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Title:
Estimating population size of Pacific harbor seals (Phoca vitulina richardsi) at Children's Pool Beach in La Jolla, California, using photo-identification

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## Acceptance Date:

01-01-2011

## Series:

UC San Diego Electronic Theses and Dissertations

## Degree:

M.S., UC San Diego

## Permalink:

https://escholarship.org/uc/item/9n87h01f

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#### Abstract

: Children's Pool Beach in La Jolla, CA is a Pacific harbor seal (Phoca vitulina richardsi) rookery at the center of a large legal controversy. Due to the heated contention surrounding this rookery, very few scientific studies have been done on the population of harbor seals that use this haul-out site. Maximum daily haul-out counts rarely exceed 200, and management decisions have been framed around the assumption of a largely resident population of no more than approximately 250 seals. In this study I used photo- identification and mark-recapture methods to estimate the total population of Pacific harbor seals that used Children's Pool Beach as a haul-out site during January - October 2008. I photographed the ventral surfaces of adult harbor seals at Children's Pool Beach, and then entered each good to high quality photograph into an interactive computer-assisted photographmatching system for individual identification. Each individual identification was confirmed by both a trained volunteer and myself, resulting in a 4\% visual matching error rate. After analysis concluded, 480 unique adult harbor seals were individually identified after applying the $4 \%$ visual matching error rate. Abundance estimation was calculated using the Chapman-Petersen capture-recapture model. My calculations yielded a population estimate of 596 individuals during January - October 2008, which is two to three times larger than previously believed. These findings suggest a population that is at least partially open with considerable coastal movement, suggesting that Children's Pool Beach is potentially part of a regional network of interconnected haul-out site


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## UNIVERSITY OF CALIFORNIA, SAN DIEGO

Estimating population size of Pacific harbor seals (Phoca vitulina richardsi) at Children's Pool Beach in La Jolla, California, using photo-identification

A thesis submitted in partial satisfaction of the requirements for the degree Master of Science in

Biology
by

Traci A. Linder

Committee in charge:
Professor David S. Woodruff, Chair
Professor David A. Holway
Professor James J. Moore

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The thesis of Traci A. Linder is approved and it is acceptable in quality and form for publication on microfilm and electronically:

# University of California, San Diego 

2011

## DEDICATION

This thesis is dedicated to my parents who have supported my education every step of the way. Thank you Mom and Dad for encouraging my independence and allowing me to grow into the person I now am today.
$\ldots$ and to the seals.

## EPIGRAPH

Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect.

Chief Seattle, 1855

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## ACKNOWLEDGEMENTS

I would greatly like to thank all of those who have helped me along the way with this project. Without each and every one of you, the completion of this thesis would have never been possible. I would like to thank Lex Hiby (Conservation Research, Ltd.) the creator of the photo-identification software, especially for his constant communication with me from across the Atlantic. None of this would have been possible without the support of my advisor Professor Jim Moore. Thank you for helping me take this project above and beyond a simple Master's thesis; from a trip to Baja, Mexico during the peak of the swine flu epidemic, all the way to Quebec, Canada where I presented my research at the Society of Marine Mammalogy conference. I would like to thank Professor David Woodruff for being generous enough to chair my committee and Professor David Holway for serving on my committee. None of my analysis would have been possible without the patience and selfless guidance of Dr. Tomo Eguchi... I cannot thank you enough for your willingness to donate your valuable time. To the dedicated docent group La Jolla Friends of the Seals, and the various San Diegans that have reached out to me offering photographs, collected literature on the seal colony, and even their time to volunteer for the project. Lastly, I would like to give a very special thanks to the many UCSD undergraduate volunteers that have played a very important role in this project over the years: Michelle Jones, Abby Cannon, Jenny Phillips, Laura Marx, Tyler Kern, Michelle Tieu, Alexandra Portanova, Angie Kemsley, Melissa Galinato, Erika Lentz, and Sara Mangosi... you are all amazing.

## ABSTRACT OF THE THESIS

Estimating population size of Pacific harbor seals (Phoca vitulina richardsi) at Children's Pool Beach in La Jolla, California, using photo-identification

## by

Traci A. Linder<br>Master of Science in Biology<br>University of California, San Diego, 2011<br>Professor David S. Woodruff, Chair

Children's Pool Beach in La Jolla, CA is a Pacific harbor seal (Phoca vitulina richardsi) rookery at the center of a large legal controversy. Due to the heated contention surrounding this rookery, very few scientific studies have been done on the population of harbor seals that use this haul-out site. Maximum daily haul-out counts rarely exceed 200, and management decisions have been framed around the assumption of a largely resident population of no more than approximately 250 seals. In this study I used photo-identification and mark-recapture methods to estimate the total population of Pacific harbor seals that used Children's Pool Beach as a haul-out
site during January - October 2008. I photographed the ventral surfaces of adult harbor seals at Children's Pool Beach, and then entered each good to high quality photograph into an interactive computer-assisted photograph-matching system for individual identification. Each individual identification was confirmed by both a trained volunteer and myself, resulting in a 4\% visual matching error rate. After analysis concluded, 480 unique adult harbor seals were individually identified after applying the $4 \%$ visual matching error rate. Abundance estimation was calculated using the Chapman-Petersen capture-recapture model. My calculations yielded a population estimate of 596 individuals during January - October 2008, which is two to three times larger than previously believed. These findings suggest a population that is at least partially open with considerable coastal movement, suggesting that Children's Pool Beach is potentially part of a regional network of interconnected haulout sites.

## INTRODUCTION

The Pacific harbor seal (Phoca vitulina richardsi) population has been steadily increasing since 1940, and is a growing influence on the near-shore ecosystem (Hanan 1996). At individual haul-out sites, harbor seal counts range from one to one thousand seals and average at approximately fifty (Hanan and Beeson 1994). Counts at haul-out sites provide valuable information, but only account for the number of seals using that haul-out site at one given time. The major objective of this study was to estimate the total number of Pacific harbor seals that use the haul-out site Children's Pool Beach in La Jolla, CA using photo-identification and mark-recapture methods.

The harbor seal (Phoca vitulina) is the most widely distributed among all pinnipeds, spanning a range over $16,000 \mathrm{~km}$ across the North Pacific and North Atlantic oceans (Perrin et al. 2008). There are five distinguishable subspecies and San Diego, CA is home to Phoca vitulina richardsi, whose distribution extends from the Pribilof Islands in Alaska down to near-shore coastal and estuarine areas in Baja California, Mexico (Carretta et al. 2008). Adults have an average mass of 90 kg and measure 1.2 to 1.9 m in length, with males usually being larger than females (Nicholson 2000). Generally males live to be 20-25 years old and females live to be 30-35 years old (Bell 2001).

Harbor seals have a wide range of pelage colors, from near white to dark brown, as well as varying degrees of contrasting spots and rings (Stutz 1967, Kelly 1981). Each individual has a unique pelage pattern, and therefore can be individually indentified within a population (Crowley et al. 2001). These pelage patterns remain
consistent in shape and location over time for at least several years in adults (Stutz 1967, Yochem et al. 1990) and at least 16 months in pups and subadults (Kelly 1981).

Like all other pinnipeds, harbor seals are amphibious and spend much of their time on land. This movement from the water onto land for a given length of time is termed 'hauling-out'. Most energetic activities such as breeding and foraging take place in water, so it's necessary that they come onto land to rest. Harbor seals haulout not only for rest, but also to regulate their body temperature through thermoregulation, facilitate digestion, as well as for pupping and molting for a few months every year (Perrin et al. 2008). Harbor seals primarily occur near shore, hauling-out on sand or cobble beaches, rocky islets, estuarine mudflats, and inter-tidal ledges (Harvey et al. 1995). They prefer haul-out sites that are protected from wind and waves, and allow access to deep water for foraging (Perrin et al. 2008).

One aspect of harbor seal haul-out behavior is the high degree of site fidelity that they exhibit. With some degree of variation, the majority of harbor seals will only use one haul-out site year round, and rarely will they use more than two sites (Yochem et al. 1987). Although harbor seals are non-migratory, they may travel hundreds of kilometers in search of food or breeding habitats (King 1983, Reeves et al. 1992). Harbor seals will typically stay within a 50 km range of haul-out sites, but they have been reported to use haul-out sites up to 192 km apart (Yochem et al. 1987) and occasionally travel 300 - 500 km to find food or suitable mating areas (Herder 1986). Younger individuals (<2 years) and adult males have the highest dispersal rate and the lowest rate of site fidelity (Härkönen and Harding 2001).

California has approximately 400 - 600 harbor seal haul-out sites, and an estimated population of 34,233 harbor seals (Hanan 1996; Lowry et al. 2005; Carretta et al. 2008). There are an unknown number of harbor seals that occur along the west coast of Baja California at least as far south as Isla Asuncion, which are not included in the California stock. National Marine Fisheries Services reports that this is because "it is not known if there is any demographically significant movement of harbor seals between California and Mexico and there is no international agreement for joint management of harbor seals" (Carretta et al. 2008). However, a 2009 photoidentification study documented individuals moving between the haul-out site at Las Islas Coronados off of Baja Mexico and our study haul-out site, Children's Pool Beach in La Jolla, CA, which are located approximately 50 km apart (Cannon 2009).

Children's Pool Beach is a small beach (approximately 400 sq m), and the focus of a large debate between the champions of animal rights and human rights. Starting in the mid-1990s, Pacific harbor seals began to use Children's Pool Beach in downtown La Jolla, CA as a year-round haul-out site and for pupping during winter and spring. However, the site is sheltered by the construction of a sea wall and is designated as a "bathing pool for children" in a 1931 grant, and the exclusion of people for health reasons has led to a heated legal controversy that has gone all the way to the State Legislature. Despite the high profile of the rookery, the number of seals using it remains unknown. Maximum counts have rarely exceeded 200, and debates (and management decisions) have been framed around the assumption of a
largely resident population of no more than approximately 250 seals (La Jolla Friends of the Seals unpublished observations) (Figure 1).

Given that individuals have been documented moving between Children's Pool Beach and Las Islas Coronados, I predicted that the population is much larger than the maximum haul-out counts of approximately 200 individuals. I also predicted that many transient seals use Children's Pool Beach as a resting area between their coastal movement to either Baja, Mexico or northern rookeries in the California Channel Islands. Census data were collected by individual photo-identification based on the use of pattern recognition software.

I can be reached via email at TRACILINDER 'at' GMAIL ‘dot' COM, for any inquiries regarding my data and research.

## MATERIALS AND METHODS

## Data collection

The ventral surfaces of adult harbor seals were photographed at Children's Pool Beach in La Jolla, CA using a Canon Rebel XTi camera with a 200 - 400mm Tamron lens. Photographs were taken from cliffs approximately six meters high on the northeast side of the beach and on a sea wall approximately three meters high along the southwest side, between January - October 2008. Individuals were photographed between 3 - 23 meters from the camera. Data collection was done opportunistically, ranging between one to seven times per month and usually occurred between the hours of 1100 and 1500. I photographed all individuals displaying a ventrum view (angle of the seal's body is slight to moderate from the camera, and head, hips, and both foreflippers are visible), who were not excessively sandy or obviously molting. I chose to only photograph ventrums given that a single standard viewpoint of each seal would lessen the chance of misidentifying an individual. It's also been observed that pelage markings on the ventral surface "appear[ed] to be especially informative and favorable for distinction by the human eye" (Crowley et al. 2001). However, the majority of seals lie on their ventrums perpendicular to the ocean, which reduced the number of individuals that I was able to photograph on each occasion. In a similar study done at Tugidak Island in Alaska, they found that only $15-30 \%$ of seals observed per day showed the ventrum view, which in turn reduced their daily recapture rates (Hastings et al. 2008).

## Organization of photographs

One to three photographs were taken of each seal with a ventrum view, in an attempt to achieve the highest quality image of every seal photographed. Photographs were rated into four categories of quality (poor, fair, good, and high). Quality was based on the lighting, resolution of the picture, angle of the seal in the photograph, and overall visibility of the spot pattern to be analyzed. Only the good to high quality photographs were used for the study, and the highest quality image of each seal from each capture occasion was chosen to be used for their individual identification. All seals photographed with any varying range of distinctive spot patterns were able to be indentified. The few adult seals that I excluded from the study were those that had uniform pelage without any spots, and those going through a molt that left the pelage unidentifiable. Each seal from a photograph was categorized by sex (male, female, unknown) and additional comments were often added to photographs, highlighting any distinctive scars, behaviors, or general notes about that individual.

## Photograph-matching system

Each photograph of an individual chosen for identification was entered into an interactive computer-assisted photograph-matching system (software developed by Conservation Research Ltd; www.conservationresearch.co.uk). Hastings et al. (2008) evaluated the performance of this software, and deemed it a very efficient and objective method for identifying individual harbor seals through photo-identification.

The software was only capable of analyzing one image at a time. When an image of an individual was chosen to be analyzed, the user then manually placed reference dots around the edge, midline, and special points (nose, chin, left ear, right ear, base of the foreflippers, mid foreflipper, and mid pelvis) on the individual's body. These dots allowed the software to recognize the overall size, shape and orientation of the individual in the photograph. After all of the dots had been appropriately placed, the software then created a 3-dimensional body model that was superimposed around the entire ventral side of the seal. The software used an algorithm that enhanced the fit of the 3-dimensional body model to the ventrum in the photograph, resulting in a model that corrected for viewpoint and posture of the seal (Figure 2).

The superimposed 3-dimensional body model had to be an exact fit around the individual, in order for the software to accurately identify and analyze the spot patterns on that individual's chest and abdomen. These regions were then isolated from the rest of the seal's body (Figure 3), allowing the software to evaluate the greyshade values from the specified areas at an array of points defined by the overlying 3dimensional body model. The numerical description that resulted from this grey-scale intensity analysis was called the "identifier array". These identifier arrays were the software's numerical descriptions of an individual's unique pelage patterns. After identifier arrays were created for an individual's abdomen and chest, they were then stored in a database along with all other accompanying information about that individual, including their temporary identification number.

After an individual's information had been stored in the database, two comparison algorithms then calculated the correlation coefficient between the identifier array of that individual and those of other individuals already in the database, searching the database to see if the newly input individual had already been previously identified. The two algorithms used were identified as the " n " algorithm and the " $c$ " algorithm, and were complementary to one another. The " $c$ " algorithm worked well on amorphous patterns but failed if a lot of the pattern was obscured, while the " n " algorithm could cope with obscured areas but worked less well on amorphous patterns (Hiby pers. comm. 2011).

The " n " and "c" algorithms used the newly calculated correlation coefficient to generate two separate lists of seals in the database that could be potential matches to the newly input individual. Each individual in the database that was being compared was listed by rank (i.e. seal with rank 1 appeared first in the comparison list) along with a similarity score generated by the correlation coefficient of the identifier arrays (i.e. seal with rank 1 had a similarity score of 0.92 to the newly input individual) (Figure 4). One result of this correlation coefficient based matching system was that the software listed almost every individual in the database as a potential match, ranging in similarity scores of greater than $98 \%$ to less than $2 \%$. Therefore, the algorithms' lists of potential matches grew larger as more individuals were entered into the database, creating a growing number of individuals that had to be visually compared to confirm a match. Trained student volunteers visually examined approximately the top $50 \%$ of all potential matches from both lists generated by the
separate algorithms, attempting to find an image of the newly input individual already identified in the database. If a previous image (or multiple images from different dates) of the newly input individual appeared in the database, the match was then visually confirmed. The newly input individual's temporary identification number was erased, as it was then automatically assigned the identification number of the previous image(s) of itself already present in the database. If there were no previous images of that individual in the database, it was then entered into the database under its current identification number, and was considered a newly identified individual. All matches were visually confirmed by both a trained student volunteer and myself, making the probability of a false positive (an incorrect match) match highly unlikely. In fact, visually confirming all matches reduces the possibility of a false positive match to close to zero (Hastings et al. 2001).

## Testing for false negatives

To search for potential false negatives (missed matches) in the database, I randomly chose one image each from 350 individuals in the catalog to be erased from the database and then re-entered into the photo-identification software for a second time. Some re-entered individuals had at least one other image in the database for a visual match to be confirmed, while others had been sighted on only one occasion and therefore had no other images to be matched to in the database. The student volunteers performing this task followed the same procedures with the same diligence as the first time these individuals were entered into the software, and were completely
unaware if existing matches of any of these individuals were already in the database. The only change in procedure that occurred during this process was at the visual comparison stage. When a list of possible matches from the database came up for comparison every possible match from both algorithms' lists was visually checked instead of just the top $50 \%$ of both lists. Given that I already knew which of the 350 individuals existed in the database in previous images and therefore had at least one match, I was able to calculate the error rate in which individuals were misidentified as a new individual and not correctly matched to a previous image. At the end of this screening process I found the visual matching error rate to be approximately $4 \%$. This means that approximately $4 \%$ of 'unique individuals' in the catalog were misidentified and mistakenly entered into the catalog under new ID numbers, creating close to a $4 \%$ overestimate of the total catalog count. The error rate in this study was very close to the visual matching error rate of $4.5 \%$ (all false negatives) found in the evaluation study of this program by Hastings et al. (2008).

## Abundance estimation

Mark-recapture techniques are an efficient method for animal abundance estimation along with various other demographic parameters (Seber 1982). However, traditional mark-recapture studies are invasive to the animals (i.e. marking by branding or tagging), and can often alter the animals' natural behaviors after the tagging event. Photo-identification serves as an alternative, non-invasive method of identifying individuals for abundance estimation. In this technique, a 'capture' is
defined as the identification of an individual on a given day, regardless of the number of photographs that were taken of that individual on that day. The first identification of each individual is considered to be the 'marking' event, as that then allows the researcher to uniquely identify that individual thereon. Every time an individual is identified after they've been initially 'marked' is then considered a 'recapture' of that individual.

To estimate abundance using my capture-recapture data, I used the Chapman modification of the Petersen capture-recapture model (Chapman 1951). The majority of capture-recapture studies have some degree of heterogeneity: departures from purely random sampling, varying behavior in the study animals, etc. In this study, I was not able to sample completely randomly, as I could only photograph individuals displaying their ventrum at the time of observation. It's also likely that individuals expressed different haul-out behaviors during each sampling occasion (i.e. preferences to haul-out on their backs or to haul-out close to the sea wall or cliff where I would photograph). The heterogeneity in this study resulted in the increased probability that multiple captures of the same individuals within my study period were not independent, therefore resulting in an underestimate of abundance (Cerchio 1998, Hammond 1990). Calambokidis et al. (1990) recommends the use of Chapman's model because it produces slightly larger abundance estimates than the similar Bailey's model, therefore correcting the underestimate due to heterogeneity. The Chapman modification of the Petersen capture-recapture model to estimate population size, $N$, is as follows: $N=[(M+1)(C+1) /(R+1)]-1$, where $M$ is the number of
unique individuals captured during the first sampling occasion, C is the number captured during the second sampling occasion, and R is the number of individuals that were captured during both sampling occasions.

The assumptions of this model are random sampling, no immigration, no emigration, no births, and no deaths (Chapman 1951). While using the Chapman modification of the Petersen capture-recapture model for abundance estimation corrected the underestimate produced by the non random sampling, the analysis had to be designed to minimize the effects of births, deaths, immigration, and emigration. This was done by using data from every pair of sequential months as my two capturerecapture sampling occasions (i.e. January and February, February and March, etc.). By making each capture occasion approximately one month apart, I minimized the effects of temporary immigration and emigration by limiting the amount of time that individuals had to move in and out of the study site (Caughley 1977). The one month survival rate of an adult harbor seal is greater than $99 \%$ (Eguchi pers. comm. 2010), which minimizes the effect of death. Lastly, pups were not included in this study in order to completely eliminate the effect of births. The abundance estimates from each pair of sequential months were then averaged, in order to find the mean abundance estimate from January - October 2008.

## RESULTS

A total of 695 good and high quality images of individual harbor seals that were taken between January and October 2008 were used for individual identification. From these images, 500 unique adult harbor seals were individually identified. Of the remaining 195 images, 146 were recaptures of previously identified individuals, and 49 were duplicate images of seals mistakenly analyzed multiple times on the same day. The total number of 500 uniquely identified adults drops down slightly to 480 after applying our $4 \%$ visual matching error rate. Of these 480 individuals, $17 \%$ were males, $11.2 \%$ were females, and $71.8 \%$ were of unknown sex (Figure 5). $31.62 \%$ of the females, $28.18 \%$ of the males, and $10.74 \%$ of the unknown sex individuals were recaptured on at least one occasion. Each sex group differed between the average number of occasions that each was captured; females were captured an average of 1.57 occasions, males were captured an average of 1.67 occasions, and unknown sex individuals were captured an average of 1.18 occasions throughout the duration of the study. The difference between the average number of occasions that females were captured versus males was not statistically significant $(t=-0.45, \mathrm{df}=132, \mathrm{p}=0.655)$ (Figure 6).

The distribution of captures ranged from 420 individuals captured on only one occasion, to one individual who was captured on eight different occasions $(\mathrm{SD}=2.45, \mathrm{MAX}=8, \mathrm{MIN}=1, \mathrm{n}=8)($ Figure 7). Out of the total 500 identified individuals, 80 individuals ( $16 \%$ ) were recaptured on at least one occasion. Proximity
between capture occasions seemed to have little effect on the recapture rate, as many recaptured individuals were seen across multiple months throughout the study. The highest number of recaptures took place in the months of April and May 2008, during the end of the pupping season and beginning of the molting season at Children's Pool Beach $(\mathrm{SD}=4.8, \mathrm{MAX}=18, \mathrm{MIN}=2, \mathrm{n}=13)$ (Figure 8). The highest capture rate was also during April and May ( $\mathrm{SD}=53.66, \mathrm{MAX}=172, \mathrm{MIN}=1, \mathrm{n}=10$ ) (Figure 9), but the months with the most days of data collection were April and February (SD $=1.9, \operatorname{MAX}=7, \operatorname{MIN}=1, \mathrm{n}=10)($ Figure 10 $)$.

The abundance estimates calculated from the Chapman-Petersen method using sequential months ranged from 55 to 1611 individuals (Table 1). This range of abundance estimates shows relatively poor precision given that the coefficients of variation (CV) ranged from 0.19 to 0.70 , and one third of the calculated $95 \%$ confidence intervals (CI) either met or dropped below zero. The highest abundance estimates occurred at the end of the pupping season and beginning of the molting season during the paired months of April and May, and May and June. The lowest abundance estimates occurred at the end of summer during the paired months of July and August, and August and September; however it should be noted that there was only one capture occasion during the month of August. The mean of all ChapmanPetersen abundance estimates yielded an intermediate estimate of 596.09 individuals, which is only $19.22 \%$ larger than the minimum population count of 500 individuals, and $24.19 \%$ larger than the minimum population count with the applied $4 \%$ visual matching error rate of 480 individuals.

## DISCUSSION

This study showed that there was monthly variation in the number of adult harbor seals using Children's Pool Beach between January and October 2008. It is not surprising that the highest number of captures and recaptures occurred during the months of April and May, at the end of the pupping season and beginning of the molting season at this haul-out site. The time of annual pupping and molting varies geographically for each population, but pupping typically occurs around spring followed by the molting process during the summer. In all populations, both the number of seals hauled-out as well as the duration of time hauled-out increase during these energetically costly processes (Perrin et al. 2008). Pacific harbor seals experience a 'catastrophic molt' in which they lose their hair in sheets over a period of only one to two months. During this catastrophic molt they have a decreased ability to retain heat, and will spend considerably less time in the relatively cold water and more time hauled-out on land (Perrin et al. 2008).

The drop in captures and recaptures during the fall and winter months could have been due to individuals foraging at other haul-out sites in warmer waters. A study done on the diet and foraging ecology of the harbor seals at Children's Pool Beach showed that Pacific sanddab and Pacific hake dominated their diet during the autumn and winter, however these species do not occur in the La Jolla kelp forest near Children's Pool Beach (Greenslade 2002). Greenslade suggests that the harbor seals at Children's Pool Beach "traveled some distance away from the [site] to feed because
the prey species in their diet did not reflect the species known to live in the area immediately surrounding the [site]" (Greenslade 2002).

While male harbor seals are generally slightly larger than females, this species is not sexually dimorphic, and therefore can only accurately be sexed if displaying their ventrum. Although using a ventrum view for this study did aid in the sexing of individuals, this purely visual process was still very difficult. The disproportionately high number of unknown sex individuals in the catalog was due to multiple factors; some seals were too far from the camera in the photograph to distinguish their sex, and others had sand or another seal obscuring their pelvic area. It should also be noted that I was the only person visually sexing the seals, so someone with more expertise in this field may have been able to sex a higher proportion of the catalog. I was also very cautious when I sexed each individual, and would never identify an individual as either 'male' or 'female' unless I was certain. If there was any uncertainty, the individual was put into the category of 'unknown sex'.

In general, adult females have been recorded as exhibiting a high degree of natal philopatry and are known to mate and give birth in the area where they were born. In contrast, males often show an increase in dispersal rate and a decrease in site fidelity as they increase in age (Härkönen and Harding 2001). My study found that a slightly higher proportion of females than males were recaptured on at least one occasion; however the males that were recaptured were seen more often than the recaptured females. These sex-based recapture rates corresponded with a similar study that found that females had the highest recapture probability, while unknown sex
individuals had the lowest (Mackey et al. 2007). Although the majority of individuals were only recaptured on one occasion, the eight recaptures of one individual indicates that more recaptures may have been possible with a higher sampling effort. Recaptures may have also increased if the timing of the sampling periods had been standardized (Crowley 2001). Sampling should have been consistent throughout the entire study to have assured equal probability of capture of individuals with temporally staggered residency at Children's Pool Beach (Gabriele 1992).

The Chapman-Petersen method calculations were designed to minimize bias and maximize precision in the population estimates; however assumptions of this method were violated in this study. The greatest source of error in capture-recapture studies is unequal catchability (Caughley 1997). This is often due to a property inherent in the behavior of an individual in the immediate vicinity of a capturing device, or a property depending on relative opportunity of capture (Caughley 1997). Since photo-identification is a non-invasive technique and doesn't require physical capture of the seal, it is less likely that heterogeneity in capture probability occurred due to the capture device (Canon Rebel XTi camera). It is more likely that some individuals have a lower capture probability due to an innate behavior to spend more time in the water than on land, or a preference to haul-out in areas on the beach that are difficult to photograph. Some individuals would have a higher capture probability if they had an innate preference to haul-out on their side or back and display their ventrum. Unequal capture probability most likely occurred during the molting period because of the increased length of time that harbor seals spend hauled-out (Daniel et
al. 2003). The timing of the molt differs by both sex and age, as young seals begin molting first, followed by adult females, and lastly adult males (Thompson \& Rothery 1987; Daniel et al. 2003). Females have a higher probability of capture during the pupping season as they haul-out for extended periods to conserve valuable energy (Perrin et al. 2008). All heterogeneity in capture probability would lead to an underestimate in abundance (Cunningham 2009).

Another violation of the Chapman-Petersen method was the possible occurrence of temporary immigration and emigration during the study. While these biases were reduced by restricting the period between capture occasions (Caughley 1997), it's still possible that these processes were occurring to some degree. Even though it's been shown that there is coastal movement between the haul-out sites of Children's Pool Beach and Las Islas Coronados (Cannon 2009), it is unknown at what rate this exchange is occurring. The Chapman-Petersen method is biased upward by both immigration and emigration (Begon 1979; Caughley 1997). Temporary emigration can result in an overestimation of abundance, because closed population models treat absent individuals as present but not captured (Begon 1979). However, a low number of recaptures makes it difficult to distinguish between the absence of individuals due to temporary emigration and the presence of individuals with very low capture probabilities (Cerchio 1998). Without knowing the rate of occurrence of immigration and emigration during the study, it's impossible to determine the degree of bias in the calculated abundance estimates.

This study has demonstrated that the computer-assisted photograph-matching system used (Conservation Research Ltd) effectively facilitated the filtering and matching of photographs of adult harbor seals. I have also shown that trained human observers can recognize individual harbor seals based on their unique pelage markings. It was imperative in this study that the natural pelage markings of each captured individual remained permanent and invariant throughout the duration of the study. My results indicate that even though the pelage of some individuals was temporarily obscured during the annual molt, there was no change in the pelage pattern of the new coat; thus deeming natural mark loss as negligible.

It's been found in previous capture-recapture studies of harbor seals that the capture, handling, and attachment of tags affects haul-out patterns and site use (Yochem et al.1987). The goal of my study was to find out how many adult harbor seals naturally use Children's Pool Beach as a haul-out site; given that the disturbance of tagging prompts harbor seals to relocate to new sites (Yochem et al. 1987), it was crucial that I limit the amount of human disturbance as much as possible for this study. Photo-identification worked well for this study as a non-intrusive method that allowed a large number of animals to be 'marked' without causing any disturbance to the animals and their natural behaviors.

My study began as a cataloging effort to count each individual seal that used Children's Pool Beach as a haul-out site, and was not originally intended to be a markrecapture study. Given that the study did not begin with the intent of mark-recapture population estimation, there were certain parameters of the study that should have
been changed. If this study were to be repeated or continued, I would suggest the following modifications: (1) standardize the number and rate of capture occasions each month (2) increase the number of capture occasions to increase the sample size and recapture rates (3) have only $2-3$ people enter photographs into the computerassisted photograph-matching system and visually inspect the results, to maintain standardized procedures and reduce any possibility of human error. The software application MARK is commonly used to provide population estimates of marked animals from closed population studies. I attempted to use MARK to produce a population estimate for my study, but was unable due to the lack of standardized capture occasions and low recapture rates. If both of these components were changed in a future study, I recommend that MARK or a similar software application be used to produce a population estimate.

## CONCLUSION

This study showed that natural pelage patterns are an effective way to distinguish individual harbor seals through the use of photo-identification. Photoidentification through the aid of pattern recognition software proved to be a useful tool for marking large numbers of animals with minimal energy and negligible disturbance to the animals. The majority of sequential month abundance estimates and the mean abundance estimate for January - October 2008, were higher than any maximum single day counts at Children's Pool Beach. The results of this study indicate that the population of Pacific harbor seals that use Children's Pool Beach as a haul-out site may be two to three times larger than previously believed. These findings suggest a population that is at least partially open with considerable coastal movement; most likely between haul-outs at the California Channel Islands, Children's Pool Beach, and Las Islas Coronados. Management decisions regarding Children's Pool Beach need to be framed in the context that this haul-out is potentially part of a regional network of interconnected resting and pupping sites.


Figure 1. Counts of seals present at Children's Pool Beach, La Jolla, CA. Unpublished data courtesy of La Jolla Friends of the Seals; months with < 5 days of observations excluded. These data were collected by volunteer docents with varying training and on an irregular schedule. Maxima are reasonably reliable; averages should be considered rough indicators of the true numbers of seals.


Figure 2. The photo-identification software creating a 3-dimensional model of the seal's body. The yellow reference dots are the special points (nose, chin, left ear, right ear, base of the foreflippers, mid foreflipper, and mid pelvis) that are manually placed on the seal's body.


Figure 3. The photo-identification software extracting the chest region where the pelage spot patterns will be analyzed.


Figure 4. Left image is the new seal that has just been entered into the photoidentification software. Right image is one of multiple potential matches from the database.


Figure 5. Proportion of identified males, females, and unknown sex individuals out of the total population count. $\mathrm{N}=480$ individuals (after applied visual matching error rate of $4 \%$ )


Figure 6. Average number of occasions males, females, and unknown sex individuals were captured throughout the duration of the study. The difference between the average number of occasions that females and males were captured was not statistically significant (two-sample t -test: $\mathrm{t}=-0.45, \mathrm{df}=132, \mathrm{p}=0.655, \alpha=0.05$ ).


Figure 7. Distribution of individuals captured between one to eight occasions. $\mathrm{N}=500$ individuals $(\mathrm{SD}=2.45, \mathrm{MAX}=8, \mathrm{MIN}=1, \mathrm{n}=8)$


Figure 8. Distribution of recaptures throughout the duration of the study. Given that data collection occurred opportunistically, the date range was broken down per every 50 individuals entered into the catalog. ( $\mathrm{SD}=4.8, \mathrm{MAX}=18, \mathrm{MIN}=2, \mathrm{n}=13$ )


Figure 9. Distribution of the total number of captures (includes recaptures) that occurred each month during the study period (January - October 2008). $\mathrm{N}=646$ captures $(\mathrm{SD}=53.66, \mathrm{MAX}=172, \mathrm{MIN}=1, \mathrm{n}=10)$


Figure 10. Number of capture occasions that occurred during each month of the study period (January - October 2008). $\mathrm{N}=36$ capture occasions ( $\mathrm{SD}=1.9$, MAX $=7$, MIN $=1, \mathrm{n}=10$ )

Table 1. Chapman-Petersen population abundance estimates using sequential months as capture-recapture sampling occasions. See text for Chapman-Petersen equation and definition of variables.

| Sample 1 | Sample 2 | M | $\mathbf{C}$ | $\mathbf{R}$ | $\mathbf{N}$ | S.E. | CV | $\mathbf{9 5 \%} \mathbf{C I}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| January | February | 12 | 63 | 0 | 831 | 583 | .70 | $-334.99-$ <br> $1,996.99$ |
| February | March | 63 | 61 | 7 | 495 | 153.99 | .31 | $187.02-$ <br> 802.98 |
| March | April | 61 | 156 | 16 | 607.38 | 139.6 | .23 | $328.18-$ <br> 886.58 |
| April | May | 156 | 129 | 22 | 886.39 | 164.15 | .19 | $558.09-$ <br> $1,214.69$ |
| May | June | 129 | 61 | 4 | 1,611 | 630.61 | .39 | $349.78-$ <br> $2,872.22$ |
| June | July | 61 | 27 | 3 | 433 | 179.28 | .41 | $74.44-$ <br> 791.56 |
| July | August | 27 | 1 | 0 | 55 | 27.5 | .50 | $0-110$ |
| August | September | 1 | 47 | 0 | 95 | 66.47 | .70 | $-37.94-$ <br> 227.94 |
| September | October | 47 | 43 | 5 | 351 | 123.29 | .35 | $104.42-$ <br> 597.58 |

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