Estimating Sustainable Bycatch Rates for California Sea Lion Populations in the Gulf of California

JARED G. UNDERWOOD,*‡ CLAUDIA J. HERNANDEZ CAMACHO,*† DAVID AURIOLES-GAMBOA,† AND LEAH R. GERBER*

*Ecology, Evolution and Environmental Science, School of Life Sciences, Arizona State University, College & University Drive, Tempe, AZ 85287-1501, U.S.A.
†Centro Interdisciplinario de Ciencias Marinas-IPN, Av. IPN s/n Col. Playa Palo de Santa Rita, La Paz BCS 23096, México

Abstract: Commercial and subsistence fisheries pressure is increasing in the Gulf of California, Mexico. One consequence often associated with high levels of fishing pressure is an increase in bycatch of marine mammals and birds. Fisheries bycatch has contributed to declines in several pinniped species and may be affecting the California sea lion (Zalophus californianus) population in the Gulf of California. We used data on fisheries and sea lion entanglement in gill nets to estimate current fishing pressure and fishing rates under which viable sea lion populations could be sustained at 11 breeding sites in the Gulf of California. We used 3 models to estimate sustainable bycatch rates: a simple population-growth model, a demographic model, and an estimate of the potential biological removal. All models were based on life history and census data collected for sea lions in the Gulf of California. We estimated the current level of fishing pressure and the acceptable level of fishing required to maintain viable sea lion populations as the number of fishing days (1 fisher/boat setting and retrieving 1 day’s worth of nets) per year. Estimates of current fishing pressure ranged from 101 (0–405) fishing days around the Los Machos breeding site to 1887 (842–3140) around the Los Islotes rookery. To maintain viable sea lion populations at each site, the current level of fishing permissible could be augmented at some sites and should be reduced at other sites. For example, the area around San Esteban could support up to 1428 (935–2337) additional fishing days, whereas fishing around Lobos should be reduced by at least 165 days (107–268). Our results provide conservation practitioners with site-specific guidelines for maintaining sustainable sea lion populations and provide a method to estimate fishing pressure and sustainable bycatch rates that could be used for other marine mammals and birds.

Keywords: bycatch, California sea lion, fisheries, gill-net entanglement, Gulf of California, population viability, Zalophus californianus

Estimación de Tasas de Captura Incidental Sustentables para Poblaciones de Lobos Marinos en el Golfo de California

Resumen: La presión de las pesquerías comerciales y de subsistencia está aumentando en el Golfo de California, México. El incremento de la captura incidental de mamíferos y aves marinas a menudo es una consecuencia asociada con altos niveles de presión de pesca. La captura incidental de pesquerías ha contribuido a las declinaciones de varias especies de pinípedos y puede estar afectando a la población de lobo marino de California (Zalophus californianus) en el Golfo de California. Utilizamos datos sobre pesquerías y enmallamiento de lobos marinos en redes agalleras para estimar la presión de pesca actual y las tasas de pesca bajo las que se pudieran sostener poblaciones de león marino en 11 sitios de reproducción en el Golfo de California. Utilizamos 3 modelos para estimar tasas de captura incidental sustentables: un modelo de crecimiento poblacional simple, un modelo demográfico, y una estimación de la remoción biológica potencial. Todos los modelos se basaron en datos de la historia de vida y de censos de lobos marinos en el Golfo de California. Estimamos el nivel de la presión de pesca actual y el nivel de pesca aceptable requerido para mantener poblaciones viables de lobos marinos como el número de días de pesca (1 pescador/barco

‡email jared.underwood@asu.edu
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colocando y recuperando el valor de 1 día de redes) por año. Las estimaciones de la presión de pesca actual variaron entre 101 (9-405) días de pesca alrededor del sitio de reproducción Los Machos y 1887 (842–3140) alrededor de Los Isotes. Para mantener poblaciones viables de lobos marinos en cada sitio, el nivel de pesca permisible actual podría ser aumentado en algunos sitios y debería ser reducido en otros. Por ejemplo, el área alrededor de San Esteban podría soportar hasta 1428 (935-2337) días de pesca adicionales, mientras la pesca alrededor de Lobos debería ser reducida en por lo menos 165 (107–268) días. Nuestros resultados proporcionar a los profesionales de la conservación directrices específicas para cada sitio para mantener poblaciones sustentables de leones marinos y proporcionan un método para estimar la presión de pesca y las tasas de captura incidental sustentables que podrían ser utilizadas en otros mamíferos y aves marinas.

Palabras Clave: captura incidental, lobo marino de California, enmallamiento en red agallera, Golfo de California, viabilidad poblacional, Zalophus californianus

Introduction

Obtaining accurate information on fisheries-related bycatch for marine mammals and birds is a global challenge in marine conservation biology (Read et al. 2006). Here we present a method for estimating current fishing pressure and sustainable bycatch rates based on entanglement data and life history parameters for marine species (pinnipeds, cetaceans, or birds). This method is illustrated with the California sea lion (Zalophus californianus) population in the Gulf of California (Gulf) as a case study. Using this method, an estimate of incidental catch and the relative intensity of fishing pressure can be approximated indirectly from the number of entangled animals recorded. Sea lion entanglement rates are relatively straightforward to document, and information can be collected quickly. Assuming that the number of entangled individuals indicates relative fishing pressure, the use of site-specific data on entanglement and life history parameters permits one to estimate the level of allowable fishing pressure.

The California sea lion is a polygynous pinniped that breeds on islands of the eastern Pacific Ocean from British Columbia in Canada to Las Islas Marias in Mexico and in the Gulf (Odell 1981). After an apparent recovery from exploitation in the 19th and 20th centuries, the current status of California sea lions in the Gulf is uncertain. Szteren et al. (2006) compared the most recent survey (24,062–31,159) with a 1994 census (31,393 individuals) and found an approximate 20% decline between 1994 to 2004. The most recent census data at the rookery level indicate that increases in several large breeding colonies are masking rapid declines in several smaller rookeries (Szteren et al. 2006). Although census numbers indicate a declining population, estimates of the population-growth rate for the Gulf seem to indicate a stable to slightly increasing population (Gonzalez-Suarez et al. 2006; Szteren et al. 2006). Another way to assess the status of the population is to estimate the probability of a reduction in population size over time. Gonzalez-Suarez et al. (2006) found that the probability of a 30% reduction in population size after only 3 generations (15 years) was >65% for 8 of the 11 rookeries used in the analysis. Because of the uncertainty associated with census data and subsequent population-growth rate estimates, it is difficult to ascertain the true status of this population.

Recent reports estimate that 30,000 fishers in 18,000 boats currently fish in the Gulf and that unregulated gill-net fishing has doubled in the last decade and continues to grow (CONANP 2006). The type of fishing that most commonly conflicts with California sea lions is the set gill-net fishery (Julian & Beeson 1998; Aurioles-Gamboa et al. 2003). In fact, the threat of mortality due to incidental catch in gill nets is one of the gravest problems facing sea lions in this area (Zavala-Gonzalez & Mellink 1997; Programa de Manejo, Islas del Golfo de California 2000; Aurioles-Gamboa et al. 2003). Although the direct impact of gill-net fishing on the sea lion population in the Gulf is unknown, incidental catch in gill and other fishing nets has contributed to population declines in northern fur seals (Callorhinus ursinus), harbor seals (Phoca vitulina stejnegeri), and harp seals (P. groenlandica) and is at least partially responsible for declines in Steller sea lions (Eumetopias jubatus) (Fowler 1987; Woodley & Lavigne 1991). In the Gulf, recent observations indicate an increased rate of entanglement in the northern Gulf (Zavala-Gonzalez & Mellink 1997). Increases in entanglement almost certainly signal an elevated rate of mortality due to incidental catch, which may be one of the principle reasons why sea lion populations in the northern Gulf are in decline.

We devised a method to estimate the current level of fishing pressure and a sustainable bycatch rate for 11 breeding colonies found throughout the Gulf. We assumed movement was limited between breeding colonies. Although movement between rookeries is possible and occasionally does occur, the level of movement between rookeries is thought to be minimal on the basis of genetic and mark-recapture studies in the Gulf (Maldonado et al. 1995; Gonzalez-Suarez et al. 2006; Young et al. 2007; Hernandez-Camacho et al., 2008a). This method for estimating sustainable bycatch rates can
help managers in the Gulf establish a fishing strategy that will allow sea lion populations in the region to persist. These methods could also be applied to other marine bird and mammal species.

Methods

We estimated the current level of fishing around sea lion rookeries of the Gulf of California and the maximum fishing pressure that could be sustained while ensuring viable sea lion populations. To estimate the current level of fishing pressure, we used fisheries and sea lion entanglement data from southern California and sea lion entanglement data from the Gulf. To estimate the level of fishing that would maintain viable sea lion populations in the Gulf, we used 3 methods. All 3 estimate the number of sea lions that can be removed and still maintain a viable population. For each method, after we determined the potential number of sea lions that could be removed, we translated the estimate into allowable fishing pressure by calculating the fishing effort required to remove that number of individuals.

First, we constructed a simple population model from the most recent population estimate and the discrete rate of annual population growth ($\lambda$) for each sea lion rookery. Second, we followed the same approach as in the simple population model but with the $\lambda$ value estimated from demographic data that were available for only 1 of the 11 sites (Los Islotes; Fig. 1). This second method allowed us to incorporate the effect of differential, incidental catch mortality across age classes into estimates of allowable bycatch rates. In the first 2 methods, the $\lambda$ estimate incorporated the current level of fishing pressure. We asked how much fishing pressure could be increased or how much it should be reduced so that $\lambda = 1.00$. Finally, we calculated the potential biological removal (PBR) for each rookery with the most recent population estimate and 0.5 the maximum net growth rate for pinnipeds.

Estimating Mortality Rates

To estimate the level of fishing that could be sustained while allowing persistence of sea lion populations in the Gulf, it was first necessary to estimate a per-net rate of sea lion mortality. We used that rate as a measure of catch per unit effort (CPUE) because it is a derivative of the CPUE recorded for the southern California set gill-net fishery and is commonly used to describe bycatch data for marine mammals (Carretta 2001). In the southern California set gill-net fishery each boat typically sets 2 to 4 nets/fishing day, with an average of 3.08 nets/day (Julian & Beeson 1998). The CPUE is recorded as the number of sea lions taken per fishing day (Julian & Beeson 1998; Carretta 2001). Nevertheless, fishers in the Gulf commonly set only 2 nets/day (V. Cruz, personal communication). To make a comparison between these 2 fisheries, we calculate CPUE as per net mortality.

Over a 5-year period, observers recorded an average kill rate of 0.39 sea lions/fishing day (range 0.25–0.61). Thus, the kill rate for every net set in the southern California set gill-net fishery was approximately 0.13 sea lions/fishing day (range 0.08–0.20). Because the mortality rate per net for the Gulf is unknown, we estimated this value from California data (Stewart & Yochem 1990; Julian & Beeson 1998). In California, however, each net is about 450 m long and nets used by fishers in the Gulf are measure only 220–330 m (Zavala-Gonzalez & Mellink 1997; Julian & Beeson 1998). Consequently, we modified our estimated Gulf per net mortality rate to be 50% of the California rate (0.04–0.10 sea lions/net).

Although fishing practices certainly vary between California fishers and Mexican fishers, there are similarities that allow for comparisons to be made. The boats used in Mexico are generally much smaller, but the gear used and the length of time nets are left until retrieval are...
similar (Zavala-Gonzalez & Mellink 1997; Julian & Beeson 1998; Aurioles-Gamboa et al. 2003). In addition, in both California and Mexico, fishers and sea lions do not pursue the same species (Julian & Beeson 1998; Aurioles-Gamboa et al. 2003). Sea lions are caught incidentally as they enter an area with nets. Finally, the most important factor that determines bycatch rate in pinnipeds is the size of the net mesh opening (Zavala-Gonzalez & Mellink 1997; Julian & Beeson 1998; Aurioles-Gamboa et al. 2003). Sea lions cannot enter nets with a small mesh size and can swim through nets with a large mesh size. Sea lions are most commonly caught in gill nets with a mesh size of 20–22 cm, which is the mesh size for gill nets in both the Californian and Mexican set gill-net fisheries (Julian & Beeson 1998; Aurioles-Gamboa et al. 2003).

**Estimating Fishing Pressure**

We estimated fishing pressure by incorporating data on entanglement and number of total nets fished from southern California with entanglement information from the Gulf (Stewart & Yochem 1990; Zavala-Gonzalez & Mellink 1997; Julian & Beeson 1998; Carretta 2001). We estimated current fishing pressure for each rookery in the Gulf ($F_g$) as

$$F_g = \frac{E_g \times F_c}{E_c},$$

where $E_g$ is the rookery-specific number of entangled individuals for the Gulf ($0–29$), $F_c$ is the estimated number of nets set per year in the southern California set gill-net fishery ($5,984–22,086$), and $E_c$ is the estimated number of individuals entangled per year from California ($97 – 193$). This annual estimate of entanglement refers only to live individuals currently entangled in fishing debris; animals with old entanglement wounds or scars were not included in these estimates.

This approach was used to identify an estimated number of nets set per year around each rookery in the Gulf and to identify the highest and lowest number of nets set to incorporate uncertainty associated with these data. Because the gill nets used by fishers in the Gulf are approximately half as long as those used in California, we doubled the estimate derived from the equation to normalize the size of the nets with those from southern California. When calculating the upper and lower estimates of fishing pressure, the highest (upper) or lowest (lower) estimates available for entanglement at a specific Gulf rookery and the highest or lowest estimates of entanglement and number of nets from California were used.

To obtain entanglement values for each rookery in the Gulf, we used 5 years of entanglement records, in which each rookery was sampled once a year (Zavala-Gonzalez & Mellink 1997; Aurioles-Gamboa et al. 2003). We used a comparable 5-year data set from the Channel Islands of California to obtain California entanglement estimates (Stewart & Yochem 1990) and a 5-year data set from southern California, where fisheries data were collected by onboard observers as part of a National Marine Fisheries Service and California Department of Fish and Game project to estimate total number of nets set per year in the set gill-net fisheries (Julian & Beeson 1998). Population estimates for southern California were derived from Lowry and Maravilla-Chavez (2005). Although entanglement and fisheries data were collected asynchronously to the most recent population estimate, the most recent population estimates were used to provide an approximation of current fishing pressure.

**Estimating Sustainable Levels of Bycatch: Simple Population-Growth Model**

One metric of population viability is the mean and variance in the discrete rate of $\lambda$. We used a simple population-growth model to estimate the level of fishing pressure that would sustain sea lion populations given the constraint of $\lambda = 1.00$. We used recent estimates of total population size and $\lambda$ for each rookery (Gonzalez-Suarez et al. 2006; Szteren et al. 2006) to determine the number of individuals produced ($N_p$) annually at each rookery:

$$N_p = N_{t+1} - N_t,$$

where

$$N_{t+1} = \lambda^t N_t,$$

and $N_t$ is defined as the population size ($N$) at a given time ($t$). The population size ($N_t$) is derived from the most recent census data for all age classes at each rookery. We calculated the level of allowable fishing pressure by estimating the number of “surplus” individuals produced annually by increasing populations ($\lambda > 1.00$) or the number of individuals that would be needed so as to reverse the trend of a declining populations ($\lambda < 1.00$) such that $\lambda = 1.00$. We used this estimate to determine the level of additional fishing pressure allowable, or the level by which current fishing pressure should be reduced, to maintain sea lion populations.

This annual production estimate ($N_p$) was calculated for the best predicted $\lambda$ value, and for the upper and lower 95% confidence interval, $\lambda$ value estimates for each rookery. Gonzalez-Suarez et al. (2006) used the diffusion-approximation model to estimate $\lambda$ for each rookery (Dennis et al. 1991) and proposed that the best-predicted $\lambda$ value is the most robust estimate of population growth (Gonzalez-Suarez et al. 2006). The diffusion-approximation model uses linear regression to estimate the general trend and variability in $\lambda$. Data used to estimate $\lambda$ consisted of periodic census information collected since the late 1960s for each of the 11 rookeries (Gonzalez-Suarez et al. 2006). We considered the upper
and lower production estimates for \( N_p \) in our analyses so as to incorporate uncertainty in estimates of \( \lambda \).

We then divided these production estimates by the estimated per-net mortality rate (\( M \)) (lower, average, upper estimates) to generate the approximate number of net sets (\( F_e \)) required to maintain \( \lambda \leq 1.00 \),

\[
F_e = \frac{N_p}{M}.
\]

The \( F_e \) was then converted to number of fishing days by dividing \( F_e \) by 2. A fishing day is defined as 1 fisher/boat setting and retrieving 1 day’s worth of nets. We divided \( F_e \) by 2 because that is the estimated number of nets set per day for a Mexican fisher. A fisher who fishes every day of the year would accumulate 365 fishing days. Some islands have current levels of fishing that exceed 365 fishing days; this implies that more than 1 fisher/boat is using that area (5 fishers fishing every day equals 1825 fishing days). We used number of fishing days because it is a standard metric of CPUE.

Estimating Sustainable Levels of Bycatch: Demographic Model

Although estimates from our population-growth model provide a basic understanding of how fishing might affect a rookery, these estimates do not consider demographic differences in mortality and the effect that these differences have on \( \lambda \). Demographic information sufficient to allow the construction of a Leslie matrix was available for one rookery in the Gulf (Los Islotes). To more accurately identify sustainable bycatch levels for Los Islotes, we developed an age-structured Leslie-matrix model to explore the sensitivity of sea lion population growth to bycatch mortality. In this model \( \lambda \) was estimated as the dominant eigenvalue from the Leslie matrix. Because each rookery has potentially different demographic parameters, we could only apply our model to the Los Islotes rookery. Nevertheless, we expect that the broader conclusions drawn from this analysis may apply to the other rookeries in the Gulf.

The model was populated with demographic data from a cohort life table for females at Los Islotes Island in the southern Gulf (Hernandez-Camacho et al. 2008b). Fertility estimates were only available for sea lions aged 10–19 years (Hernandez-Camacho et al. 2008a). Thus, estimates for younger individuals were derived from values reported for California sea lions at San Miguel Island, California (Melin 2002).

We performed an elasticity analysis to determine the relative impact of age-specific fertility and survival on \( \lambda \) (Caswell 2001). Although the model was age-based, the matrices were analyzed by age groups: juveniles (0–3 years old), young adults (4–7 years old), adults (8–11 years old), and old adults (12–18 years old). To obtain a single value for each age group, we summed the age-specific elasticities for age classes included in that age group (Caswell 2001).

We used our demographic model to consider 2 scenarios with distinct incidental catch probabilities for juvenile and adult animals. For the first scenario we assumed that all individuals had an equal chance of mortality due to incidental catch, similar to our assumption in the simple population-growth model. We based this assumption on the fact that the proportion of individuals that were seen entangled at Los Islotes was the same as their overall proportion in the population (Aurioles-Gamboa et al. 2003). This first scenario estimated the level of mortality in all age classes that would generate the minimum sustainable population-growth rate (\( \lambda = 1.00 \)).

Because the actual proportion of individuals in each age class that die as incidental catch is unknown, our second scenario addresses how the population-growth rate would be affected if those dying in the nets are all juveniles. Juveniles are the most commonly observed entangled animals at the majority of rookeries in the Gulf (Zavala-Gonzalez & Mellink 1997). In addition, in Steller sea lions, juveniles are more likely than adults to become entangled in fishing nets (NRC 2003). In our second scenario we focused on identifying the increased juvenile mortality rate that would cause the entire population’s growth rate to reach the equilibrium rate of \( \lambda = 1.00 \).

We used the estimated mortality rates and the most recent population census data to estimate the number of individuals that could be removed from the population while maintaining \( \lambda = 1.00 \). This estimate of individuals was divided by the estimated per-net mortality rate (\( M \)) (lower, average, upper estimates) to generate the approximate number of net sets (\( F_e \)) allowable. In this way, uncertainty in population growth could be considered in management decisions.

Estimating Sustainable Levels of Bycatch: Potential Biological Removal

To compare results from our simple population model and demographic model to standard methods used by the U.S. National Oceanic and Atmospheric Administration, we also estimated the potential biological removal (PBR) for sea lions in the Gulf. The goal of this approach is to ensure that marine mammal stocks are maintained at a level at which they are a functioning component of their ecosystem (Barlow et al. 1995). A PBR calculation provides the allowable level of removal from the population as a number of individuals. The PBR for the California sea lions is calculated as the minimum population size times 0.5 the maximum growth rate for pinnipeds (0.5 of 12%) times a recovery factor of 1.0 (NMFS 2003). We calculated PBR for each sea lion rookery in the Gulf to provide a site-specific estimate of the number of sea lions that can be removed. These production estimates were then divided by the estimated per-net mortality rate (\( M \)) (lower, average, upper estimates) to generate the approximate number of net sets (\( F_e \)) allowable.
Table 1. Estimated level of current fishing pressure around California sea lion rookeries in the Gulf of California, Mexico.

<table>
<thead>
<tr>
<th>Rookery</th>
<th>Estimate of fishing days*/year</th>
<th>Range of no. of fishing days/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Jorge</td>
<td>1444</td>
<td>402–3,290</td>
</tr>
<tr>
<td>Lobos</td>
<td>591</td>
<td>144–1,718</td>
</tr>
<tr>
<td>Granito</td>
<td>444</td>
<td>89–1,485</td>
</tr>
<tr>
<td>Los Cantiles</td>
<td>210</td>
<td>55–479</td>
</tr>
<tr>
<td>Los Machos</td>
<td>101</td>
<td>0–405</td>
</tr>
<tr>
<td>El Partido</td>
<td>223</td>
<td>69–493</td>
</tr>
<tr>
<td>El Rasito</td>
<td>241</td>
<td>0–961</td>
</tr>
<tr>
<td>San Esteban</td>
<td>1718</td>
<td>419–3,307</td>
</tr>
<tr>
<td>San Pedro Martir</td>
<td>936</td>
<td>51–2,171</td>
</tr>
<tr>
<td>San Pedro Nolasco</td>
<td>230</td>
<td>0–664</td>
</tr>
<tr>
<td>Los Islotes</td>
<td>1887</td>
<td>842–3,140</td>
</tr>
<tr>
<td>Total</td>
<td>8024</td>
<td>2,072–18,113</td>
</tr>
</tbody>
</table>

*A fishing day is defined as 1 fisher/boat setting and retrieving 1 day's worth of nets (2 nets). When the estimated number of fishing days at a rookery exceeds 365 this implies that multiple fishers are using a site. These estimates are not derived from empirical data but from an extrapolation of entanglement data.

Results

Current Fishing Pressure

The areas around certain rookeries were more commonly fished than others (Table 1; Fig. 2). The amount of current fishing pressure ranged from a minimal number of fishing days around Los Machos (101) to over a thousand fishing days around rookeries such as San Jorge (1444), San Esteban (1718), and Los Islotes (1887).

Simple Population-Growth Model

Our simple population-growth model showed that the level of fishing pressure the area around each rookery can withstand while still maintaining sea lion populations depends on the population size, $\lambda$, and the level of current fishing pressure (Fig. 3; Table 2). As expected, fewer

Figure 2. Current estimated fishing pressure around each sea lion rookery in the Gulf of California, Mexico, measured as number of fishing days.

Figure 3. The number of fishing days allowable around each sea lion rookery in the Gulf of California, Mexico, derived from (a) the best estimate of $\lambda$, (b) the lower 95% CI estimate of $\lambda$, and (c) the upper 95% CI estimate of $\lambda$. A negative number of days signifies that current fishing pressure should be reduced by that number of days to achieve a minimum sustainable population-growth rate for sea lions of $\lambda \leq 1.00$. 
allowable fishing days could be sustained around rookeries with small population size, low $\lambda$, or high fishing pressure. When the best estimates of $\lambda$ were used, only the areas around the Lobos and Los Cantiles rookeries required a reduction in fishing pressure. For areas around other rookeries the number of additional fishing days permissible varied widely. The number of fishing days allowable was reasonably large around San Esteban (935–2337), which has a large sea lion population (5000–6000 animals). Nevertheless, around the similar-sized rookery of San Jorge (3000–4000 animals), a $\lambda$ close to 1.00 significantly reduced the number of fishing days (594–1485). Finally, the number of fishing days was even more limited when the sea lion population was small such as at El Rasito (300–400 animals), which despite having one of the highest population-growth rates, could only sustain 88–220 additional fishing days.

For the area around all but one rookery, when the lowest estimate for $\lambda$ was used, our model suggested that fishing pressure should be reduced to maintain sea lion populations. When the highest estimated $\lambda$ value was used, the area around all rookeries could sustain some additional fishing pressure.

**Demographic Model**

Our demographic model for Los Islotes yielded an estimate of $\lambda$ of 1.12. Results of our elasticity analysis showed that $\lambda$ depended more on survival than on reproduction. In addition, population-growth rate was more sensitive to juvenile survival than to adult survival (Fig. 4).

Assuming that juveniles and adults have an equal chance of dying in nets, an 11.1% increase in mortality to all age classes at Los Islotes yielded a $\lambda$ of 1.00. Based on this estimate, the number of additional allowable fishing days around Los Islotes ranged from 169 to 422. For the second scenario, in which only juveniles were killed in the nets, a 23.5% increase in the juvenile mortality could be sustained before $\lambda = 1.00$. Here, 56–139 additional fishing days would be permissible. This corresponded to an approximately 66% reduction in the number of allowable fishing days if only juveniles are taken. The number of fishing days allowed when juveniles are more likely to be taken as bycatch was much smaller due partially to the fact that the population contained far fewer juveniles than adults, so a 23.2% decrease in juveniles resulted in a smaller number of sea lions that could be taken.

![Figure 4. Elasticity values for California sea lions in the Gulf of California derived from the life table constructed for the Los Islotes rookery between 1980 and 1997.](image-url)
Potential Biological Removal

The PBR calculation yielded permissible fishing pressure estimates that were generally within the range calculated with the other methods (Table 2). The number of allowable fishing days ranged from 113 to 281 around El Rasito to several thousand fishing days around rookeries such as San Jorge (1150–2875) and San Esteban (1700–4250). Because this method assumed populations for all rookeries were increasing, no reduction in fishing pressure would be required.

Discussion

There are several hypotheses for why California sea lions in certain areas of the Gulf are in decline. Szteren et al. (2006) hypothesize that the decline is associated with a reduction in sardine (Sardinops sagax) populations. Although a reduction in sardines may be a contributing factor, we propose that recent declines might also be related to an increase in fishing effort and associated sea lion bycatch. For example, census data for all but 1 of the 8 (Granito, Los Cantiles, Los Machos, El Rasito, Lobos, San Pedro Martir, San Esteban, and El Partido) sea lion rookeries in the central Gulf show a population decrease of 13–61% since the early 1990s (Szteren et al. 2006). This decline occurred at the same time that Zava1-Gonzalez and Mellink (1997) found that fishing pressure and entanglement had increased in that area of the Gulf.

Our results show that little additional fishing pressure would represent a significant threat to sea lion viability, especially if fishing pressure disproportionately affects the juvenile age class. Results from our demographic model highlight the importance of considering demographic differences among life stages in estimating fishing pressure that will sustain viable sea lion populations. In particular, on the basis of reported elasticity pattern, when juveniles are disproportionately taken as bycatch, this will reduce the allowable fishing pressure.

Current Fishing Pressure

Current fishing pressure around most rookeries appears to be relatively limited. Although 18,000 boats regularly fish the Gulf, there are vast stretches of shoreline that do not harbor California sea lions; therefore, conflict between fishing and sea lions in these areas is minimal. In addition, only some fishers use the techniques and gear that commonly ensnare sea lions (Aurioles-Gamboa et al. 2003). Finally, because rookeries are generally fairly isolated, these regions may be less geographically desirable to fisherman compared to areas in close proximity to towns. Nevertheless, all of the rookeries currently experiencing the greatest level of fishing pressure are close to major population centers either in Baja California or on mainland Mexico. The San Jorge rookery (1444 fishing days) is close to the popular tourist destination and major port town of the northern Gulf, Puerto Peñasco/Rocky Point. The Los Islotes rookery (1887 fishing days) is in Bahia La Paz and is very close to the capital city of Baja Sur, La Paz. Finally, the San Esteban rookery (1718 fishing days) is close to the town of Bahia Kino, which is the only major town along the Gulf in the state of Sonora, Mexico. As these and other towns continue to grow, the areas around rookeries will almost certainly experience additional fishing pressure.

Regardless of the level of current fishing pressure, it is important to understand the precarious balance that now exists between sea lions and local fishing communities. As one can see from the El Partido example, even a rookery that presently has relatively low levels of fishing (69–495 fishing days) can support relatively little additional fishing pressure (106–338 fishing days) without influencing the viability of California sea lions.

Caveats

At rookeries where populations are currently declining, bycatch is probably not the only contributing factor. The Los Cantiles and Lobos rookeries are both thought to be declining, yet the current estimated fishing pressure is not drastically different from that experienced by other rookeries in the Gulf. Other factors such as sardine production may be affecting these rookeries. Nevertheless, a reduction in fishing pressure surrounding these rookeries might positively affect the population. Reduction in fishing pressure positively affects population growth (Woodley & Lavigne 1991), and this was the main reason for the nearshore fishing closures in California (Carretta 2001). In addition, the prohibition of fishing camps in the area around Los Islotes in the Gulf has resulted in a 75–80% reduction in annual entanglement between 2002 and 2005.

There is considerable uncertainty associated with our results. To obtain data sufficient to more accurately guide policy, one would need to know much more about the interaction of the set gill-net fishery and the California sea lion. Data needs include the mortality rate for sea lions entangled in nets, the number that become entangled each year, differential survival across sex and age classes, actual site-specific information on fishing effort, and variability of the interaction as it relates to temporal and spatial placement of nets. Better demographic and life-history data for islands other than Los Islotes would also be needed. In addition, because estimates of entanglement and current population size were not collected simultaneously, if fishing pressure has changed dramatically, our estimates of sustainable bycatch may be over- or underestimates. Bayesian approaches could also be
applied to incorporate this uncertainty as data become available (Hilborn & Mangel 1997).

Several additional factors could alter the estimated number of allowable fishing days. First, if fishers altered spatial or temporal fishing practices, this could alter the number of allowable fishing days. Second, population census data were collected during summer months when sea lion numbers at each rookery peak. Thus, the number of allowable days would also fluctuate on the basis of the population size. Although the number of sea lions at each rookery fluctuates throughout the year, a significant portion of the breeding population uses the rookery year round. Finally, juvenile and possibly adult abundance are likely to be density-dependent, which may violate the assumptions of the diffusion approximation model that we used to calculate \( \lambda \). Nevertheless, Sabo et al. (2004) found that under certain types of density dependence, although the assumption of density dependence is violated, the diffusion approximation methods can still accurately and conservatively estimate population viability parameters.

Despite these caveats, we believe our results can contribute to fisheries management plans so that viable sea lion populations can persist in the Gulf (Fig. 3; Table 2). We used 3 estimates for \( \lambda \) (best, lower, and upper) and the PBR calculation method to identify a range of potential guidelines. We believe this will allow managers to choose a set of results on the basis of their level of risk aversion. Nevertheless, until the actual fishing pressure at each site is known, managers can use allowable fishing estimates created with the lowest estimate of \( \lambda \) to ensure precautionary approach to management.

Conclusion

One of the great difficulties in conservation biology is the dual goal of sustaining local economies without damaging the resources on which economies depend. In the Gulf, 30,000 fishers and their families depend on the sea for a livelihood (CONANP 2006). Our models show that well-managed fishing around the islands of the Gulf is necessary for the California sea lion to persist. This does not mean fishing should be eliminated; rather, certain types of fishing and fishing equipment around sea lion rookeries and feeding areas should be regulated carefully. We anticipate that analyses such as those we describe here may be applied to other locations and for other marine mammal or bird species.

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