Spatial Analysis of Habitat Use Patterns of Harbor Seals (*Phoca vitulina richardii*) in San Francisco Bay, California

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A Geographic Information System (GIS) was used to investigate relationships between harbor seals and hydrographic features in San Francisco Bay (SFB), California. From January to May, 2001, we conducted a pilot study on harbor seal habitat use in SFB, using VHF and satellite-linked telemetry. Analysis was done on an integrated database of behavioral and environmental data. Four harbor seals were captured and tagged (VHF: 1 adult female, 2 subadult females; PTT: 1 adult male) at a major SFB haul-out site in January 2001. Using ArcView GIS, we overlaid harbor seal locations onto a digital elevation model (USGS DEM) of bathymetric features. We calculated distances traveled from primary harbor seal haul-out sites to foraging areas, as well as the farthest distance traveled by each seal from its primary haul-site. Fixed kernel utilization distributions were estimated in order to define individual home ranges and foraging areas. Additionally, a spatial dive model (interpolated from point locations of mean dive length) was created to investigate dive patterns within individual home ranges. Three of four seals tagged in the pilot study used consistent foraging areas, within a mean distance of 6 km from each individual's primary haul out site. Maximum distance traveled by any seal tracked was 59.58 km, representing a shift by the adult female to an alternate rookery. Home range estimates varied widely from 50 km2 (sub-adult female) to 638 km2 (adult female). There was some overlap of harbor seal foraging areas with prominent SFB bathymetric features, such as major shipping channels. Mean water depths in which seals were located ranged from 6-11 m. This study complements an ongoing monitoring program investigating the effects of a large-scale seismic retrofit of the Richmond-San Rafael Bridge on the SFB harbor seal population. The use of GIS to analyze spatial patterns of habitat use within SFB greatly enhances the ability to assess effects on the resident population. Research continues on harbor seal movements and foraging activities using VHF and satellite-linked telemetry. Future analysis will incorporate vegetation and prey distribution, sediment type, and primary productivity in order to accurately model environmental features encountered by the SFB harbor seal population.

INTRODUCTION

Harbor seals were first documented in San Francisco Bay (SFB) in the 1920's (Bonnot 1928), and the SFB seal population is currently estimated at approximately 400-500 seals (Reed, pers. comm., 2000). SFB is a highly urbanized environment, and harbor seals in SFB are subject to pressures from pollution, shoreline development and increasing levels of human activity (Fancher 1987, Risebrough et al. 1980). Although some radiotracking work was conducted in the south San Francisco Bay in the early 1990's (Kopec and Harvey 1999), little is known about seal movement patterns in the central and north SFB.

The present work was conducted as part of the Richmond Bridge Harbor Seal Survey, initiated by Caltrans to monitor responses of harbor seals in the Bay to the seismic retrofit of the Richmond-San Rafael Bridge. We summarize here results of a pilot study to assess the feasibliity of using VHF and satellite-linked telemetry to investigate harbor seal movements and habitat use patterns within SFB.

METHODS

Capture and Tagging

- San Francisco Bay (37ºN, 122ºW) is situated in north central California and is the largest estuary on the Pacific coast of the conterminous United States.
- SFB is relatively shallow (~80% less than 10 m) with deep waters in around the estuary mouth and commercial shipping lanes
- Mowry Slough (MS) is the largest rookery in SFB, Castro Rocks (CR) is the largest rookery in north/central SFB, while Yerba Buena Island (YBI), although a major haul-out, is not used extensively for pupping (Fig. 1)
- Four seals were captured and tagged at Castro Rocks (VHF: 1 adult female, 2 subadult females; satellite PTT: 1 adult male)
- Tags were glued to the seals' pelage using Loctite 422 adhesive (headmount Advanced Telemetry Systems VHF tags) or 5-minute marine epoxy (dorsally-mounted Telonics ST-18 PTT)
- Radio-tagged seals were tracked from land or aboard a 19 ft Boston whaler. A triangulation method, using hand-held directional antennas (SD = 3-5º) and receivers (ATS R4000 and AVM LA 12-Q), was used to locate radio-tagged seals.
- Locations for the satellite-linked transmitter were processed through System Argos, Inc.

Data Analysis

- Daily locations were plotted using the Arcview Geographic Information System (GIS) to investigate relationships between harbor seals and oceanographic features, as well as, spatial patterns of distribution in SFB.
- Locations were integrated with a USGS digital elevation model (DEM) of bathymetric features in SFB to describe mean depths of at-sea locations and associations with topography.
- To describe shape and size of home ranges, we used a fixed kernel home range method with bandwidth chosen via least squares cross validation (Worton 1989; Seaman and Powell 1996).
- 95% kernel describes the area actually used by the animals, and 50% kernel for core activity centers (haul-out sites and/or foraging areas). Kernel polygons refer to the probabilities of the animal being found within that concentric area.
- A continuous surface of harbor seal dive intervals was created from interpolating sample points of dive interval across the 50% kernel of an individuals home range (IDW, fixed radius). This exercise was undertaken to explore the feasibility of using surface analyses to analyze harbor seal dive behavior in relation to its spatial pattern of habitat use.
- The home range analyses in this study were conducted using a program extension (Spatial Animal Movement Extension; Hooge and Eichenlaub, 1998) to Arcview GIS 3.2

RESULTS

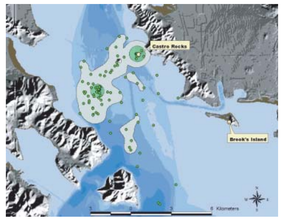

Fig. 2 Daily locations and kernel home range (95% and 50% polygons) of subadult harbor seal (1.221) radio-tagged in SFB.

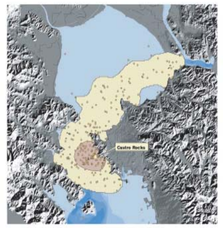

Fig. 3 Daily locations and kernel home range (95% and 50% polygons) of adult male harbor seal satellite-tagged in SFB.

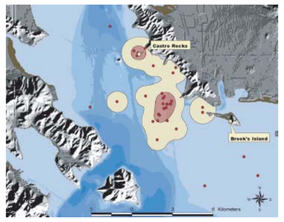

Fig. 4A Daily locations and kernel home range (95% and 50% polygons) of adult female harbor seal (1.310) radio-tagged in SFB.

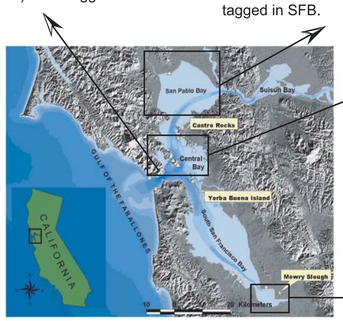

Fig. 1 Location, bathymetry, and primary harbor seal haul-out sites (yellow triangles) of SFB. The largest haul out sites in SFB are identified by name.

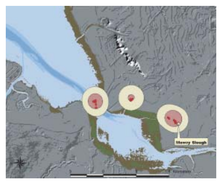

Fig. 4B The focus of activity of adult female harbor seal (1.310) alternated between north-central SFB (Fig. 4A) and south SFB (Fig. 4B) during the study. By mid-February it shifted its activity to a rookery site in south SFB (MS) for the duration of the pupping season,

Table 1. Movements (km) and home ranges (km^2) of sub-adult and adult harbor seals VHF radio and satellite-tagged in SFB

Seal ID*	Study Days	Home Range	Mean Distance to Foraging Areas	Maximum Distance from CR	Mean depth
RT 1.221	99	50.3 km^2	3.3 km (+/- 2.1 km)	10.66 km	6 m
RT 1.310	15**	683.6 km^2	3.2 km (+/- 2.3 km)	59.58 km	11 m
PTT 15345	74	175.5 km^2	7.3 km (+/- 0.8 km)	21.44 km	7 m

*A fourth seal, RT 1.652, relocated to another haul out site (YBI) immediately after tagging
**Pregnant adult female relocated to a rookery site (MS) after 15 days, remaining for duration of pupping season

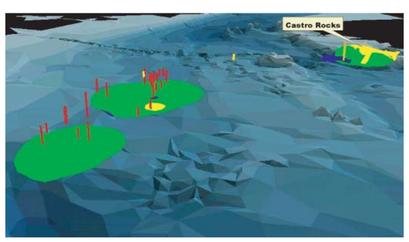

Fig. 5 Spatial dive model illustrating relationship between harbor seal behavior, dive interval, and bathymetry in SFB. Vertical lines represent dive interval length and behavior (milling-red; traveling-yellow; nearshore-orange). Continuous surface of dive interval represents diving activity across 50% kernel home range of sub-adult female (1-2 min-yellow; 3-4 min-green; 5-6 min-blue).

Table 2. Spatial model of dive activity of sub-adult female harbor seal in SFB

Dive Interval (min)	Dive Interval Area	Mean Depth (Interval Area)	Behavior
1-2 min	0.24 km^2	5 m	Nearshore
3-4 min	1.42 km^2	11 m	Milling
5-6 min	0.16 km^2	14 m	Milling

SUMMARY

· Results of our pilot study indicate that VHF and satellite-linked telemetry are both feasible ways of obtaining information on haul out patterns, movements and foraging activities of harbor seals in San Francisco Bay

· The difficulty of capturing animals using the Castro Rocks (CR) haul out site prevents large numbers of animals being tagged simultaneously; however, results obtained from our tagged seals will help provide insight into aspects of the seals' use of the bay that cannot be obtained from haul out site visual surveys alone

· With regard to large scale bridge construction projects in SFB: if seal haul out patterns at Castro Rocks are disturbed due to construction activities, telemetry studies will enable us to track the movements of seals within and around the San Francisco Bay. Tracking tagged animals will add valuable information to our understanding of how SFB seals respond to these disturbances.

· Although preliminary results are presented, the development of spatially explicit models integrating GIS and harbor seal behavior at the micro-scale should lead to innovative means for describing patterns of harbor seal habitat use in SFB. Futher research is required to test this exercise as a meaningful tool for examining harbor seal habitat use in SFB.

· Further research on the movements and foraging activities of harbor seals is required to understand habitat use patterns of San Francisco Bay seals; future research will incorporate vegetation and prey distribution, sediment type, and primary productivity in order to accurately model environmental features encountered by the SFB seal population

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