 1990, Hanan[3] 1996):

$$G = e^{m} - 1$$

[17]Paulbitski, P.A. 1972. The adaptive hauling behavior and population variance of harbor seals, *Phoca vitulina richardi*, which haul-out at Strawberry Spit, Richardson Bay. Unpublished manuscript, San Francisco State University, January 1972.

[18]Paulbitski, P.A. 1976. Unpublished data, cited in Kopec, A.D. and Harvey, J.T. (1995) Toxic pollutants, health indices, and population dynamics of harbor seals in San Francisco Bay, 1989-1992. Moss Landing Marine Laboratories, P.O. Box 450, Moss Landing, CA USA 95039-0450

Maximum seal counts do not include pups; whenever such data were available, we included as a separate category maximum number of pups counted each year, at each site.

In order to test whether long-term trends in seal numbers differed by site, we compared the slopes of the regression lines (natural logarithm of maximum count versus year) for the three sites, using Analysis of Covariance methods as described in Zar (1996).

Statistical Analyses: Recent Data (1998-2002)

For our recent surveys (1998-2002), we ran further analyses to evaluate possible trends revealed in the intensive survey efforts. For each site, we used Kruskal-Wallis nonparametric ANOVAs to determine whether maximum daily counts at each site differed by year. Since we began our surveys in May 1998, we ran these whole year comparisons on 1999-2002 only. In addition, we used Mann-Whitney U tests on maximum daily counts for each site to determine whether significant differences existed in seal site use by season (pupping/molting versus fall/winter). We used Kruskal-Wallis tests to evaluate whether differences existed between years in the number of seals using each site during a given season. When running seasonal comparisons, we only included data from years for which we had a complete season of data; for the pupping/molting season we used data from 1999-2002, for fall/winter we used data from 1998-2001. Maximum daily counts for the 1998-2002 analyses were defined as the maximum number of seals counted at a given site on each day surveyed. All statistical analyses, including regressions, were considered significant at $\alpha = 0.05$.

We calculated pup production for each year as the maximum number of pups counted during the pupping season, divided by the maximum number of adult/subadult seals counted during the same season, multiplied by 100. We then calculated a mean pup production rate for years 1999-2002, for all three sites.

Statistical Analyses: Aerial Survey Data (1982-2002)

Finally, in order to determine whether trends existed in the CDFG aerial survey data (1982-2002), and to compare these data with the counts from SFB researchers (Paulbitski[17] 1972; Paulbitski and Maguire 1972; Paulbitski[18] 1976; Fancher[2] 1979; Risebrough et al.[5] 1980; Alcorn and Fancher[10] 1980; Fancher and Alcorn 1982; Fancher[14] 1987; Allen[1] 1991; Kopec and Harvey[6] 1995; D. Kopec, personal communication; Green et al.[15] 2002), we ran a simple linear regression on the natural logarithm of the CDFG counts for all SFB haulout sites combined, and on the summed CDFG counts for the three sites featured in this paper: CR, YBI and MNS. CDFG surveys for SFB were not completed in 1997-1999, so no data were available for those years.

RESULTS

Long-term Trends (1970-2002)

Seasonal counts at CR during 1970-2002 revealed a steady increase in the number of adult and subadult harbor seals using that site, both during the pupping/molting season (r^2=0.78, P<0.001; mean annual growth rate: 6.1%) and during the fall/winter season (r^2=0.79, P<0.001; mean annual growth rate: 5.3%) (Fig. 2). A slight increase was also seen in number of pups counted at CR from 1970-2002 (r^2=0.77, P<0.001) (Fig. 2).

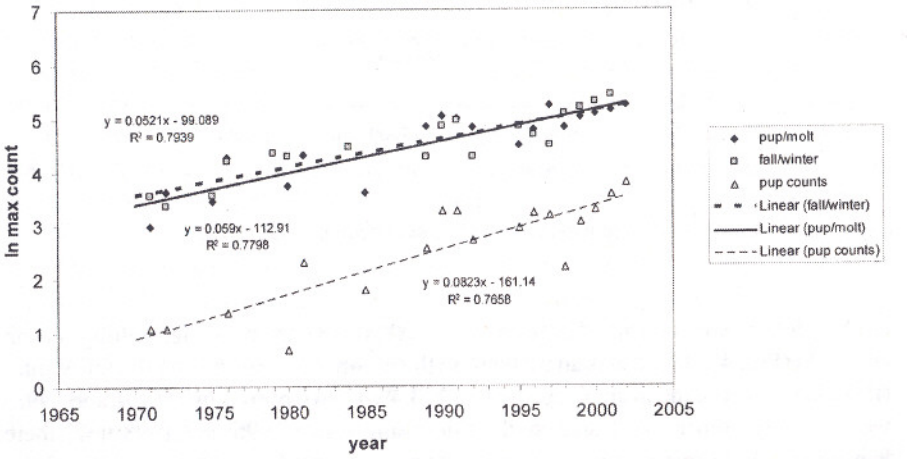

Figure 2: Castro Rocks maximum harbor seal counts (1970-2002)

YBI is a newer haulout site for SFB seals. Data available for YBI prior to 1980 suggest that few if any seals used this site in those years; no seals were present during a pupping/molting season count in 1970 (Paulbitski[18] 1976). Only 10 seals were counted at YBI in fall/winter season count in 1980, and no pups had been reported at YBI prior to that date by U.S. Coast Guard personnel living nearby (Fancher[14] 1987). For this reason, we found that a linear regression was not suitable for the 1970-2002 YBI data.

Given the paucity of data prior to 1989, we examined trends and growth rates for both seasons, and number of pups seen, for only those years when more consistent data were available for YBI (1989-2002). Based on linear regressions of the natural logarithm of maximum seal count by season since 1989, numbers of adult/subadult seals at YBI during the pupping/molting season did increase over the years (r^2=0.81, P<0.001; mean annual growth rate: 9.0%) (Fig. 3). There was no significant change in numbers during the fall/winter season (r^2=0.02, P>0.68). As with adult/subadult numbers during the pupping season, the number of pups counted each year at YBI also increased from 1989-2002 (r^2=0.87, P<0.001) (Fig. 3), although pup counts at this site remained low, with a maximum of 9 pups in 2001.

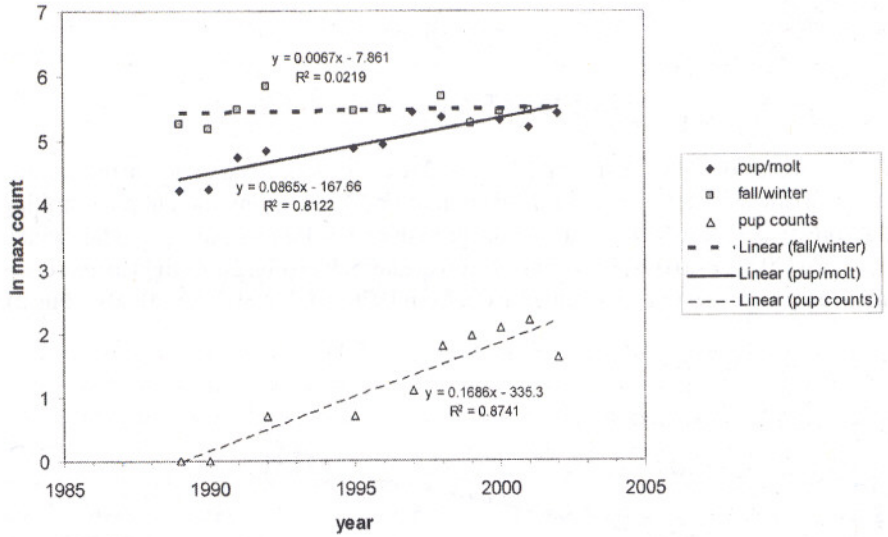

Figure 3: Yerba Buena Island maximum harbor seal counts (1989-2002)

No change was seen at MNS from 1970-2002 during the pupping/molting season ($P>0.05$) (Fig. 4). There was an increase in the number of seals during the fall/winter ($r^2=0.42$, $P<0.005$; mean annual growth rate: 3.4%). Two pup counts (1996 and 1998) were removed from the MNS analysis due to low sample size (1996: n=1, 1998: n=2); there was a very slight increase in the number of pups counted at MNS from 1970-2002 ($r^2=0.21$, $P<0.05$) (Fig. 4).

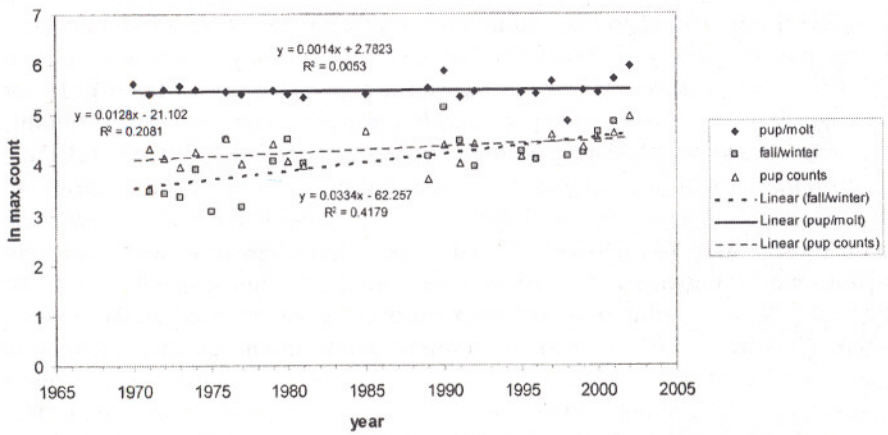

Figure 4: Mowry Slough maximum harbor seal counts (1970-2002)

The slopes for the three site regression lines were significantly different ($F_{(2, 97)}$ = 7.6168, P<0.001), further illustrating the differences in long-term trends in seal numbers at these three sites.

Recent Data (1998-2002)

In the comparisons of seal numbers across years at each site in the recent data, there was a significant difference in the number of seals using CR by year (H=16.34, df=3, P<0.01). A steady increase was seen in seals using CR in recent years, mirroring the yearly trend since 1970. There was no significant difference in the numbers of seals using YBI in recent years (H=4.33, df=3, P>0.22), although there was a drop in mean maximum count in 2002 (Table 1). There was a significant difference seen in counts at MNS across years (H=16.49, df=3, P<0.01), with little difference seen in the 1999-2000 counts, followed by a marked increase in numbers counted in 2001-2002 (Table 1).

In comparing seasonal use at each site for the recent data (1999-2002), numbers at CR were significantly higher during the pupping/molting season than during the fall/winter, for all years (1999: W=23423.5, P<0.001; 2000: W=24561.5, P<0.001; 2001: W=23012.5, P<0.001) (Table 1). At YBI, numbers were significantly higher during the pupping/molting season for two years, 1999 (W=5156.5, P<0.01) and 2000 (W=3227.5, P<0.05). Although numbers were slightly higher during the pupping/molting season for 2001, the difference between seasons was not significant (W=3408.5, P>0.21) (Table 1). At MNS, numbers were significantly higher during the pupping/molting season than during the fall/winter season, for all years (1999: W=10952, P<0.001; 2000: W=8691.0, P<0.001; 2001: W=5776.5, P<0.001) (Table 1).

A steady increase was seen across years (1999-2002) in numbers of seals using CR during the pupping/molting season (H=26.21, df=3, p<0.001) (Table 1). No significant differences were seen across years (1998-2001) in number of seals at CR during the fall/winter season (H=1.13, df=3, p>0.77). At YBI, no significant differences were seen across years in numbers of seals using this site during the pupping/molting seasons (H=0.76, df=3, P>0.85) (Table 1). However, a significant difference was seen in the number of seals at YBI during the fall/winter season (H=14.39, df=3, p<0.005), with numbers in 1998 markedly lower than other years. At MNS, there was a significant difference in numbers of seals present during the pupping/molting season (h=14.41, df=3, P<0.005), with increases seen in 2001 and 2002 counts (Table 1). There was a slight increase across years in the number of seals counted at MNS during the fall/winter, but the differences were not statistically significant (H=7.45, df=3, P>0.05).

Pup production rates at CR for 1999-2002 ranged from 14.0% to 26.5% (with rate increasing each year), with a mean of 19.4% ± 2.70% SE for the four years. At YBI, a site not previously considered a pupping site, pup production rates ranged from 3.1% to 6.3%, with a mean of 5.1% ± 0.70% SE; rate did not increase across years. At MNS, the largest rookery in SFB, pup production rates ranged from 32.1% to 39.1%, with a mean of 35.7% ± 1.60% SE; rate did not increase across years.

Table 1: Summary of harbor seal counts by year and season, 1998-2002: A) yearly mean of daily maximum counts, and n; B) seasonal mean and range of daily maximum counts; P/M = pupping/molting season (March-July); F/W = fall/winter season (August-February)

A) **Mean ± SE by year, and n**

	1998[a]	1999	2000	2001	2002
Castro Rocks	52.7 ± 2.88 n=199	65.7 ± 2.77 n=280	70.3 ± 3.02 n=287	75.2 ± 3.32 n=274	80.4 ± 4.23 n=255
Yerba Buena Island	56.7 ± 4.55 n=108	91.0 ± 4.67 n=129	83.3 ± 4.36 n=102	89.3 ± 4.93 n=99	78.3 ± 4.94 n=109
Mowry Slough	36.9 ± 3.78 n=89	50.7 ± 3.67 n=165	53.6 ± 4.41 n=144	77.6 ± 6.54 n=114	75.3 ± 6.62 n=125

[a]5/1/98 to 12/31/98 only

B) **Mean ± SE and (range) by season**

Year:	1998		1999		2000		2001		2002	
Season:	*P/M*[b]	*F/W*	*P/M*	*F/W*	*P/M*	*F/W*	*P/M*	*F/W*	*P/M*	*F/W*[c]
Castro Rocks	68.3 ± 4.51 (16-121)	51.4 ±3.14 (0-160)	86.7 ± 3.71 (12-150)	54.9 ± 3.56 (0-179)	96.6 ± 3.58 (12-161)	56.2 ± 3.59 (0-201)	107.3 ± 4.25 (6-172)	64.5 ± 4.70 (0-225)	117.5 ± 5.20 (9-200)	55.7 ± 5.96 (0-226)
Yerba Buena Island	99.5 ± 8.93 (22-213)	57.9 ± 5.72 (0-296)	98.6 ± 7.57 (3-198)	80.6 ± 4.59 (7-193)	93.5 ± 6.77 (4-204)	76.9 ± 6.10 (0-231)	95.0 ± 7.40 (16-277)	86.2 ± 5.94 (10-238)	96.6 ± 7.10 (12-226)	49.7 ± 6.71 (0-206)
Mowry Slough	79.6 ± 8.17 (10-129)	23.4 ± 2.47 (0-117)	93.0 ± 6.47 (10-243)	27.1 ± 2.47 (0-109)	93.6 ± 6.54 (16-230)	24.2 ± 2.11 (0-105)	127.7 ± 9.65 (11-300)	31.0 ± 3.27 (0-128)	147.6 ± 11.10 (40-384)	33.8 ± 2.07 (0-70)

[b]beginning 5/1/98, [c]ending 12/31/02

Aerial Survey Data (1989-2002)

The linear regression on the CDFG counts (1982-2002) revealed a slight increase in the numbers counted in SFB (r^2=0.23, P<0.05) (Fig. 5). No significant trend was seen in the summed counts for the three haulout sites, CR, YBI and MNS (r^2=0.03, P>0.47) (Fig. 5).

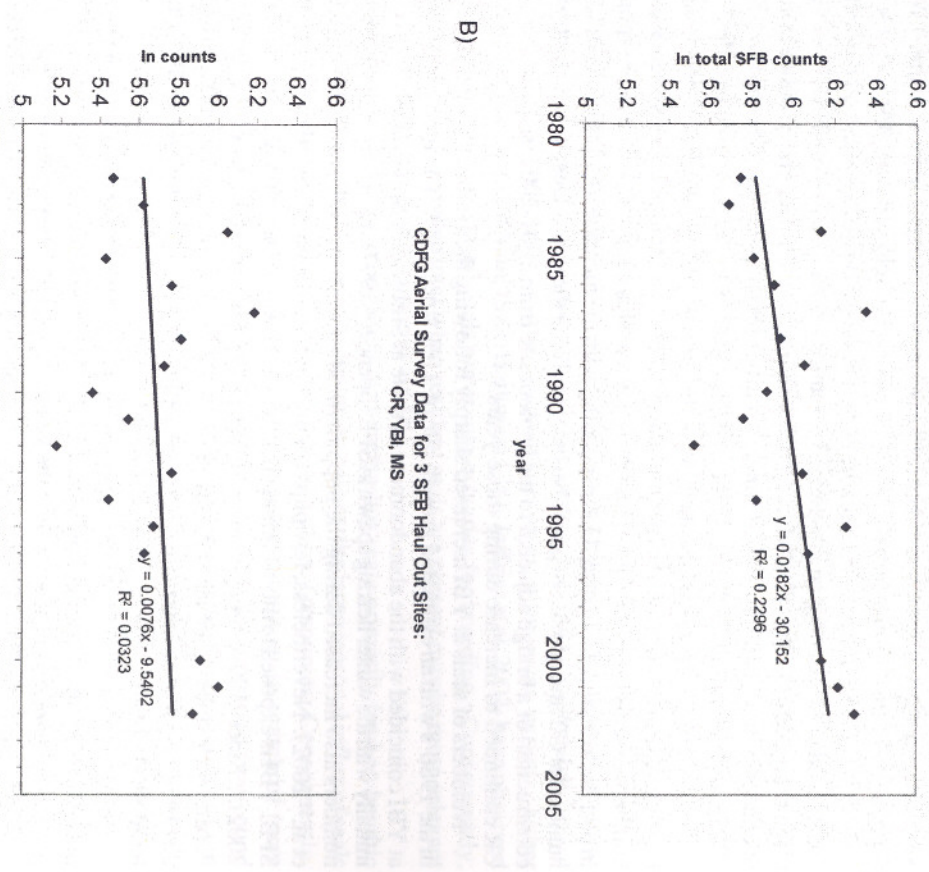

Figure 5: CDFG aerial survey data for SFB, 1982-2002. A) Counts from all SFB haul out sites combined; B) counts for three sites (currently the largest in SFB): CR, YBI, MS (sources: Fluharty 1999, Read and Sweetnam 2002; R.Read, CDFG, pers. comm. 2003)

DISCUSSION

Since passage of the Marine Mammal Protection Act (MMPA) in 1972 in the United States, several studies have documented the recovery of species, particularly of pinnipeds such as harbor seals (Allen et al. 1989, Harvey et al. 1990, Stewart et al. 1988, Sydeman and Allen 1999, Jeffries et al. 2003). Within a large urban estuary such as SFB, though, we document a mixed response and recovery of harbor seals that was likely due to a combination of factors including habitat alteration, disturbance, pollution, prey availability and/or survey techniques.

Our analyses revealed different trends in numbers of seals using the three primary SFB haulout sites across years and in seasonal use patterns for each site. We documented from the long-term (1970-2002) dataset, 1) no change in adult/subadult seal numbers at MNS during the pupping/molting seasons, 2) an increase in seal numbers at CR for all seasons, and 3) an increase at YBI during all seasons, followed by a leveling-off in recent years (1989-2002) during the fall/winter season. Generally, annual rates of change of <10% are considered small for harbor seal populations (Thompson et al. 1997), and no sites in SFB achieved that growth rate over the past three decades.

When looking at historical data in SFB, the growth rates at CR of 6.1% (pupping/molting seasons) and 5.3% (fall/winter seasons) reflect a small but steady increase in numbers of seals using this site. This site is tide and space limited, which may explain in part the low rate of increase. Corresponding with the increase in adult/subadult seal numbers at CR, the number of pups also increased over the years. Despite major retrofit construction of a bridge adjacent to the haulout site from 2001-2002, seal numbers at CR continued to increase during those years.

Numbers of seals at YBI increased sharply following the establishment of the site in the 1980's with an estimated growth rate of 9.0% since 1989. The increase of seals at YBI coincided with the abandonment of a site at Strawberry Spit (Allen[1] 1991) and initially with the winter herring spawn in SFB (Spencer[16] 1997). However, more recently, numbers also increased during the pupping/molting season (Galloway[19] 2000, Green et al.[15] 2002). Nevertheless, few pups occur at YBI compared to the other two sites in SFB. YBI is exposed to more human disturbance than the other two sites (Green et al.[15] 2002). Since 1999, though, the numbers have leveled off, suggesting density-dependency since space is limited at this location. In addition, in late 2002, a major disturbance event occurred, involving a 212-m dry dock grounding on YBI, that temporarily restricted seal access to the site.

In contrast with CR (the north bay pupping site), numbers of adult/subadult seals present during the pupping/molting season at MNS, the largest pupping site in SFB, have not changed significantly over the years since 1970. Higher seal numbers were recorded during the 2001-2002 pupping seasons, but whether these two years represent the beginnings of a population increase at MNS will require continued monitoring. MNS was one of the earliest haulout sites discovered in SFB (Bonnot 1928) and seals

[19]Galloway, M.J. 2000. Factors influencing scanning rates of harbor seals at Yerba Buena Island, California. M.A. Thesis, San Francisco State University, San Francisco, CA. 90 p.

have apparently been using the rookery for thousands of years (Fancher[2] 1979). MNS is a relatively undisturbed site located in a wildlife refuge and accessible at a wide range of tidal heights. The lack of increase of seals at MNS since passage of the Marine Mammal Protection Act, when contrasted with increases at many nearby coastal haulout sites at Point Reyes (Sydeman and Allen 1999) during the same time period, suggests that other factors may be influencing productivity at MNS.

Trends in seasonal differences between sites in SFB confuse these apparent trends. During the fall/winter season at MNS, for example, the growth rate was 3.4%, and the long-term growth rate at YBI was greater during the pupping/molting than during the fall/winter seasons. In addition, there was a time lag between the increase in use of YBI by adult/subadult seals during the pupping/molting season, and the start of the increase in pup numbers at this site, with increases in pup numbers only seen after 1998.

Fancher[2] (1979) noted in the 1970's that there was a strong seasonal influx of seals to MNS during the pupping/molting season and suggested that two groups of seals were using the site: a resident population of around 50-70 seasonal and a larger transient group that moved into the area to breed. Even taking into account the reduced amount of time harbor seals spend on the haulout site outside of the pupping/molting season (Allen Miller[7] 1988, Thompson et al. 1998), there appeared to be a large seasonal immigration of seals to the MNS area during the breeding season. Fancher[2] (1979) and Risebrough et al.[5] (1980) suggested that many of the seals present in SFB for the breeding season came from outside of SFB, and recent telemetry data support this conclusion (Torok[20] 1994, Green et al.[15] 2002). Green et al.[15] (2002) noted that 29% of seals tagged in SFB used coastal haulout sites over a one-year period. Other researchers (Brown and Mate 1983, Harkonen 1987, Jeffries et al. 2003) have observed similar trends where coastal seals move into estuaries for breeding. Consequently, examining trends in fall/winter when resident seals are present may be more relevant in determining population increases at MNS.

Harkonen (1987) suggested that because harbor seals primarily feed on benthic prey and do not fast during the breeding/molt seasons, the large seasonal influx of seals into an estuarine habitat results in a local depletion of prey resources. Consequently, many seals may leave an estuarine area after pupping/molting in search of more abundant prey, leaving behind a small number of seals that are supported year-round by local estuarine resources. Limited prey during the breeding/molt seasons would explain the smaller number of year-round resident seals at MNS and could explain the low rate of increase of SFB seals since passage of the MMPA. When prey abundance increased in SFB during the winter months as a result of herring spawning in the bay, seasonal increases in seal numbers were seen at the sites closest to herring spawning areas, CR and YBI. In addition, these sites also reveal an annual trend upwards over the past two decades. And too, the increase in harbor seal populations at coastal sites

[20]Torok, M.L. 1994. Movements, daily activity patterns, dive behavior, and food habits of harbor seals (*Phoca vitulina richardsi*) in San Francisco Bay, California. M.S. Thesis. California State University, Stanislaus and Moss Landing Marine Labs, Moss Landing, CA. 88 p.

(Allen et al. 1989, Sydeman and Allen 1999) would be reflected in the increased numbers of seals moving into SFB in response to localized prey increases.

To understand trends in numbers of harbor seals using the three haulout sites in SFB, changes in use at other haulout sites in SFB should be reviewed. Harbor seals have been reported to shift site use in response to prey movements, disturbance or other factors (Paulbitski 1975, Risebrough et al.[5] 1980, Brown and Mate 1983, Harkonen 1987, Allen[1] 1991, Greenstreet et al. 1993, Thompson et al. 2001). Consistent annual data for all sites in SFB do not exist; however, there are data on significant historical increases or decreases at some SFB sites. For example, Strawberry Spit, where around 100 seals annually hauled out in the 1970's, was abandoned in the early 1980's due to disturbance and a shift in prey resources (Fig. 1; Paulbitski 1975, Allen[1] 1991). Strawberry Spit itself was used only after seals were disturbed from a previous historical haulout site at Strawberry Point (Allen[1] 1991). Bartholomew and others documented the abandonment of a harbor seal haulout site at the foot of the San Francisco-Oakland Bay Bridge in the 1940's, possibly in response to increased disturbance from a nearby naval base (Fig. 1; Bartholomew 1949, Risebrough et al.[5] 1980).

More recently, new haulout sites have been documented in SFB over the past two decades. Seals began using Corte Madera Marsh in northern SFB in the 1980's (Fig. 1), coincident with the abandonment of Strawberry Spit and the restoration of marsh habitat (Allen[1] 1991). The SFB delta, in the northeastern-most reaches of SFB, was used by seals in the 1930's and 1940's, but by the 1970's, seals were only seen occasionally in the area (Paulbitski and Maguire 1972). In 1993, aerial surveys conducted by CDFG identified a new haulout site on Ryer Island, Suisun Bay (Fig. 1), where numbers have risen from 10 seals in 1993 to 53 in 2002 (R. Read, personal communication). These new haulout sites may be absorbing seals shifting away from areas that were abandoned, or may represent real increases in seal numbers in SFB. Recent data suggest that the current harbor seal population in SFB is somewhat higher than the CDFG estimate (Green et al.[15] 2002; Lowry and Caretta[21] 2002; the present study).

Understanding trends at individual sites in SFB is an easier task than defining a population trend for all of SFB. Strong environmental signals such as El Niño Southern Oscillation (ENSO) events are uniformly detected in harbor seal population numbers across all sites, both in SFB (as seen in this study during the 1998 ENSO event) and at coastal sites (Allen et al. 1989, Sydeman and Allen 1999). Other factors affecting SFB harbor seal population trends, such as disturbance or pollutants, may be more difficult to interpret. As Hanan[3] (1996) noted, recent increases in survey numbers could simply be the result of improved censusing techniques; however, recent data reflect the same overall trends seen in the historical data, and improved censusing alone may not explain the recent increases.

The CDFG annual surveys conducted during the molting season show a slight increase in the SFB population, but the annual counts were based on one aerial survey

[21]Lowry, M.S. and Carretta, J. (2002) Pacific harbor seal, *Phoca vitulina richardii*, census in California during May-July 2002. NOAA Technical Memorandum NMFS-SWFSC-353. 77 p.

per year and, for SFB, were timed to fall at medium to low tides (Fluharty[11] 1999), which does not consistently coincide with the maximum numbers of seals present on all SFB haulout sites (Risebrough et al.[5] 1980, Kopec and Harvey[6] 1995, Green et al.[15] 2002). CDFG surveys, though, did not detect any increase at individual sites such as CR, MNS, and YBI (Fig. 5). This would suggest that if trend sites are to be used to monitor seal numbers in a given area, once-annual aerial surveys would not be sufficient to understand local population trends or seasonal patterns of use. CDFG surveys are not suitable for detecting population tends in areas such as SFB but are used only to detect trends in the state population (R. Read, personal communication). Consequently, regional managers must rely on local long-term monitoring data to guide management actions.

We recommend that in SFB, harbor seals should be surveyed annually during all four seasons at the three primary SFB haulout sites in order to accurately detect SFB population trends. Given that seals may shift haulout site location in response to disturbance and/or prey movements, data from trend sites should be used in conjunction with the annual California statewide aerial surveys, to aid in the interpretation of aerial survey data, and to document any new or lost seal haulout sites. Similarly, a complete understanding of seasonal and yearly use of certain significant haulout sites is important, providing an understanding of seal population trends that may not be available from once-yearly aerial surveys alone.

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