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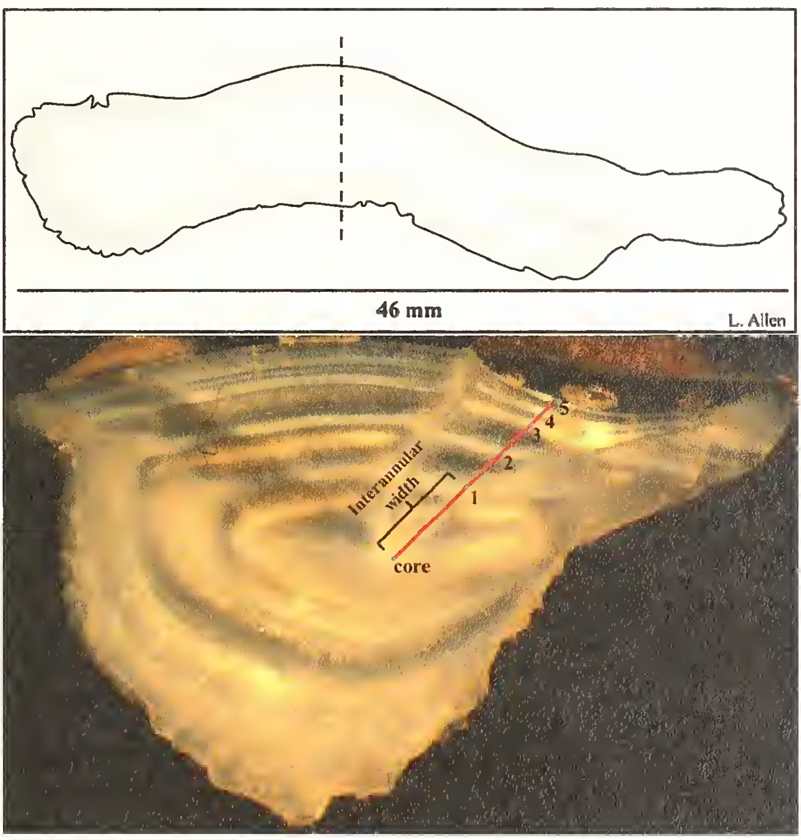


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# Growth, Development, and Reproduction in Gulf Corvina (*Cynoscion othonopterus*)

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*Abstract.*—Gulf corvina, *Cynoscion othonopterus*, is a vital component of commercial fisheries in the northern Gulf of California, but a lack of information on life history parameters have thus far prevented a comprehensive stock assessment. In this project, 530 specimens of Gulf corvina were collected from commercial gill net fisheries in the Colorado River Delta region in Sonora, Mexico, to characterize population structure, age and growth patterns, age and size at sexual maturity and batch fecundity. Fish ranged from 145 mm to 1013 mm in total length and from 1 to 8 years of age. Von Bertalanffy growth model parameters were: $L_\infty = 1006$ mm, k = 0.255/yr, $t_0$ = 0.616 years. Growth rates of Gulf corvina did not differ significantly between sexes, although females were predicted to reach a larger asymptotic length. Mean size ($L_{m50}$) and age ($A_{m50}$) at sexual maturity from histological analyses of gonad tissues was 294.7 mm and 2.3 years for females and 267.5 mm and 2.0 years for males. Maturity estimates from otolith analyses did not differ between sexes and were similar to maturity estimates derived from gonadal histology, indicating that energy allocation shifts from growth to maturation and reproduction after year two. Batch fecundity ranged from 240,394 to 1,219,342 eggs with a mean of 684,293 eggs per spawn, and was correlated to both total length and gonad-free body weight. The distribution of oocyte diameters and oocyte stages indicate that Gulf corvina is a multiple batch spawner with asynchronous oocyte development and indeterminate annual fecundity.

## Introduction

The Gulf corvina, *Cynoscion othonopterus* (Jordan & Gilbert 1882), is a member of the family Sciaenidae and is endemic to the northern Gulf of California, the region north of latitude 28°61′ S (Robertson and Allen 2008). Adult Gulf corvina are carnivorous, feeding on benthic crustaceans, mollusks, and schooling fishes such as anchovies and sardines (Román-Rodríguez 2000). Spawning is restricted to the upper reach of the Gulf of California and is correlated to tidal patterns: adults migrate to the Colorado River Delta during the weeks preceding the new and full moons of March and April and form massive spawning aggregations in the estuary (Erisman et al. 2012). The spawning season is tightly linked to the timing of historic spring floods of the Colorado River, which created an extensive brackish nursery habitat for Gulf corvina and other fish (Rowell et al. 2005, 2008).

The commercial fishery for Gulf corvina is economically significant in the northern Gulf of California (Paredes et al. 2010; Rodríguez-Quiroz et al. 2010) and has a direct conservation impact, because it is centered inside the upper Gulf of California and Colorado River Delta Biosphere Reserve (DOF 2007). The fishery primarily targets the spring spawning aggregations, in which small boats (8–9 m in length) use gillnets with a mesh size of 14.6 cm and lengths up to 293 m to harvest fish as they move to the river's mouth to spawn (Román-Rodríguez 2000; DOF 2007; Paredes et al. 2010; Erisman et al. 2012). Over the past two decades, the Gulf corvina fishery has emerged as an important economic component of the communities of El Golfo de Santa Clara, El Zanjón, and San Felipe in the northern Gulf of California (Román-Rodríguez 2000; Rodríguez-Quiroz et al. 2010). In El Golfo de Santa Clara, annual harvest increased from 3.2 tons to 1,278 tons between 1993 and 1996 and has ranged between 1,767 to 4,370 tons since 2000 (CONAPESCA 2010). The estimated average annual value of the Gulf corvina catch from 1995 to 2007 in El Golfo de Santa Clara was $2,318,303 USD, constituting about 30% of the total value of all major fisheries in the town (Rodríguez-Quiroz et al. 2010).

The Gulf corvina is one of only a few fish species in Mexico that is regulated by an official management plan (DOF 2007), and concerns exist that the stock is overexploited and highly susceptible to a collapse (Musick et al. 2000; Rodríguez-Quiroz et al. 2010; Erisman et al. 2010a). Efforts to conserve the species and to create a sustainable fishery have been developed by government agencies in cooperation with stakeholders and regional non-governmental organizations (DOF 2005, 2007; Paredes et al. 2010). Similarly, important research on the biology and fishery of Gulf corvina has been completed (e.g., Román-Rodríguez 2000; Campoy and Román-Rodríguez 2002; Rowell et al. 2005; Erisman et al. 2012). Nevertheless, significant gaps exist related to the life history of Gulf corvina, which impede the completion of a comprehensive stock assessment necessary to regulate harvest. Such information is crucial for fisheries management, since life history traits represent key parameters used in stock assessments and comprise the core determinants of stock responses to both environmental and anthropogenic influences (King and McFarlane 2003; Shin et al. 2005).

In this study, we analyzed samples of Gulf corvina harvested by commercial fishers to characterize several life history parameters necessary for a stock assessment: population demographics, somatic and otolith growth, gonad development, and fecundity. Our specific objectives were to characterize population structure, determine growth rate by sex, estimate and validate age and size at maturity using gonadal histology and otolith annuli measurements, and describe variations in batch fecundity in relation to fish length and body mass.

## Materials and Methods

### *Collection of Specimens*

A total of 530 Gulf corvina were obtained from commercial fishers at El Golfo de Santa Clara and El Zanjón from March 2009 to May 2011. Four hundred large individuals with a mean total length (TL) of 716 mm were collected from the corvina fishery in March to April in 2009 and 2010. Given the size selectivity of the Gulf corvina gill net fishery (i.e., 14.6 cm mesh size selects for fish larger than 50 cm), an additional 130 small specimens (mean = 301 mm) were collected from the bycatch of two other commercial gill net fisheries: the commercial blue shrimp fishery (*Litopenaeus stylirostris*; 5–6 cm mesh; September–December 2009) and the bigeye croaker fishery (*Micropogonias megalops*; 6–9 cm mesh; April–May 2011) in order to obtain individuals representing younger age classes.

Meristic (e.g., 23–27 soft rays on second dorsal fin) and morphometric (e.g., presence of scaly sheath covering at least half the soft rays on the second dorsal fin) characteristics, known to be diagnostic of Gulf corvina, (Chao 2003; Robertson and Allen 2008) were used to confirm each specimen as *C. othonopterus* and to avoid inclusion of congeneric species known to inhabit the region (*C. parvipinnis*, *C. reticulatus*, and *C. xanthulus*) in the study. Total length (TL; 1 mm), total body weight (TW; 0.1 g), and sex were recorded for each fish. Otoliths were removed, dried, and stored, and gonads were removed, weighed (GW; 0.1 g), and preserved in a 10% formalin-seawater solution. Gonad-free weight (GFW) was calculated for each sample as follows:

$$GFW = TW - GW. \tag{1}$$

*Age, Growth, and Population Structure*

Sagittal otoliths (Figure 1) were removed from 492 fish (219 males and 273 females) using the method described by Craig et al. (1999) to analyze patterns related to age and growth. In the laboratory, the otolith weight (0.0001 g) and otolith radius (0.0001 mm) were measured. These data were used for age validations under the assumption that otolith weight and radius increase as fish grow and age and to verify precision of ageing methods (Cailliet et al. 1996). Otoliths were mounted on wood blocks with cyanoacrylate adhesive and a 0.5 mm dorsal-ventral cross-section was made through the focus using a Buehler-IsoMet double bladed low speed saw with diamond edged blades (Allen et al. 1995). Sections were polished using silicon carbide lapping paper and imaged while submerged in water in a black backed watch glass under a dissection scope. Each otolith was aged by two independent readers from digital images of otolith cross sections using ImageJ (Rasband 1997–2009) (Figure 1), as preliminary estimates using direct observations through the scope showed no evidence of distorting the band pattern and did not affect age estimates.

The limited seasonal availability of samples across multiple age classes prevented a marginal increment analysis to validate age determination. However, nonlinear regression was used to test for a relationship between age and otolith weight, age and otolith radius, and length and otolith radius to provide some validation for our methods of age determination and to allow for calculations of fish length directly from otolith measurements in future studies. Age and length were designated as the explanatory variables, whereas otolith weight and otolith radius were designated as the response variables. The age and length data were then fit to the following von Bertalanffy growth model (VBGM):

$$L_t = L_\infty [1\text{-}e^{-K(t-t_0)}] \tag{2}$$

where $L_t$ = length at age t, $L_\infty$ = predicted maximum length, K = growth coefficient, and $t_0$ = theoretical age at zero length. This equation was fitted for males and females separately, and an analysis of the residual sum of squares (ARSS) was used to compare VBGM's by sex (Ratkowsky 1983; Chen et al. 1992). An ANCOVA was used to test for differences in length at age by sex.

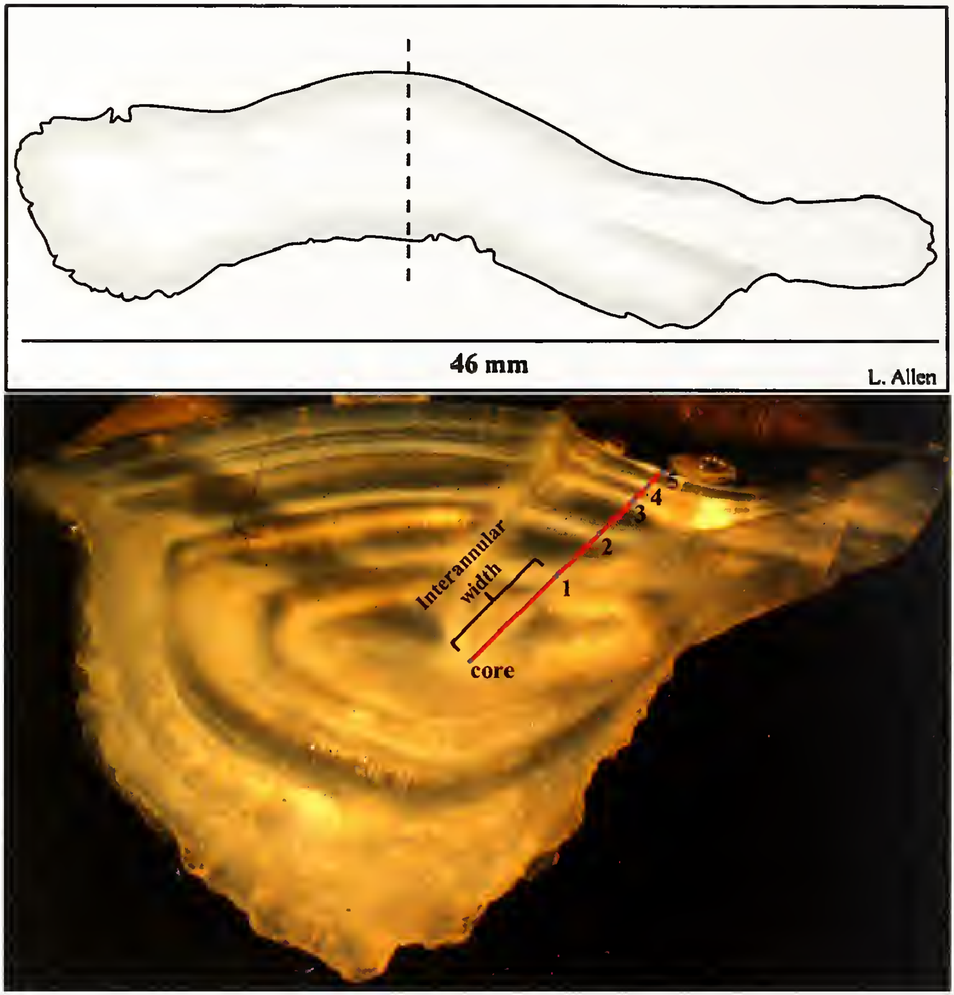


Fig. 1. Sagittal otoliths of Gulf corvina. (top) Drawing of a whole otolith from an average age 5 yr individual, where the dashed line represents where a section was taken through the focus. (bottom) Transverse section of a sagittal otolith from a 749 mm, age 5 yr individual, where numbers demarcate annuli, core is marked, and there is an example of where interannular width measurements were taken.

### *Reproductive Development and Sexual Maturity*

Standard histological techniques (Humason 1972) were used to perform microscopic examinations of gonad tissues, which provided a means to distinguish sexually mature individuals from immature individuals that had never spawned before. Briefly, preserved samples of gonad tissues were taken from the central portion of one lobe, embedded in paraffin, sectioned transversely to 5–6 micron thickness, and stained with Haemotoxylin and Eosin Y. Classification of gonadal development stages followed Brown-Peterson et al. (2007). Sexually mature females were classified as containing oocytes in early to advanced (i.e., hydrated) stages of vitellogenesis, whereas sexually mature males were identified by the presence of spermatozoa within spermatocysts, lobules, or fully developed sperm ducts. Diagnosis of sexual pattern followed criteria outlined for fishes by Sadovy and Shapiro (1987) and Sadovy De Mitcheson and Liu (2008). For both sexes, the mean size at sexual maturity ($L_{m50}$) was estimated by fitting a logistic function to the proportion ($P_m$) of mature fish in 20 mm ($L_S$) size categories:

$$P_m = \left(1 + e - r^{(L_{Smid} - L_{m50})}\right) - 1 \tag{3}$$

where $L_{Smid}$ is the midpoint of the $L_S$ class, $L_{m50}$ is the mean $L_S$ at sexual maturity and $r$ is a constant that increases in value with the steepness of the maturation schedule (Erisman et al. 2010b). The same procedure was used to estimate mean age at sexual maturity ($A_{m50}$) using the proportion of mature fish in each age class.

Variations in the widths between annular bands (i.e., interannular widths) in otoliths were analyzed as another estimate of age at sexual maturity to compare with traditional estimates derived from histological analyses of gonad tissues. Rationale for this method was based on two assumptions: (1) otolith growth is generally proportional to somatic growth (Pannella 1971); (2) the ontogenetic shift to sexual maturation coincides with slowed somatic growth as energy is reallocated from growth to reproduction (Charnov et al. 2001), which is reflected in otolith growth rates. Growth rates subsequent to the first year continue to decrease as fish grow at increasingly slower rates. We hypothesize that when sexual maturity is reached, otolith growth rates slow (i.e., smaller interannular widths) to a continuous rate. One hundred and twenty fish estimated to be 5 years of age or older were randomly selected, distances between annular bands (interannular width) were measured from digital images of otolith cross sections (Figure 1), and differences between adjacent interannular widths were compared via an ANOVA with a post-hoc Tukey test.

### *Batch Fecundity*

Batch fecundity (BF), or the number of oocytes released in a single spawning event, was estimated by the gravimetric hydrated oocyte method (Hunter et al. 1985). We analyzed 58 sexually mature females (2009, $n$ = 36 and 2010, $n$ = 22) collected from the corvina fishery with ovaries containing hydrated oocytes. Females with ovaries containing both hydrated oocytes and new (< 6 hr) post-ovulatory follicles (POF's) were excluded. The presence of new POF's indicates that spawning may have begun prior to sampling, which could lead to an underestimation of BF (Hunter and Macewicz 1985). Each ovary was first blotted dry with bibulous paper, and three subsamples were then removed from each the anterior, middle, and posterior region of ten ovaries (right or left was chosen at random) and weighed (0.0001g). Oocytes from each subsample were teased apart from follicles and tissue using forceps and a spatula, arranged in a single layer on a slide using water and a spatula, and imaged. Oocytes were categorized by developmental stage (Figure 2, Table 1) and enumerated using ImageJ (Rasband 1997–2009). Batch fecundity was extrapolated for each sub-sample:

$$BF = NOSS/SSW \times GW \tag{4}$$

where BF = batch fecundity, NOSS = number of oocytes in subsample, SSW = subsample weight (range = 0.0316 to 0.1420 g), and GW = gonad weight, and averaged for each region to verify that hydrated oocytes were distributed uniformly within the ovary. A one-way ANOVA was used to test for differences in BF among the three regions of the ovary. Notably, 25 ovary samples were weighed both before and after formalin preservation in order to estimate changes in gonad weight due to the preservation process and calculate a correction factor.

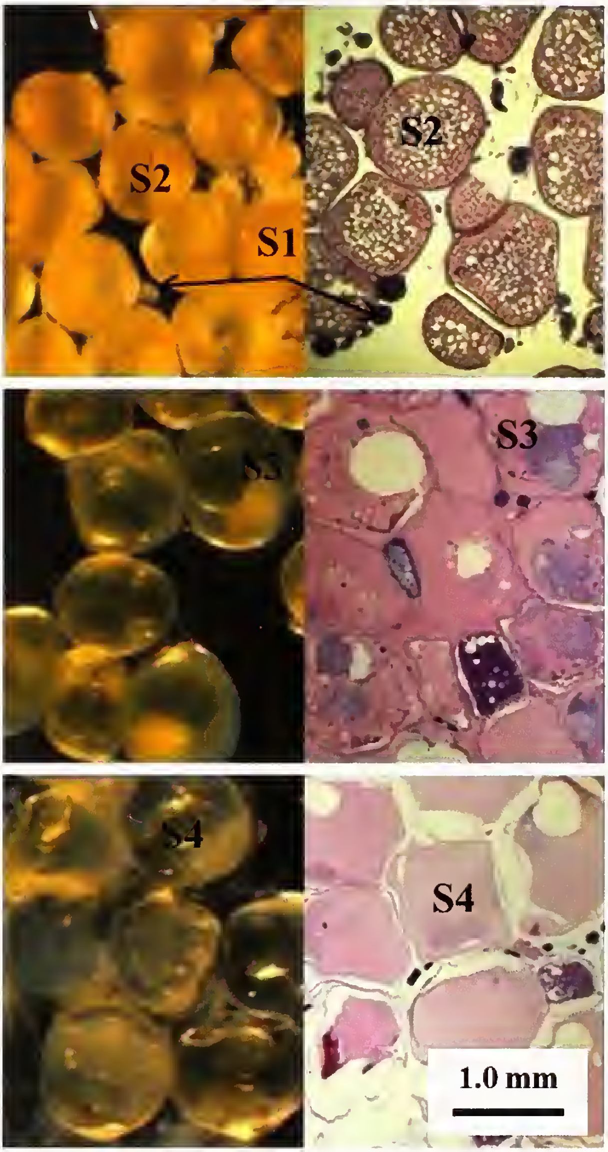


Fig. 2. Oocyte developmental stage classifications of Gulf corvina. (top) S1 = stage 1 and S2 = stage 2 under (left) dissection scope and (right) histological section. (middle) S3 = stage 3 under (left) dissection scope and (right) histological section. (bottom) S4 = stage 4 under (left) dissection scope and (right) histological section.

In order to verify the delineation of developmental stages, the vertical and horizontal diameter of up to 55 (mean = 28) oocytes per stage were measured (0.0001 mm) and averaged in 10 randomly chosen subsamples (Macewicz and Hunter 1994) using ImageJ (Rasband 1997–2009). A one-way ANOVA and post-hoc Scheffé test were used to compare oocyte diameters between stages and validate oocyte stage classification (Hunter et al. 1989). An ordinary least-squares regression was used to fit batch fecundity to GFW and length for each year and for the combined data (Hunter et al. 1985). Gonad-free weight was

Table 1. Description of developmental oocyte stages used to classify Gulf corvina oocytes in fecundity estimates and histological analyses.

| Stage | Description |
|---|---|
| 1 | Previtellogenic to early vitellogenesis, oocyte very small (<0.7 mm), uniformly opaque, usually found with stage 3 and 4 oocytes but not as part of same batch |
| 2 | Mid to late vitellogenesis, many small oil droplets present, resulting in granular appearance, mean diameter of 0.93 mm |
| 3 | Migratory nucleus, oil droplets have coalesced into single droplet, oocyte retains spherical shape, mean diameter of 1.21 mm |
| 4 | Hydrated, oocyte becomes irregular in shape and is uniformly translucent, mean diameter of 1.16 mm |

used, because hydrated oocytes significantly affect the TW of a female (Hunter et al. 1985). ANCOVA was used to compare BF at length and weight between years.

## Results

### *Age, Growth, and Population Structure*

Fish ranged in length from 145 to 1013 mm (mean = 605±190 mm) and age from 1 to 8 yrs (mean = 4.5±1.6 yrs) (Figure 3). Males ranged in length (± SD) from 255 to 895 mm (mean = 636.1±145 mm) and age from 2 to 8 yrs (mean = 4.7±1.3 mm), whereas females ranged in length from 215 to 1013 mm (mean = 642±168 mm) and age from 2 to 8 yrs (mean =4.9 ±1.4 mm). No significant relationship was found between either mean length (ANOVA, df = 1, F-ratio = 0.367, p = 0.545) or mean age (ANOVA, df = 1, F-ratio = 1.610, p = 0.205) of males and females.

A significant relationship was found between otolith radius and age (n = 488, $p < 0.01$), otolith weight and age (n = 457, $p < 0.01$), and between otolith radius and length (n = 488, $p < 0.01$) (Figure 4). The VBGM equation was estimated for all samples ($L_t = 1006[1\text{-}e^{-0.255(t-0.616)}]$, $R^2 = 0.84$; Figure 5), for males ($L_t = 913[1\text{-}e^{-0.313(t-0.644)}]$, $R^2 = 0.83$), and females ($L_t = 1086[1\text{-}e^{-0.222(t-0.617)}]$, $R^2 = 0.86$). The ARSS indicated that VBGM's did not significantly differ between sexes, ($F\text{-ratio}_{male} = 1.03$, $p_{male} = 0.40$, $F\text{-ratio}_{female} = 1.11$, $p_{female} = 0.16$). The ANCOVA interaction term was not significant (df = 436, F-ratio = 0.051, p = 0.822) and the subsequent analysis without the interaction term indicated that age was not significantly correlated to sex (df = 437, F-ratio = 3.737, p = 0.054) but was correlated to length (df = 437, F-ratio = 1,190.720, $p < 0.001$). Further examination of the residuals related to the age-at-length data showed a distinct pattern, such that samples acquired from the fishery were much larger at age than bycatch samples (Figure 5).

### *Reproductive Development and Sexual Maturity*

Histological analyses of gonadal tissues revealed no evidence of morphological or functional hermaphroditism in Gulf corvina, indicating that the species follows a gonochoric sexual pattern (i.e., separate sexes or dioecy). Specifically, All gonadal samples consisted of either male or female structures only, and bisexual tissue (i.e., containing both male and female tissues) were not present. The minimum size and age at sexual maturity were 277 mm and 2 yrs for females and 255 mm and 2 yrs for males. The mean size ($L_{m50}$) and age ($A_{m50}$) at sexual maturity was 294.7 mm and 2.1 yrs for females and 267.5 mm and 2.0 yrs for males (Figure 6). Analyses of differences between adjacent interannular widths

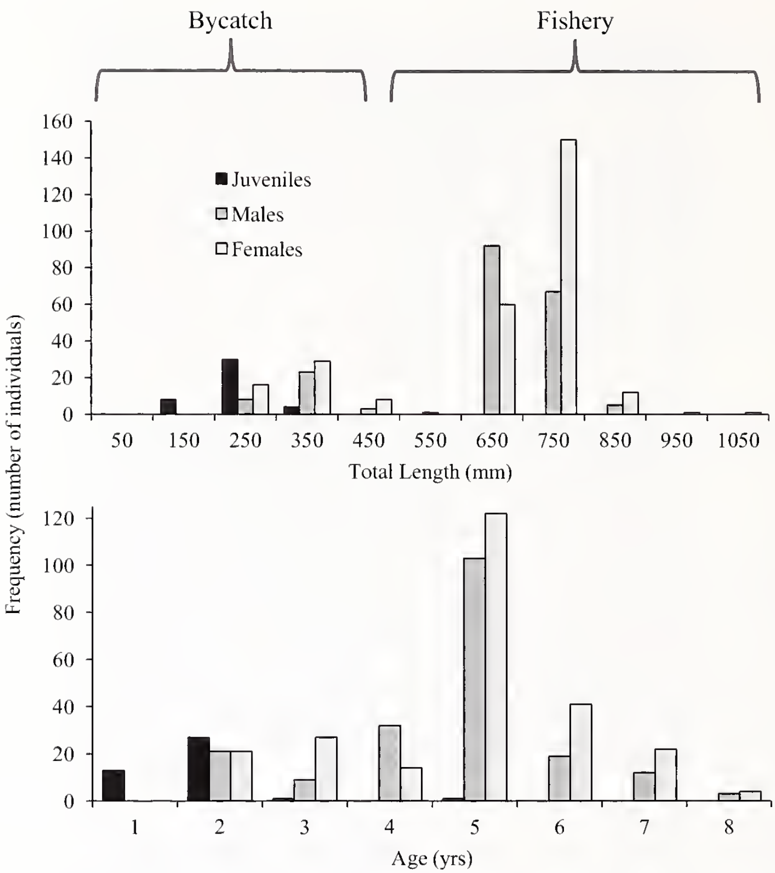


Fig. 3. Size (top) and age (bottom) distribution of Gulf corvina sampled from the targeted Gulf corvina fishery and as bycatch from other commercial fisheries from 2009 to 2011.

in otoliths indicated that at the onset of maturity adjacent interannular widths were significantly different from one another (ANOVA, $n = 527$, $df = 6, 520$, F-ratio $= 86.691$, $p < 0.001$) (Figure 7). A post-hoc Tukey test indicated that growth rates slowed to a constant rate after age two, as indicated by the comparison of the year 3 - year 4 difference to the year 4 - year 5 difference ($p = 0.859$). The same results were found when males and females were analyzed separately ($p = 0.936$ and $p = 0.978$, respectively).

### *Batch Fecundity*

The smallest mature female found with hydrated oocytes was 4 yrs of age and 665 mm long. Batch fecundity estimates among the three ovarian regions (anterior, middle, and posterior) were not significantly different (ANOVA, $n = 30$, $df = 18$, F-ratio $= 0.3384$, $p = 0.718$). Therefore, the distribution of oocyte stages within an ovary were considered to be homogenous, and subsamples thereafter were taken from any region of an ovary. Mean oocyte diameters differed significantly between stages, ($n = 762$, $df = 758$, F-ratio $= 1606.316$, $p < 0.001$), and a post-hoc Scheffé test indicated that all stages were significantly different from one another ($p < 0.001$) except for stage 3 and 4 oocytes ($p = 0.053$) (Figure 8). Stage 1 oocytes had a mean diameter of $0.4377 \pm 0.0085$ mm. Stage 2 oocytes had a mean diameter of $0.9300 \pm 0.0095$ mm. Stage 3 oocytes had a mean

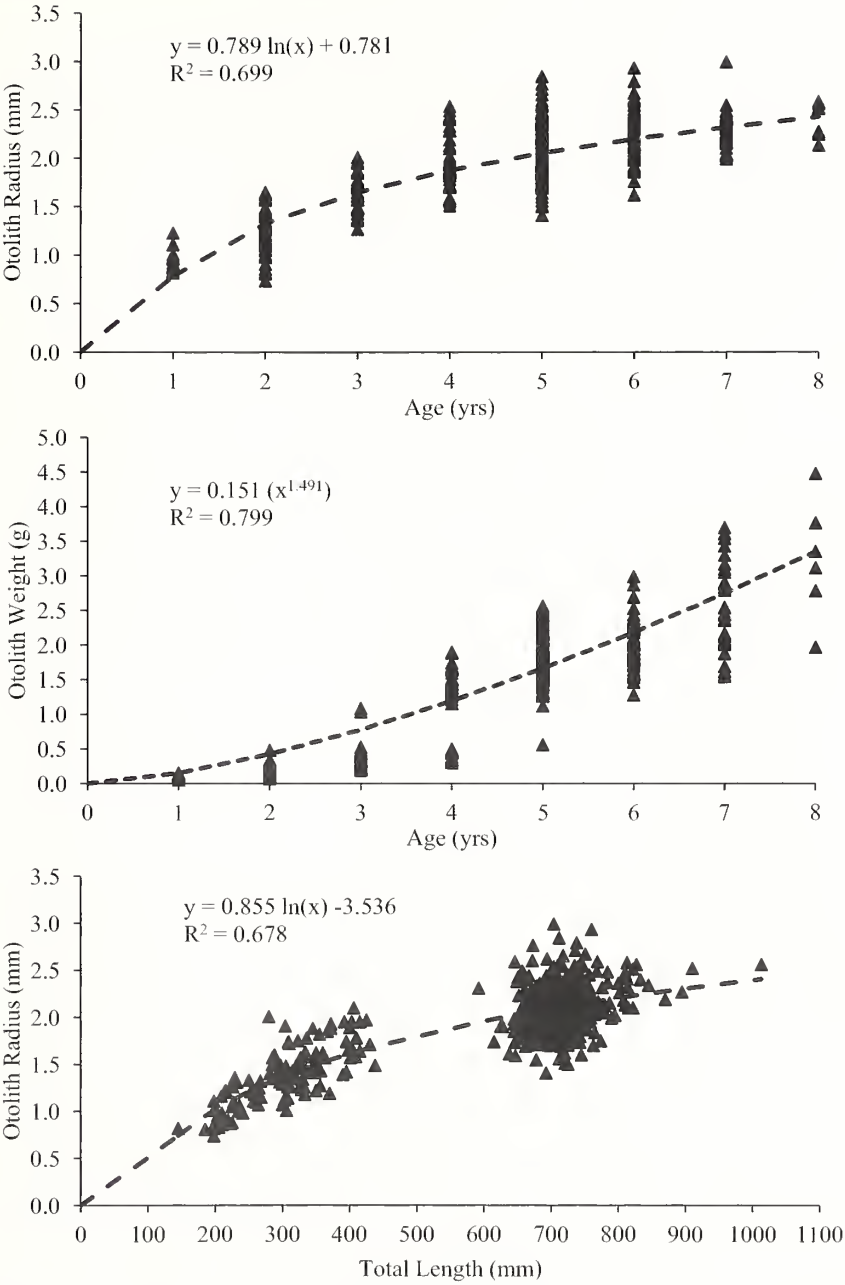


Fig. 4. Plot of nonlinear regressions of: (top) otolith radius and age ($n = 488$, $p < 0.01$); (middle) otolith weight and age ($n = 457$, $p < 0.01$); and (bottom) otolith radius and TL ($n = 488$, $p < 0.01$). Data points represent observed data while dashed lines indicate predicted values.

diameter of $1.205 \pm 0.014$ mm, and stage 4 oocytes had a mean diameter of $1.162 \pm 0.007$ mm. Stages 3 and 4 were both counted for estimates of batch fecundity.

Estimates of BF ranged from 240,394 to 1,219,342 eggs with a mean of 684,293 eggs per spawn. In 2009 samples, a significant relationship was found between BF and both length

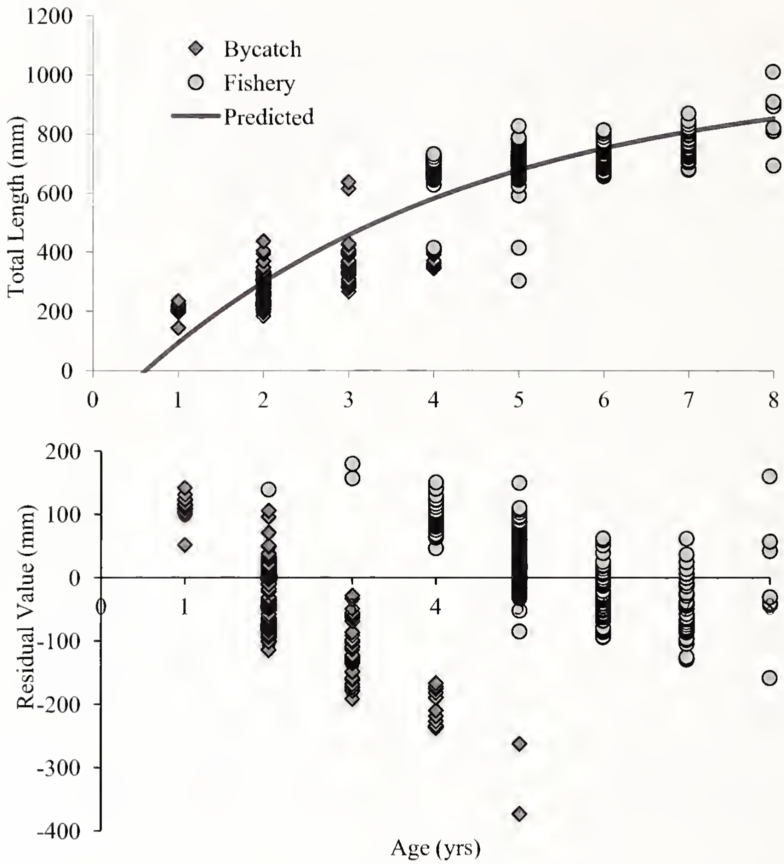


Fig. 5. (top) Age at length data by source and the von Bertalanffy growth model calculated from 492 samples of Gulf corvina. (bottom) Plot of residual values by source for length at age (observed-predicted) data included in the growth model.

(F-ratio = 26.354, $p < 0.001$) and GFW (F-ratio 22.812, $p < 0.001$) (Figure 9). However, in 2010, BF was not significantly related to TL (F-ratio = 1.333 p = 0.262) or GFW (F-ratio = 3.359, p = 0.082). For the combined 2009 and 2010 data BF was again significantly dependent on both length (F-ratio = 19.044, $p < 0.001$) and GFW (F-ratio = 17.102, $p < 0.001$). The interaction term of the ANCOVA comparing BF and length between years was not significant (df = 54, F-ratio = 2.418, p = 0.126) but the subsequent analysis without the interaction term indicated that BF was significantly correlated to year (df = 55, F-ratio = 34.339, $p < 0.001$) and length (df = 55, F-ratio = 22.222, $p < 0.001$). The interaction term of the ANCOVA comparing BF and GFW between years was not significant (df = 54, F-ratio = 2.668, p = 0.108) but the subsequent analysis without the interaction term indicated that BF was significantly correlated to year (df = 55, F-ratio = 36.538, $p < 0.001$) and GFW (df = 55, F-ratio = 22.075, $p < 0.001$).

## Discussion

The collective results of this study indicate that the Gulf corvina is a fast growing sciaenid fish that attains sexual maturity at a relatively small size (200 mm) and young age (2 yrs). With respect to reproductive pattern, the species is best described as a

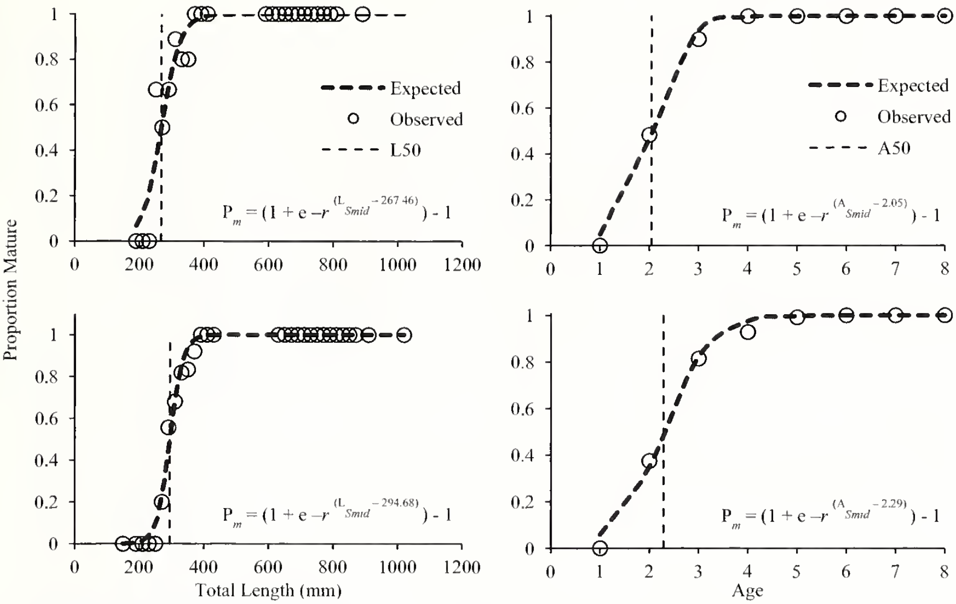


Fig. 6. Cumulative length (left) and age (right) frequency plots for male (top) and female (bottom) Gulf corvina sampled from the commercial harvest between 2009 and 2011.

gonochoric, multiple batch spawner (asynchronous oocyte development) with indeterminate annual fecundity.

Results from the growth model indicated that growth rates in males and females were similar. However, the asymptotic length ($L_\infty$) predicted for females (1086 mm) was higher than that for males (913 mm). Of fish sampled, about 75% were greater than 600 mm and over 65% were age 5 or older. These results are likely a product of the narrow size range (c. 650–1013 mm) of fish captured by the commercial gill net fishery, which targets adult

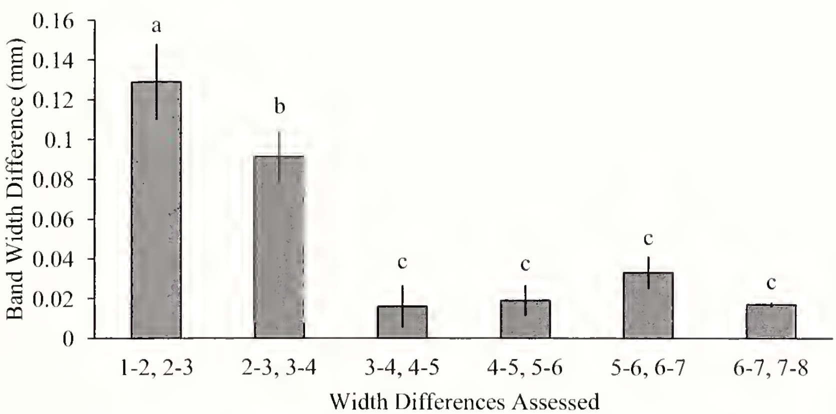


Fig. 7. Differences in adjacent interannular widths (± 1 SE; n = 527, df = 6, 520, F-ratio = 86.691, $p < 0.001$) in Gulf corvina; growth rate decreased at the end of the second year, indicating the onset of maturity.

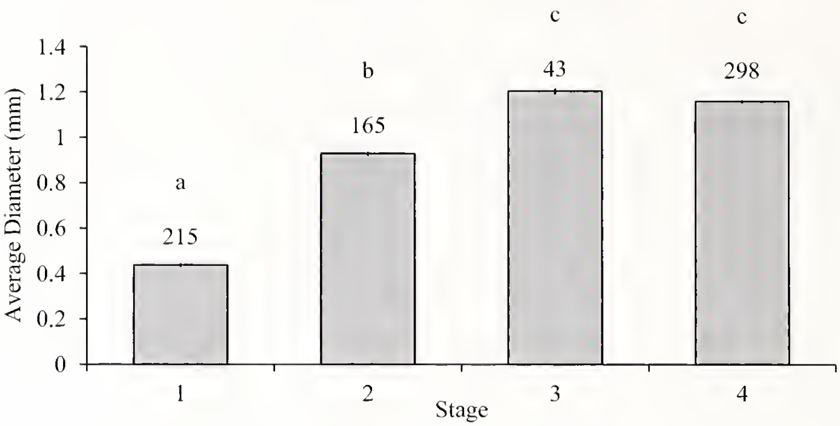


Fig. 8. Mean diameter (± SE) of the four developmental stages of Gulf corvina oocytes; data labels indicate sample sizes. Due to similarities in oocyte diameter, Stage 3 and 4 oocytes were combined to estimate batch fecundity.

corvina during their spawning season. Alternatively, it may be that females do reach a larger maximum length, which has been seen in congeners (e.g., *C. nebulosus*; Ihde 2000).

The overall growth pattern of Gulf corvina is characterized by rapid early life growth that slows a couple years after the onset of sexual maturity. A reduction in population size is commonly accompanied by a phenotypic response of earlier maturation and faster growth rate (Hutchings 2005; Policansky 1993). Associated benefits of early maturation include increased likelihood of reproducing before harvest and greater fitness (i.e., more chances to spawn; Hutchings and Baum 2005). However, earlier maturity may also result in reduced fecundity, decreased post-spawning survival, potentially less fit offspring, and increased probability of negative population growth (Hutchings and Baum 2005; Berkeley et al. 2004).

The large size that Gulf corvina reach in such a short time is similar to other sciaenids that co-occur in the Gulf of California (*Cynoscion xanthulus*, Riedel et al. 2007; *Totoaba macdonaldi*, Román-Rodríguez and Hammann 1997), with rapid growth early in life, reaching an average length of 279 mm by age 2 and 359 mm by age 3 (Figure 5). This is likely a result of the high productivity that characterizes the northern Gulf of California (Brusca 2010), since fish production is largely dependent on primary production (Ryther 1969; Dailey et al. 1993) and food availability tends to be positively correlated to increased growth rates of fishes (Weatherley 1972). The Gulf has extraordinarily high levels of primary productivity, due mainly to upwelling, tidal mixing, and thermohaline circulation (Alvarez-Borrego 2010; Zeitzschel 1969), which in-turn supports some of the world's largest sardine, anchovy, and shrimp populations and fisheries (Alvarez-Borrego 2010), all of which are food for Gulf corvina (Román-Rodríguez 2000). Similarly, positive correlations between growth rate and water temperature are common in sciaenids and many other marine fishes (Lankford and Targett 1994; Brander 1995; Williams et al. 2007), and sea surface temperatures in the upper Gulf of California average 24° C and exceed 32° C during the summer months.

Our initial estimates of the growth parameter (k) of 0.255/yr appeared relatively low for a species with a fast growth rate and a maximum age of 8 yrs, although similar growth rates have been reported in populations of *Cynoscion* species (Shepherd and Grimes 1983; Riedel et al. 2007; Colura et al. 1994). In addition, we found clear differences in the

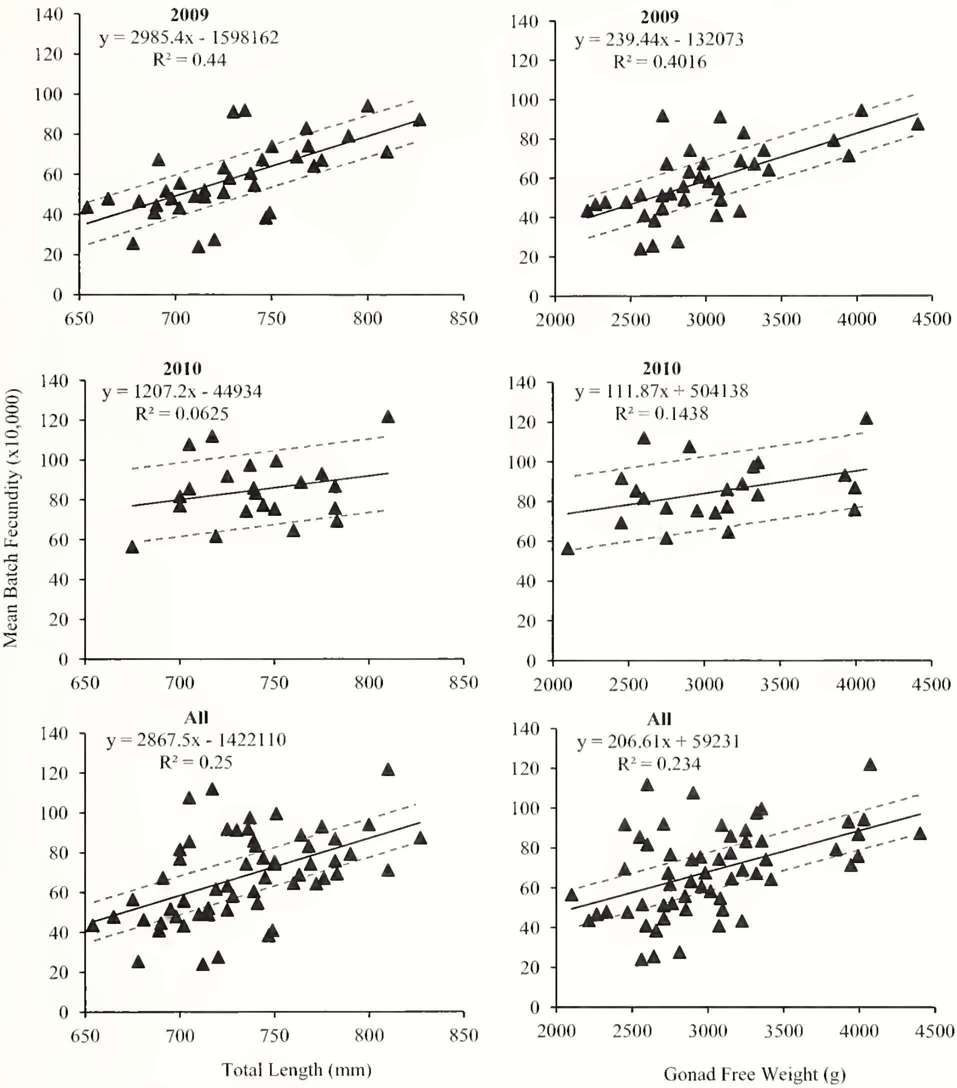


Fig. 9. (left) Ordinary least-squares regressions of batch fecundity and total length for 2009, 2010, and grouped for Gulf corvina. (right) Ordinary least-squares regressions of batch fecundity and gonad-free body weight for 2009, 2010, and grouped for Gulf corvina. For each graph, the solid black line represents the line of best fit, and the red dashed lines indicate 95% confidence intervals.

pattern of residuals between the fishery and bycatch data, which indicated that fish sampled from the targeted corvina fishery tended to be larger at age than those collected as bycatch from other fisheries. These dissimilarities may reflect that these samples were collected from two subpopulations of Gulf corvina with different growth strategies. For example, the targeted Gulf corvina fishery operates in the estuaries of the Colorado River Delta, whereas the shrimp fishery that provided most of our smaller samples operates mainly at offshore locations and habitats 50 km or more to the south or southeast (Rodriguez-Quiroz et al. 2010). Variations in growth rate were reported among populations of the weakfish (*Cynoscion regalis*) in the Middle Atlantic Bight and were attributed to varying allocations of energy to somatic growth in relation to environmental and migratory requirements and the availability of food items in each habitat (Shephard and Grimes 1983). Alternatively, such differences may simply be a product of the size selectivity of each fishery. Shrimp and croaker fisheries use 6.5–8.5 cm mesh gill nets that are deployed as drift nets and tend to land corvina less than 50 cm long. Conversely, the Gulf corvina fishery uses 14.6 cm mesh gill nets deployed in a similar fashion to purse seines (fish are encircled; see Erisman et al. 2012), and selectively removes fishes 50 cm or greater in length. Under this scenario, fish harvested by the corvina fishery may be larger than average size-at-age, whereas those landed as bycatch may be average or below average in size.

Regardless of the cause, the two sources of samples included in the age and growth study produced a VBGM with significant uncertainty, and one that may not accurately reflect the average growth rate of the species or incorporate possible variations in growth rate by location. It is important to produce unbiased life history parameters that accurately reflect the stock or population, as these feed directly into fisheries assessments (e.g., estimates of natural mortality and exploitation rates; virtual population models, calculations of sustainable yield). Even subtle changes to these life history parameters may result in significant changes in model outputs and conclusions (Chen et al. 1992; Van Den Avyle and Hayward 1999), which in turn, can result in highly different perceptions among resource managers with respect to the health or condition of the stock and changes in harvest regulations. The systematic collection of representative length samples should be implemented by a scientifically designed, fishery-independent survey that utilizes nets with a variety of mesh sizes during several periods of the year and at several locations. Results from this type of survey would provide a better representation of the overall length and age structure of the population (Van Den Avyle and Hayward 1999).

Histological analyses of male and female gonad tissues indicate that Gulf corvina reaches sexual maturity at approximately 2 yrs of age. In addition, differences in adjacent otolith growth increment widths indicate that after age two, otolith growth slows significantly, and all subsequent ages are characterized by similar slow growth rates. Tight correlation between fish size and otolith size (radius, length or weight) suggest that otolith growth rates are an appropriate proxy for estimating fish growth rates; however these relationships are nonlinear and length backcalculations must account for this (Campana and Jones 1992; Pannella 1971; Secor and Dean 1989). Measurements of otolith length, radius or width are often used in fisheries as corollaries to fish size and to back calculate fish age. While in some more fine resolution studies, using these proxies may not be appropriate, as demonstrated by Mosegaard et al. (1988) in 8–108 day experiments; however, in a lower resolution context (years vs. days or months) otolith growth appears to scale with somatic growth sufficiently to make estimates. In this study we find that Gulf corvina otolith size and weight are correlated to fish size, and otolith growth (radius) is highly representative of fish growth curves. The onset of maturity as seen in the slowing of otolith growth rates lagged that of histological analyses by a couple years. This suggests that for fish with life history characteristics similar to Gulf corvina, analyzing otoliths growth rates may provide additional archival information on age at maturity.

Fish ranging from 650 to 750 mm and 5 to 6 yrs of age were the most common in the fishery, with few fish larger than 800 mm or 8 yrs of age captured by the gillnet fishery. It is uncertain whether Gulf corvina reach lengths and ages greater than those harvested by the fishery or whether the fishery harvests the largest individuals of this species. Thus, females are harvested after an average of three years of spawning (age 5 yrs) and at only ~50% of their potential length and therefore, with much lower reproductive output. A larger size enables females to produce more oocytes because fecundity is correlated to body size (e.g., a 1400 mm female Gulf corvina could produce over 2,500,000 eggs per batch). Additionally, older females have been shown to produce higher quality oocytes and larvae that are more resistant to starvation and grow faster than those produced by younger fish (Berkeley et al. 2004).

The distribution of oocyte diameters and the presence of several developmental stages within samples indicate that Gulf corvina is a multiple batch spawner (Calliet et al. 1996; Macchi 1998). Multiple stages were present in all samples with 57 of 58 samples consisting mostly (>75%) of oocytes of one developmental stage. The presence of multiple developmental stages within a single ovary indicates that these are indeterminate spawners (Hunter et al. 1985). Also, some females captured in the morning (i.e., before spawning), showed clear histological evidence of daily spawning via the presence of both recent (<12 hr) POF's and newly hydrating oocytes. Therefore, total annual fecundity is not fixed at the beginning of the reproductive season, and immature oocytes continually mature and are spawned throughout the reproductive season (Hunter et al. 1992). In order to estimate total annual fecundity for multiple batch spawning fishes, information on both the number of times an individual spawns in a reproductive season and the percent of oocytes that are resorbed are necessary (Hunter et al. 1985). For this, a tagging study is needed to determine the number of times a female returns to the estuary to spawn in a single year.

Batch fecundity estimates ranged from 240,394 to 1,219,342 eggs with a mean of 684,293 eggs per spawn. Román-Rodríguez (2000) estimated a similar BF range of 250,000 to 808,000 eggs per batch for *C. othonopterus*. However, only nine fish were sampled in the previous study, which may have resulted in a narrower range. Our fecundity estimates differed significantly between years, with 2010 having a significantly greater fecundity. This could be due to the El Niño event that occurred from May 2009 through April 2010. During and after El Nino events significant increases in zooplankton biomass have been documented in the Gulf of California (Jiménez-Pérez and Lara-Lara 1988; Lavaniegos-Espejo and Lara-Lara 1990; Sánchez-Velaso et al. 2000). Augmented zooplankton biomass would increase the productivity of the area and likely result in a greater abundance of food for *C. othonopterus*, which would provide more energy for reproduction. Fifty percent of females mature at just less than 300 mm but the fishery targets fish greater than 600 mm. Therefore, a complete range of mature females was not used to estimate BF and fecundity is not known for smaller mature females. Fishery-independent sampling of smaller samples is needed in order to understand the correlation between BF and length at the onset of maturity.

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# Recent Mass Mortality of *Strongylocentrotus purpuratus* (Echinodermata: Echinoidea) at Malibu and a Review of Purple Sea Urchin Kills Elsewhere in California

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*Abstract.*—Mass mortalities of intertidal purple sea urchins, *Strongylocentrotus purpuratus* occurred at Malibu Lagoon State Beach, California, in 2010 and 2011. Both events followed the first heavy rain of the season, and coincided with the illegal breaching of a coastal lagoon. Osmotic shock from low-salinity lagoon water, the likely cause of death, may have acted jointly with stress from subaerial exposure during especially low tides. Massive die-offs of purple sea urchins have occurred at other localities, usually after natural conditions created lethal levels of osmotic or thermal stress, or because of human efforts to harvest or to eradicate the species. Annually recurring lagoon ruptures at Malibu, combined with predation by western gulls, can have a profound impact on the local population of *S. purpuratus* and on intertidal ecology.

## Introduction

At sunrise on October 9, 2010, in Malibu, California, dignitaries inaugurating Surfrider Beach (Malibu Lagoon State Beach) as the first World Surfing Reserve unexpectedly encountered more than 10,000 freshly killed *Strongylocentrotus purpuratus* (Stimpson, 1857) stranded at the tideline (Ralston, pers. comm.). The cause of their death was still undetermined a year later, after another, less severe mass mortality of sea urchins occurred at the same locality. What killed the sea urchins at Malibu in these two successive years, and what might cause mass mortalities of *S. purpuratus* elsewhere in California?

*Strongylocentrotus purpuratus* has a broad range of tolerance for thermal, osmotic, and anaerobic stress as evidenced by its extensive distribution from Shelikof Island, Alaska to Isla Cedros, Mexico, and from the mid-intertidal to 30 m (exceptionally to 161 m) depths (Sagarin and Gaines, 2002; Lambert and Austin, 2007; Lester et al., 2007; Pearse and Mooi, 2007; Ebert, 2010, and pers. comm.). Yet its habitat sometimes imposes stresses that exceed the species' tolerance, resulting in die-offs of purple sea urchins. Past events of this sort generally have been attributed to radical alterations in salinity or temperature, or disease. Since the same factors could have been responsible for the mass mortality at Malibu Lagoon, I discuss the specific tolerances and vulnerabilities of *S. purpuratus*, and review the causes of prior massive kills. Based on that information, I offer a hypothesis regarding the events at Malibu.

Individuals of *S. purpuratus* are weakened or killed by exposure to extreme temperatures or salinities (Schroeter, 1978). They cannot survive for more than 3 h in seawater that is ≤ 60% (~20‰) or ≥ 120% (~39‰) in concentration, and they die after 4 h, if exposed to temperatures more extreme than 1.9 to 23.5 °C (Farmanfarmaian and Giese, 1963; Giese and Farmanfarmaian, 1963; Burnett et al., 2002); vulnerability to elevated temperatures may shape the southern range limit of *S. purpuratus* (Ebert, 2010). Like other echinoids that have been tested, purple sea urchins probably can tolerate, for hours or days, mild to moderate hypoxia ($>$ 0.5 ml DO $L^{-1}$) or elevated levels of hydrogen sulfide, but cannot survive severe hypoxia or anoxia ($<$ 0.5 ml DO $L^{-1}$) (Thompson et al., 1991; Riedl et al., 2012). They withstand hypoxic conditions by curbing their oxygen consumption and exploiting anaerobic respiration, and individuals that are emersed can absorb oxygen from the air (Johansen and Vadas, 1967; Burnett et al., 2002).

Although *S. purpuratus* tenaciously grips the substrate to avoid dislodgement (Denny et al., 1985; Denny and Gaylord, 1996), large numbers of individuals have been torn from rocky reefs by wave surge under particularly harsh winter-storm conditions. Abrupt changes in salinity during storms have also proved lethal to *S. purpuratus*. Ebeling et al. (1985) reported that an extensive "urchin front" off Santa Barbara, California, was decimated by surge during a violent storm in 1983. A severe storm in 1938 ruptured a river levee, releasing a massive volume of fresh water into Newport Bay, California, killing animals as far as 3.2 km from the mouth of the bay (MacGinitie, 1939:685). Purple sea urchins were "among those animals which were most obviously devastated by the storm… hundreds of the tests were washed up on the beach or fell to the bottom between the rocks where they were visible at low tides as whitish patches. Even at the lowest tide not a single sea urchin could be seen on the rocks." Despite the massive fatalities, the population nearly recovered within a year. A flash flood in 1977, which deluged the rocky shore at Corona del Mar, California, killed 90.5% of *S. purpuratus* (a decrease of 60 per $m^2$) in the mid- and lower intertidal of the affected area (Littler and Littler, 1987). Windrows of urchins were found cast onto the beach two days after the storm, at which time salinity measured a record low 23.5‰. Sousa (1979) found a reduced density of *S. purpuratus* and crabs in an intertidal boulder field near Santa Barbara, California, where freshwater runoff from a seasonal creek reached the intertidal. In 1973, at the same locality, Schroeter (pers. comm.) observed that "a single large rainstorm caused freshwater discharge that ponded in the lower portion of the boulder field creating a purple sea urchin bouillabaisse sans fish and near complete mortality. All of the urchins that were at a slightly higher elevation (~0.1–0.2 feet higher) appeared to be unaffected." A similar rain related die-off was thought to have occurred at Sunset Bay, Oregon, where slow recovery of the population of *S. purpuratus* was anticipated (Ebert and Grupe, 2008).

Thermal stress has also caused its share of mass mortalities of *S. purpuratus*. Hedgpeth and Gonor (1969:94) recorded internal body temperatures of *S. purpuratus* "…of 26° C…in beds of urchins exposed to the sun, and maximums of 27° C. to 30° C. in some urchins. Successive days of this type of heating at low tide for periods of three to five hours led to a heat kill at the study site and other areas along the central Oregon coast, with many urchins dying in each place." They also noted that similar die-offs of *S. purpuratus* had been observed at other localities in Oregon for years. A mass mortality event coincident with water temperatures $>$ 24 °C decimated *S. purpuratus* at False Point, La Jolla, California, in the summer of 1971. Sea urchins did not reappear there until the winter of 1973, following the successful settlement of juveniles (Ebert, 1983). In another instance, several hundred dead *S. purpuratus* were found after a series of minus tides at Newport, California, and the mortality event was tentatively attributed to 24 to 27 °C water temperatures (So, 2006).*

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* So, H. 2006. Officials suspect weather played a role in mass sea urchin deaths. Los Angeles Times. August 3, 2006:B.3. Available from http://articles.latimes.com/2006/aug/03/local/me-seaurchin3 via the Internet. Accessed 2 November, 2012.

In addition, disease outbreaks have been reported among *S. purpuratus* in California, and increasingly frequently among other echinoid species, during the last several decades (Ward and Lafferty, 2004). In the 1970s, infected *Strongylocentrotus franciscanus* (A. Agassiz, 1863) were first found near San Diego, and afterwards at localities off central California (Johnson, 1971; Pearse et al., 1977). Affected animals could not grip the substrate, their ossicles deteriorated and spines detached, and they died within several months. However, the affected populations recovered (Pearse et al., 1977; Pearse and Hines, 1987). In the same region, Gilles and Pearse (1986) found a low incidence of diseased *S. purpuratus*. Lester et al. (2007) documented two different pathologies of infected *S. purpuratus*, presumed to represent distinct diseases, in an intertidal survey spanning central California to Baja California, Mexico in 2004. They found that disease prevalence was positively correlated with temperature but not with population density, leading them to suggest that "If thermal stress does increase host susceptibility, disease in *Strongylocentrotus* species could increase with global warming and increased human impacts along the coast" (Lester et al., 2007:322). Yet another source of mortality, thus far manifested by a single, massive die-off of *S.purpuratus* and less drastic damage to *S. franciscanus*, appears to have been produced by an unidentified toxin from a harmful algal bloom in northern California during 2011 (Jurgens, pers. comm.).

With respect to the mass mortalities at Malibu State Beach, California, in 2010 and 2011, I propose for reasons discussed herein that the sea urchins were killed by fresh water released through a breach in a rain-swollen coastal lagoon, which drastically lowered salinity in the intertidal zone. I also suggest that damage from osmotic stress was probably aggravated by subaerial exposure of the animals during low tides, and possibly by their burial under transported sediment.

## Materials and Methods

### *Study Site*

At present, Malibu Lagoon is an ecologically dysfunctional seasonal estuary. Roughly 0.1 $km^2$ in area, it channels water from a surrounding 284 $km^2$ drainage basin into Santa Monica Bay (Figure 1A). The lagoon is the remnant of a previously much larger estuary and wetland that, after 1900, was drastically reduced in size by repurposing natural habitat for ranching and urban development, and by constructing a dam, sewage treatment plant, railroad, and highway, all of which disrupted the estuarine lagoon system and the ecology of its biota (Ambrose and Orme, 2000). As a result "…the Malibu estuarine lagoon is no longer a natural system because, although stream floods and storm waves may sometimes reassert dominance there are now so many constraints imposed by human activity" (Ambrose and Orme, 2000:2–4; Schwarz and Orme, 2005).

The lagoon changes seasonally from closed lagoon to estuary. Typically during the summer and fall, drifting sediment forms a sand bar that blocks the estuary's mouth, allowing fresh water from the City of Malibu and Malibu Creek to accumulate in the embayment (Ambrose and Orme, 2000). Floods from winter storms rupture the sand bar, flushing brackish water, sediment, biota, nutrients, and human and animal waste from the lagoon through the breach (Ambrose and Orme, 2000; Schwarz and Orme, 2005). Usually throughout the spring, an opening in the sand bar is maintained by outflow from Malibu Creek, and by tidal flow that can move approximately 100,000 $m^3$ of water through the mouth in single tidal cycles (Ambrose and Orme, 2000). The volume may double during extreme weather conditions when the lagoon fills to the highest level (Ambrose and Orme, 2000; Schwarz and Orme, 2005). Seaward of the sand bar there is a

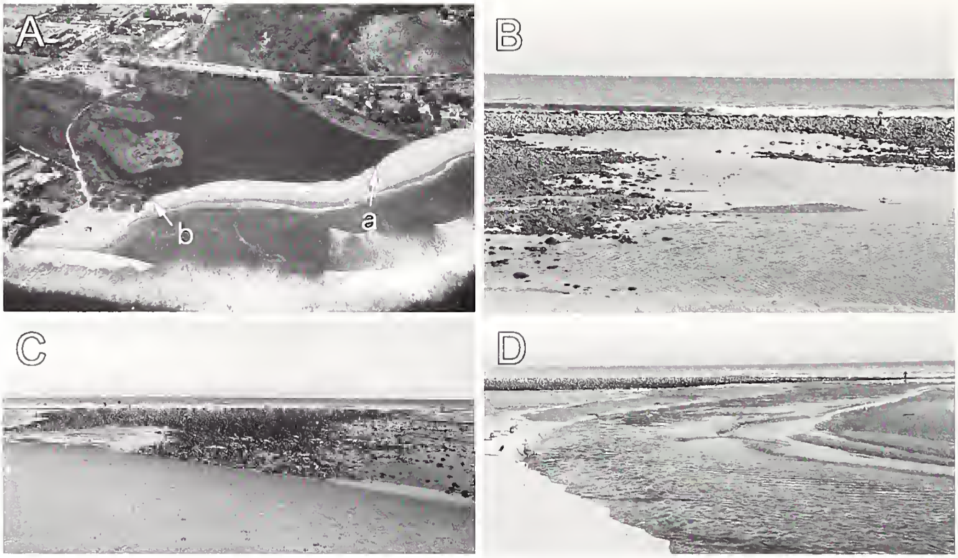


Fig. 1. Malibu Lagoon State Park and its contiguous intertidal reefs. A) Aerial view of Malibu Lagoon at high tide on September 5, 2008. Arrows indicate approximate positions of breaches through the sandbar in 2010 (a), and 2011 (b). B) Portion of Basin Reef at low tide on October 27, 2011, showing water pooled in the reef's shallow central depression, and Santa Monica Bay in the distance. C) Bird Reef in its entirety at low tide on October 15, 2011. Sediment near the cobbles was transported and redistributed after the breach on October 6, 2011. D) View of Bird Reef on October 27, 2011, showing remnants of a channel through the sandbar, which was excavated by outflow through the breach. (Photo A, courtesy H. Burdick, Los Angeles Waterkeeper).

wave-washed shelf composed of cobbles and sediment, part of which is exposed subaerially at low tides. Algal cover on the shelf is quite sparse compared to the dense growth of kelp and other macroalgae in the subtidal zone.

Beginning in 1984, the California Department of Parks and Recreation (DPR) mechanically breached the lagoon when water levels were high, in order to avert septic system failures in the adjacent Malibu Colony and Civic Center (Ambrose and Orme, 2000). The agency deliberately opened the sand bar near the western side of the lagoon in an effort to facilitate pedestrian access to the beach and to avoid spoiling the surf break. Breaching the bar at the lower semidiurnal tide maximized the grade between lagoon and ocean, maximized the amount of sediment flushed out, and increased the period that the lagoon remained open. DPR suspended the practice in 1997, when it was deemed a potential threat to tidewater gobies (*Eucyclogobius newberryi* Girard, 1854) that had been reintroduced in the lagoon (Swift et al., 1993; Ambrose and Orme, 2000). Since that year, despite a legal prohibition, the western end of the sandbar has repeatedly been breached, usually but not always when a natural breach was imminent (Pfeifer, pers. comm.), by individuals "concerned with lagoon eutrophication and the quality of the surfing environment" (Schwarz and Orme, 2005:97).

## *Methods*

Supratidal and intertidal zones at Malibu Lagoon State Beach were surveyed to investigate the origin of sea urchin kills and to gauge the impact of lagoon breaches. Information was gathered opportunistically, since mortality events were unanticipated.

By necessity, features of the biota and habitat preceding the events were determined based on the observations of local observers and from recordings made by automated monitoring equipment. After the events on 2010 and 2011, the effects and magnitudes of the kills were assessed by counting the numbers of freshly dead sea urchins deposited in beach wrack, and by measuring their body size. In addition, the population density and size of surviving animals were quantified by counting and measuring living sea urchins along intertidal transects.

*Strongylocentrotus purpuratus* was surveyed at two adjacent "reefs," i.e., platforms of cobbles and sediment on the intertidal shelf, which were separated by a channel. Basin Reef encloses a central, sandy depression and is seaward of the middle of the lagoon (Figure 1B). Bird Reef is near the western side of the lagoon and to the east of another reef on Malibu Point (Figures 1C, D). Ruptures in the sandbar closing the lagoon directed lagoon water toward Basin Reef in 2010, and toward Bird Reef in 2011 (Figure 1A).

After the kill in 2010, I visited Malibu Beach on two different days to examine dead animals that had accumulated in beach wrack and to assess their numbers: October 14 near slack tide, one week after the first mass mortality, and during low tide on October 23 (0 cm tide; referenced to Mean Lower Low Water (MLLW)). I also laid transect lines to measure the density of surviving sea urchins at Basin Reef and Bird Reef on November 5 and 7 (during $-30$ cm tides). At each 15 m long transect line, I counted animals that were exposed, or found under easily turned rocks, in fifteen 0.25 $m^2$ quadrats spaced at 1 m intervals.

One week after the kill in 2011, I examined the shore, looking for dead animals during low tide on October 13 (+9 cm tide), and once more on 15 October (+18 cm). I also surveyed the number of sea urchins in transects at Basin and Bird reefs on October 26, 27, and 28 ($-30$, $-37$, and $-34$ cm). Additionally, on October 27, 2011, I recorded the size of *S. purpuratus* at Basin Reef and Bird Reef. Calipers were used to measure the test diameter of sea urchins that survived the event, which were collected from fifteen 0.25 $m^2$ quadrats at one of the multiple transects on each reef. On October 13, 2011, I similarly measured the test diameters of urchins that died during the event, which were collected arbitrarily from wrack on the high water line, in order to compare their size to that of live animals in the intertidal zone.

Stranded sea urchins were also examined for signs of physical damage in order to determine the cause of their death. Diseased *S. purpuratus* have distinctive lesions in the integument, discoloration of the test, or "bald" patches that are bare of spines (Lester et al., 2007). Lobsters consume purple sea urchins in their entirety, sea stars denude them of spines, and fishes damage them in a characteristic manner (Tegner and Dayton, 1981). Avian predators break open the dorsal or ventral surface of the test, or rupture the peristomial membrane and remove Aristotle's lantern (Hendler, 1977; this report). In contrast, individuals exposed to lethal levels of osmotic stress initially become immobile, and remain virtually intact after they die (Giese and Farmanfarmaian, 1963).

In 2010, records of water level and water quality in Malibu Lagoon were used to infer the timing of the breach and properties of the water that was released. Water elevation relative to NAVD88 and water quality characteristics were recorded at several stations in the lagoon by Heal the Bay using YSI600XLM sondes, attached 6 to 15 cm above the benthos, which logged data at 30 min intervals (2NDNATURE, 2010). Data from the probes that were functional during 2010 were provided by M. Abramson, Santa Monica Bay Restoration Foundation.

Weather and sea state are not monitored at Malibu State Beach, necessitating the use of proxy data from nearby localities to evaluate the environmental conditions to which purple sea urchins were exposed during mortality events. Weather, wind, and wave information was based on surface reports for Zuma Beach, California, collected four times daily from 0700 to 1600 h (provided by R. Kittell, National Weather Service). Estimates of the timing and height of tides was based on NOAA tide records for Santa Monica, California. Rainfall and weather information for Los Angeles International Airport (KLAX) was downloaded from MesoWest (http://mesowest.utah.edu/index.html) and supplemented with archival records from the Los Angeles Times.

Accounts and photographs provided by numerous observers were used to reconstruct the nature and timing of the events at Malibu Beach. The sources are cited in Findings and Acknowledgements sections, and in figure legends.

## Results

### *Observations on the October 2010 Mass Mortality*

At 0600 h on October 12, 2010, the Los Angeles County Department of Beaches and Harbors (DBH) staff encountered "thousands of small purple sea urchins" at Malibu Lagoon State Beach. The beach maintenance crew disposed of some dead animals and raked others into piles. DBH contacted the Natural History Museum of Los Angeles County for information, out of concern regarding the cause of the mortality.

When I examined the beach on October 14, dead sea urchins were strewn along the high tide line between the Malibu Lagoon and Malibu Pier. Besides *S. purpuratus*, there were small numbers of *S. franciscanus*, approximately 20 *Aplysia vaccaria* Winkler, 1955, and the remains of several crabs (*Loxorhynchus* sp., *Cancer* sp.). DBH personnel said they had never before seen a similar event. They mentioned that the lagoon had breached and drained the previous week but, unaware of the time that the sea urchins died, made no connection between the breach and the mortality. Other individuals on site with whom I spoke at the time, and the news media, suggested that the mortality was related to pollution in the lagoon or to a change in water chemistry. Some explanations offered were manifestly incorrect, such as that dead sea urchins had washed out of the lagoon or had been deposited on the beach by seagulls.

Initially, I anticipated that the sea urchins may have died from one of the diseases that periodically kill *S. purpuratus* and *S. franciscanus*. However, none of the dead animals had the characteristic signs exhibited by diseased strongylocentrotids (Lester et al., 2007). They were desiccated but fairly intact, covered by spines and integument of normal appearance, and many had an unbroken peristomial membrane and Aristotle's lantern. The vast majority were so little damaged that they obviously had not been killed by predators (e.g. Tegner and Dayton, 1981). However, western gulls (*Larus occidentalis* Audubon, 1839) on the beach were observed probing and removing tissue from dead sea urchins.

To determine the time of the breach and the mortality, I contacted G. Pfeifer, an Ocean Lifeguard Specialist who had worked at the beach for 32 years. His daily log indicated that the lagoon was artificially breached on October 7 at 0930 h, and he recalled that dead sea urchins washed ashore by the morning of October 8. In addition, he mentioned that nearly every year varying numbers of dead sea urchins stranded on shore after the lagoon was breached, but that the most recent mortality was unusually large. Other sources later corroborated his recollections.

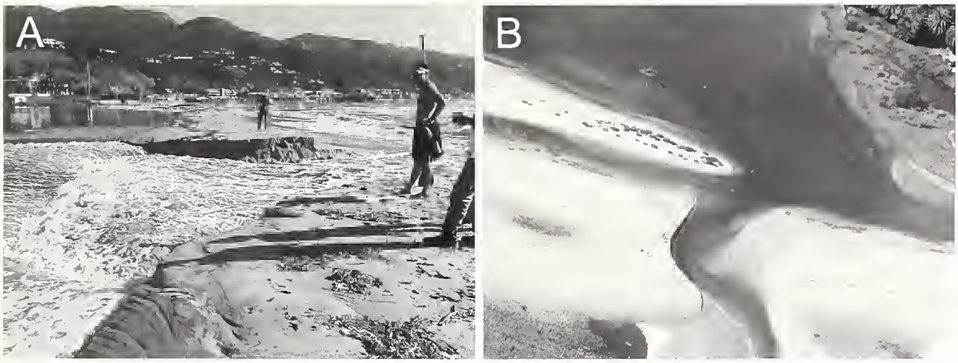


Fig. 2. Breach in the Malibu Lagoon sandbar, which was artificially created on October 7, 2010. A) Water coursing through the berm at 0947 h, shortly after the breach ruptured. B) Aerial view of the southeast portion of Malibu Lagoon on October 7, 2010 at 1315 h, showing a stream of lagoon water running through the breach, across the sandy beach, and onto the intertidal. A field of intertidal cobbles is visible at the lower left. (Photos courtesy H. Burdick, Los Angeles Waterkeeper).

It appears that a chain of events resulting in the mass mortality began on October 6, after the first significant rainstorm of the season. Rainfall in Los Angeles was a record for the date, and discharge from Malibu Creek raised the height and lowered the salinity of water in the lagoon. At Los Angeles Airport, 2.31 cm of rain fell intermittently from 0253 to 1253 h. However, it is not known if rain fell during the low tide ($-3$ cm at 1458 h) that day on the sea urchins in Malibu's subaerially exposed intertidal zone.

On October 7, a channel was dug illegally across the berm at 0915 h according to State Parks Ranger T. Hayden, who issued a citation to the individual responsible. The excavation was made near the midpoint of the lagoon where the berm was only about 1.5 m wide (Ogle, pers. comm.; Figure 1A). Although the action coincided with a maximum high tide of +183 cm at 0841 h, which raised the level of seawater at the sandbar, water in the rain swollen lagoon created a considerable hydraulic gradient. Lagoon water rapidly liquefied and ruptured the sandbar, releasing a flood of brown, sediment-laden water that swiftly extended seaward from the beach and moved eastward along shore (Ogle and Pfeifer, pers. comm.; Figure 2A). By 1030 h water level in the lagoon dropped 0.6 m (Burdick, pers. comm.), and at 1130 h a "torrent" from the lagoon still roiled the bay (Thompson, pers. comm.). At 1200 h, water continued to pour though the breach, which had by now grown to 1 to 2 m in width, although a great deal of water still remained in the lagoon (Barboza, pers. comm.). As the tide fell in the early afternoon, water from the lagoon streamed toward a central depression in Basin reef and past a layer of sediment deposited by the outflow, which in some places was $>1$ m high (Ogle, pers. comm.; Figure 1B). An aerial photograph, taken at 1315 h when the tide level was +43 cm, showed lagoon water flowing across the subaerially exposed intertidal (Figure 2B). There were minus tides that afternoon ($-15$ cm, 1544 h), and for the next 3 days ($-21$ cm, 1641 h; $-18$ cm, 1720 h; $-12$ cm, 1814 h). Thus, immediately after the breach a low tide exposed purple sea urchins to the air and to hyposaline lagoon water that pooled around the individuals situated in depressions on the intertidal shelf. Sea urchins that were immersed in fresh water, or in fresh water mixed with sea water, would have experienced osmotic stress, and the low tides occurring for several days afterwards repeatedly subjected them to heating and desiccation.

Contemporaneously with the breach event, Heal the Bay sondes in the lagoon recorded decreasing water elevations at stations 1 (near the bridge at State Route 1) and 6 (in a western side-branch of the lagoon's main channel), corroborating information provided by observers at the site. Water level began to drop at 0930 h and continued falling until 1900 h, indicating that lagoon water flowed toward the intertidal zone during low tide. Between 0930 and 1830 h the mean and range (in parenthesis) of water quality data recorded at station 6 were: salinity 1.57‰ (1.13–2.23), temperature 21.45 °C (18.32–24.12), Oxygen Reduction Potential 24.24 mV (−152.50–61.70), and pH 7.99 (7.65–8.53). Based on records at Zuma Beach, inshore seawater temperatures were approximately 17.8–21.1 °C, and air temperature during low tide was 17.8 °C. On the afternoon of October 7 and the mornings of October 8 and 9, waves were from the SW and 0.3–0.6 m in height.

On the morning of October 8, less than 24 hours after the breach occurred, large numbers of dead sea urchins were deposited onshore by the rising tide. The following day, considerably more dead animals accumulated on the beach eastward of the lagoon (see Figure 3A, B), and the number of stranded sea urchins was conservatively estimated at 10,000 on a 140 m long segment of the beach (Ogle, Pfeifer, and Ralston, pers. comm.). Over the next several days, prevailing currents moved some dead sea urchins further east toward Malibu Pier, and a small number reached Carbon Beach (Sikich, pers. comm.; pers. obs.; Figure 3C). Western gulls began to feed on dead *S. purpuratus* immediately after they were stranded, and a week later they still scavenged desiccated remains of the sea urchins, usually by removing tissue through the peristomium (Ralston, pers. comm.; pers. obs.; Figures 3D, 4A).

*Observations on the October 2011 Mass Mortality*

Two observers who described the mortality event in 2010 as particularly severe, recalled that in previous years dead sea urchins usually washed ashore after the lagoon breached (Pfeifer and Ogle, pers. comm.). However, other individuals familiar with the locality did not recall seeing dead sea urchins at the lagoon after prior breaches, or did not recall seeing significant numbers of dead sea urchins, or remembered only two die-offs of at most 1,000 sea urchins in the previous 10 years. Events in late 2011 provided an opportunity to assess the divergent viewpoints.

The first heavy rainfall of the season on October 5, 2011, which totaled 2.72 cm at Los Angeles Airport, between 0553 and 0753 h, was comparable to the rain accumulation on October 6, 2010. Runoff lowered salinity to 2 to 5‰ at various points in the lagoon where it had been 6‰ the week before (Krug, pers. comm., based on refractometer readings). After 1600 h on October 6, the lagoon was artificially breached (Pfeifer, pers. comm.). Presuming that breaching was timed to avoid detection by the authorities, it probably was accomplished during or after the +152 cm high tide at 1838 h on October 6, and possibly before the +12 cm low tide at 0117 h on October 7. Air temperatures during the period ranged from 14.4 to 15.0 °C, seawater temperatures from 17.2 to 17.8 °C, and 0.6–1.2 m high waves from the SW were recorded at Zuma Beach. The breach, located at the western end of the lagoon near Malibu Colony, directed lagoon water and sediment toward the western flank of Bird Reef, which is exposed to incoming waves from Santa Monica Bay (Figure 1D). Following the breach, daily low tides exceeded datum until October 25.

Dead sea urchins were washed ashore by the morning of October 7 (Pfeifer, pers. comm.), by a rising tide that reached +146 cm at 0746 h; I learned of their presence on

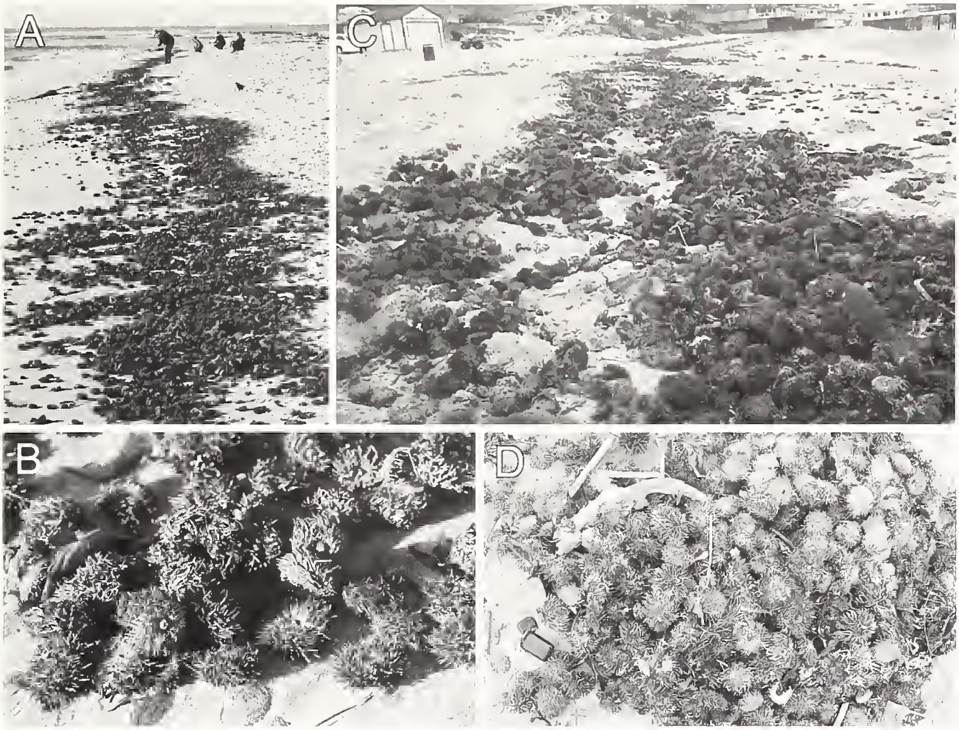


Fig. 3. Sea urchins, primarily *Strongylocentrotus purpuratus*, which were killed in a mass mortality event and stranded on the tideline at Malibu Lagoon State Beach. A) Freshly dead animals deposited by the falling tide on October 9, 2010 at 1519 h. B) Close view of the dead sea urchins in A, which are fully spined and have intact peristomial membrane and Aristotle's lantern. C) Five days after the breach on October 12, 2010, the assemblage of dead animals extends towards Malibu Pier. D) Dead urchins in beach wrack are still largely intact, although spines are missing on some abraded tests on October 14, 2010. (Photos A, B courtesy M. Ralston/AFP; C courtesy D. Murray, Heal the Bay).

October 12 (Krug, pers. comm.). On October 13, six days after the breach, I counted 2,000 dead *S. purpuratus* on the high tide mark between the eastern boundary of Malibu Lagoon and Malibu Pier. Among them were a small number of *S. franciscanus*, a *Pugettia* sp., a *Panulirus* sp. carapace, and a dead cormorant. The mean test diameter of dead *S. purpuratus* in a sample ($n = 103$) haphazardly collected from beach wrack that day, was $49.8 \pm 6.0$ mm ($\bar{X} \pm SD$). The peristomial membrane and Aristotle's lantern were intact in all but three specimens, and only 24 specimens were partially denuded of spines. Evidently, the relatively undamaged specimens were victims of the mass mortality event. However, one animal was entirely denuded of spines, and the ventral side of the test of two others was broken open. The latter, broken individuals had probably been attacked by sea gulls (Figure 4), as evidenced by the type of damage that they exhibited. Indeed, western gulls were observed scavenging dead urchins on the beach before, during and after the +0.9 cm low tide at 1652 h on that same day. On October 15, before and after a +18 cm low tide at 1811 h, I watched airborne western gulls repeatedly release *S. purpuratus* from their bills, dropping them onto rocks. I also witnessed western gulls in the intertidal zone dislodge and open urchins by penetrating just the peristomium, or by breaking into the ventral or dorsal surface of the test with their bill (Figure 4B–D). Their activities were similar during low tides on October 26–28. Although these observations


Fig. 4. Examples of predation by western seagulls (*Larus occidentalis*) on purple sea urchins (*Strongylocentrotus purpuratus*) at Malibu Lagoon State Beach. A) *L. occidentalis* feeding on freshly stranded, dead sea urchins on October 9, 2010. B) Airborne *L. occidentalis* attempting to drop and break a sea urchin on intertidal cobbles, October 26, 2011. C) *L. occidentalis* preying on intertidal *S. purpuratus* at dusk on October 15, 2011. D) Remains of *S. purpuratus* eaten by a seagull that fractured the dorsal surface of the test, October 15, 2011. (Photo A, courtesy M. Ralston/AFP).

were made during the first important series of afternoon minus tides since the previous winter, at a time that numerous *S. purpuratus* might have been expected to be present, few live purple sea urchins were seen in the mid-intertidal. However, many that were found were recent victims of gull predation (Figure 4A–D).

### *Population Density and Size Distribution*

On November 7, 2010, a month after the breach, only one living *S. purpuratus* was detected in 60 quadrats surveyed on Basin Reef, which was situated in the path of water discharged from the lagoon. The density ($\bar{X} \pm$ SD) of *S. purpuratus* in the quadrats was only $0.02 \pm 0.13$ per 0.25 $m^2$, and very few additional sea urchins were seen during an examination of the entire reef. Although comparable measurements of the population density at Basin Reef were not made prior to 2010, I was told that local surfers habitually avoided accidental contact with Basin Reef to preclude injuries inflicted by spines of the abundant purple sea urchins living there before the mass mortality (Ogle, pers. comm.). At the same site, after the breach in 2011, 212 animals were found in 113 quadrats surveyed on October 26 and 27, a mean density of $1.88 \pm 1.12$ sea urchins per 0.25 $m^2$. The statistically significant difference that was found between years, in the density of *S. purpuratus*, suggests that the population at Basin Reef was nearly exterminated in 2010, and recovered in 2011 (Mann-Whitney U test, 2-tailed, corrected for ties: U = 2,375.5,

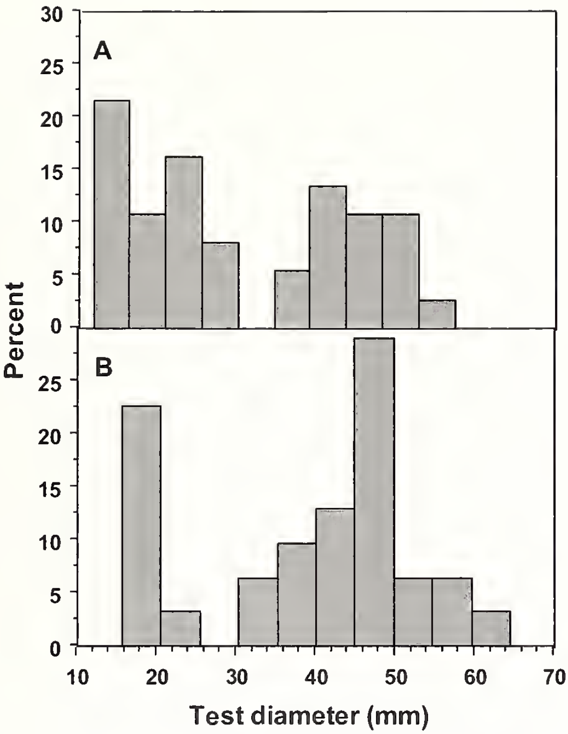


Fig. 5. Size frequency distributions of *Strongylocentrotus purpuratus* collected at Malibu Lagoon State Beach on October 27, 2011, from Basin Reef (A) and Bird Reef (B).

n = 120, P = 0.0013). In 2010, Bird Reef was not exposed to water released by the breach, and there were 277 *S. purpuratus* in the 60 quadrats surveyed there on November 5, a density of 4.62 ± 7.72 per 0.25 $m^2$. However, after Bird Reef was flooded by lagoon water during the breach in 2011, only 73 *S. purpuratus* were found there in 60 quadrats surveyed on October 27, a density of 1.22 ± 2.33 sea urchins per 0.25 $m^2$. The significant difference in population density between years, and the lesser number of *S. purpuratus* found in 2011, suggest that mortality related to the breach had drastically reduced the population density of sea urchins at Bird Reef (Mann-Whitney U test, 2-tailed, corrected for ties: U = 5729.5, n = 173, P < 0.0001).

On October 27, 2011, individuals of *S. purpuratus* were collected from transects at Basin Reef and Bird Reef, and they were measured in order to compare the sizes of animals at these two sites, each of which had been affected by a lagoon breach in a different year. At both reefs the size-frequency distributions of purple sea urchins were bimodal (Figure 5), with the smaller size class probably composed of animals between one and two years of age (year-old *S. purpuratus* are approximately 17 to 33 mm diameter, per Pearse and Pearse, 1975; Rowley, 1990). Purple sea urchins on Basin Reef, where many animals were killed in 2010, were relatively smaller in diameter than those on Bird Reef, where sea urchins were killed by the breach in 2011 (30.70 ± 13.92 mm test diameter, n = 37 versus 38.49 ± 14.23, n = 31 [$\bar{X}$± SD]). The size distribution of animals at Basin Reef could have been shaped by differential size-related mortality in 2010, or by the sizes of sea urchins immigrating to the reef after the die-off. Although adult purple sea urchins are fairly sedentary, they emerge from hiding and move in response to the availability of food and to the presence of competitors and predators (Paine and Vadas, 1969; Dayton, 1975; Schroeter, 1979; Ebeling et al., 1985; Tegner and Dayton, 1991). It is possible that the predominant, larger size class of purple sea urchins at Bird Reef, which were survivors of the 2010 and 2011 mortality events, inhibited the immigration of smaller animals, or perhaps more likely that disproportionately more small animals died during the mortality event. Although the relatively large mean size (49.8 mm diameter) of dead purple sea urchins found in beach wrack argues against the latter interpretation, it also suggests a possibility that small individuals were more readily destroyed or that large animals were preferentially transported ashore.

## Discussion

### *Mass Mortality of* S. purpuratus *at Malibu*

The behavior and physiology of *S. purpuratus* were not directly monitored during and immediately after the population was exposed to lagoon discharge. Also, meteorological and oceanographic conditions and the chemistry of water in the lagoon and the bay were not comprehensively monitored at Malibu Lagoon State Beach during mass mortality events in 2010 and 2011. As a consequence the cause of the die-offs cannot be determined with certainty, but causative factors can be inferred from the information that is available.

It is notable that the only freshly dead marine animals that were found in significant numbers at Malibu were *S. purpuratus* and *S. franciscanus*. Other animals deposited among the sea urchins on the beach were so rare that their occurrence seems unrelated to the mass mortality. The small number of dead *Aplysia vaccaria* seen in 2010 were likely senescent individuals, as this species is an annual (Audesirk, 1979; Angeloni et al. 1999). Sea urchins alone seem to have been affected, suggesting that they were more susceptible than other organisms to the causative agent(s). In addition, so many individuals of *S. purpuratus* were killed compared to *S. franciscanus* that it appears the phenomenon was restricted to the intertidal zone where the numbers of *S. purpuratus* far exceed those of *S. franciscanus*, which is primarily a subtidal species in southern California.

Circumstances of the mass mortality events in 2010 and 2011 were consistent with the hypothesis that the sea urchins were killed by brackish water released through breaches in the lagoon. In both instances, dead sea urchins appeared two days after the first major rainfall of the annual rainy season and one day after the lagoon was breached. In both instances dead animals were deposited down-current from the breach. In both instances it appeared that the population density of *S. purpuratus* was reduced on the reef closest to outflow from the lagoon, and that the population recovered to some extent within a year. Parallels between events indicate that in both cases sea urchins were killed by the same agents. However, differences in the extent of mortality between years suggest that several interacting factors were involved.

Based on the literature (reviewed in the Introduction), the physical factors most often associated with mass mortality of *S. purpuratus* included exposure to elevated temperature $\geq$ 23.5 °C, or to reduced salinity $\leq$ 21‰, for several hours. Since the salinity of water released from the lagoon was only 1 to 5‰ in 2010 and 2011, it could well have injured or killed individuals of *S. purpuratus*, even if its salinity were moderately elevated by an admixture of seawater. Ambient temperature was unlikely to have been injurious, since nearshore air and water temperatures were below lethal levels in both years. Although water temperatures $\geq$ 23.5 °C were recorded in the lagoon for 2 h during the 2010 breach, water leaving the lagoon would have cooled after exposure to the air and to sea water.

Other stressors that are potentially deleterious to *S. purpuratus* include hypoxia, toxic pollutants, emersion, and rapid burial and smothering in sediment (i.e., obrution). *Strongylocentrotus purpuratus* is resistant to hypoxic conditions (Johansen and Vadas, 1967; Burnett et al., 2002), but immersion in strongly hypoxic or anoxic lagoon water might have increased the susceptibility of individuals to osmotic stress. Dissolved oxygen (DO) concentration in the lagoon was not recorded during the interval encompassing the mortality events (Abramson, pers. comm.), but it had in the past ranged from $< 1$ mg $L^{-1}$ nearly to saturation (2NDNATURE, 2010). Even so, hypoxic lagoon water would have been aerated while flowing toward the intertidal zone. The lagoon water contains a variety of inorganic and organic pollutants, fecal bacteria, and pathogens (Ambrose and Orme, 2000; Dagit et al., 2009; BenVau, 2011), and it is possible that urban runoff from the season's initial storm contributed a concentrated "first flush" of contaminants to the lagoon. However, toxic contaminants are not seriously elevated at the site (Schiff and Bay, 2003), and a die-off of the fauna within the lagoon did not coincide with the mass mortality of intertidal sea urchins. Therefore it is unlikely that a transitory exposure to pollutants killed *S. purpuratus*. Conversely, Schroeter (1978) found that multi-day series of minus tides can weaken or kill *S. purpuratus* through exposure to desiccation, sunlight, and elevated temperatures. Although it is difficult to precisely relate Schroeter's experimental results to die-offs at Malibu, it is notable that the episode in 2010 was accompanied by a series of minus tides. In contrast, conditions in 2011 may have been relatively less stressful, accounting for the lower mortality of *S. purpuratus* that year, because the event occurred during plus tides and was preceded by 6 days without minus tides. Following the breaches, some sea urchins may have been killed by rapid burial in sediment, but direct evidence is lacking. Although a considerable amount of sediment from the breach was deposited on the intertidal shelf, waves and currents redistributed it before the reefs were examined.

### *Mass Mortality of* S. purpuratus *in California*

The catastrophic natural events, which are reviewed in the Introduction, are not the only agents of massive sea urchin kills. Humans have profoundly altered the population size of *S. purpuratus* throughout its range, often through their efforts to harvest or to eradicate sea urchins. In that respect, the mass mortalities of *S. purpuratus* at Malibu Lagoon State Park are exceptional, as they were human-caused but unintentional. They appear to have been "collateral damage" stemming from attempts to improve conditions for recreational surfing.

Paleoindians, who were the first Californians to fish for strongylocentrotid sea urchins, unwittingly initiated a 10,000-year interaction with *S. purpuratus* that has often been detrimental to the species. After Paleoindians overharvested sea otters (*Enhydra lutris* (Linnaeus, 1758)) and sheephead wrasse (*Semicossyphus pulcher* (Ayres, 1854)), eliminating the predators that had held *Strongylocentrotus* populations in check, sea urchins became a notable component of the fishers' diet (Salls, 1995; Erlandson et al., 2005; Erlandson et al., 2011).

During historical times Californians conspicuously boosted the population growth of *S. purpuratus* at least twice. In the first instance, well before 1900, sea otters between Alaska and Mexico were hunted almost to extinction by fur traders (Riedman and Estes, 1988), and absent their chief predator, sea urchins are thought to have proliferated

(Dayton et al., 1998; Tegner and Dayton, 2000; Foster and Schiel, 1988, 2010). A second population surge of purple sea urchins occurred during the 1950s, when enormous volumes of untreated sewage were discharged by metropolitan Los Angeles and San Diego. Despite the influx of toxic pollutants, sea urchins thrived on the nutrients released at sewage outfalls in southern California (North, 1974).

In response to marked increases in the numbers of *S. franciscanus* and *S. purpuratus*, concerted efforts have been made to eradicate strongylocentrotids that were deemed undesirable by the kelp-harvesting industry and various fishing interests. Beginning in the 1970s groups of divers armed with hammers smashed sea urchins, and boats spread hundreds of tons of quicklime (calcium oxide) on concentrations of sea urchins, killing them and other fauna. Temporarily exterminating sea urchins may have enhanced the recruitment rate of giant kelp (*Macrocystis pyrifera*) locally, but widespread recovery of kelp beds did not occur before large-scale upgrades of sewage treatment facilities extensively improved water quality (North, 1974; Foster and Schiel, 2010; Meux and Ford, 2010).

A subsistence fishery persisting in the 20$^{th}$ Century among Native American and immigrant populations on the West Coast reduced the numbers of *S. purpuratus* to some extent (Johnson and Snook, 1935; Greengo, 1952; Heizer and Mills, 1952; Kato and Schroeter, 1985). Some purple sea urchins have also been damaged and removed through human recreational activities (Addessi, 1994; Murray et al., 1999). In contrast, a commercial fishery initiated in the early 1970s had an extensive and long-lasting impact (Kato, 1972; Kalvass and Hendrix, 1997; Parker and Ebert, 2004). In California, old-growth stocks of *S. franciscanus* were depleted and populations collapsed, because "until the late 1980's, the sea urchin fishery was not actively managed…" (Kalvass and Hendrix, 1997:13; Rogers-Bennett, 2007). Fortunately for *S. purpuratus*, nearly 99% of the commercial harvest consisted of *S. franciscanus*, and localized removal of red sea urchins may have enhanced the access of purple urchins to food and habitat (Schroeter, 1978; Parker and Ebert, 2004).

## Conclusions

Based on available information, recent mass mortalities of sea urchins at Malibu Lagoon State Beach appear to have been the indirect result of human-caused breaches in the sand bar, a previously unreported source of sea urchin mortality. The presumed cause of death, exposure to low-salinity water, has affected populations of *S. purpuratus* elsewhere (MacGinitie, 1939; Sousa, 1979; Littler and Littler, 1987; Ebert and Grupe, 2008). At Malibu, *S. purpuratus* and *S. franciscanus* seem to have been the only animals killed by the breaches, but that could not be confirmed. Perhaps particular hydrodynamic characteristics of dead purple sea urchins (Denny and Gaylord, 1996; Stewart and Britten-Simmons, 2011) favored their massive accumulation on the tide line. At other localities, freshly killed mollusks and polychaetes have been stranded during storms (Rees et al., 1977), but none washed ashore at Malibu. However, they or other animals that were killed could have been transported offshore, as sometimes occurs following intertidal mass mortalities (e.g., Hendler, 1977; Girard et al., 2012, and pers. comm.).

No evidence was found that *S. purpuratus* died because of elevated temperature or disease. Hypoxia, hydrogen sulfide, toxic pollutants, or rapid burial in sediment may have played a role in the mortality events, but crucial facts regarding water chemistry and sediment deposition are lacking, as is information regarding the tolerance of adult purple sea urchins to physical and chemical stressors acting singly and in combination. Thus, a critical understanding of the periodic die-offs at Malibu requires further research on the behavior, physiology, and population dynamics of *S. purpuratus*, in addition to long-term monitoring of breach incidents and water quality at the lagoon.

Mortality events in 2010 and in 2011 occurred in early October, after storms that produced similarly heavy rainfall. Since it is likely that nearly equal volumes of brackish water were released from the lagoon in both events, why were ten times more *S. purpuratus* killed in 2010? In that year, at low tide, lagoon water flowed directly toward the central depression in Basin Reef, where the seaward edge of the shelf could have deterred marine water from mixing with hyposaline lagoon water and thereby mitigating its harmful effects. Consequently, in 2010, discharge from the lagoon coinciding with a diurnal minus tide, simultaneously exposed *S. purpuratus* to hyposaline water, sunlight, and dehydration for an extended period. Additionally, after emersion, purple sea urchins replace fluid in their digestive tract with air, using the inflated gut for gas exchange (Burnett et al., 2002). Having an air-filled gut may have increased their susceptibility to osmotic shock and also made them somewhat buoyant, a possibility which should be experimentally tested. Repeated exposure during several more minus tides may have resulted in the influx of additional dead sea urchins that occurred two days after the breach in 2010. In contrast, in 2011, *S. purpuratus* was subjected to less stress because Bird Reef did not impound freshwater outflow from the lagoon, and because the series of low tides subsequent to the breach were above datum. Regarding the 2011 event, timing of the breach relative to the low tide is not known.

The paucity of sea urchins found in the mid-intertidal at Malibu Lagoon State Beach was to some extent a result of seagull predation. When the beach was surveyed, western gulls repeatedly were seen attacking sea urchins on the crests of subaerially exposed reefs and around partially submerged cobbles. Their behavior resembled the birds observed at Palos Verdes Peninsula described by Snellen et al. (2007). The authors estimated that one western gull potentially could consume 3,229 *S. purpuratus* each year, and that the flock of ~45 birds that they studied could consume 145,305 sea urchins. Since greater numbers of western gulls occur at Malibu, their impact on the sea urchin population could be considerable. Moreover, similarly to the "trophic cascade" created by glaucous-winged gulls (*Larus glaucescens* Naumann, 1840) in Washington (Wootton, 1997), western gulls might indirectly increase the growth of intertidal algae at Malibu, by reducing the amount of sea urchin herbivory.

In the past, severe storms may have periodically devastated the intertidal population of *S. purpuratus* at Malibu Lagoon, as in 1998 when historic photographs (Schwarz and Orme, 2005: Figs. 6, 7) show that a remarkable El Niño event blanketed the intertidal zone with sand. However, repetitive mass mortalities at Malibu Lagoon, due to natural and artificial breaches and gull predation, appear to maintain the intertidal population of purple sea urchins at consistently low density. Population densities of *S. purpuratus* vary markedly depending on configuration and composition of the benthic substrate (Sagarin and Gaines, 2002; Ebert, 2010). Nevertheless, density of *S. purpuratus* at Malibu Lagoon is low compared to other southern California intertidal localities where 20 to 100+ individuals per $m^2$ quite often are found (Schroeter, 1978; Littler and Littler, 1987, Lawrenz-Miller, pers. comm.). Since *S. purpuratus* is an "ecosystem engineer," and since its grazing controls algal and invertebrate community structure in southern California (Ebert, 1977; Sousa et al., 1981; Rogers-Bennett, 2007:415), the low population density at Malibu may appreciably affect intertidal ecology of that locale.

California's coastal lagoons have been encroached upon and degraded by urban development for over a century, to the point that their restoration to pristine, natural condition generally seems impracticable. Consequently they have been neglected, or engineered to better serve as resources for tourism and recreation and to protect private property and public health. Virtually all efforts to preserve the ecological functionality of lagoons have been directed toward estuarine, freshwater, and terrestrial habitats (2NDNATURE, 2010; Hany and Elwany, 2011; Gladstone et al., 2006; Kraus et al., 2008). Yet the inland habitats are individual components of an ecosystem that also encompasses the marine environment. The mass mortalities at Malibu Lagoon, described herein, are manifest evidence of a linkage between the lagoon and the nearshore benthic fauna. They are also an indication that the impacts of lagoon breaches on the marine fauna of California, overlooked until now, warrant further study.

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# Review of the Purple Amole *Chlorogalum purpureum* (Agavaceae): a Threatened Plant in the Coast Ranges of Central California

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*Abstract.*—The purple amole *Chlorogalum purpureum* (Agavaceae) is a bulbous, perennial soap plant endemic to central California and listed as threatened under the U.S. Endangered Species Act since 2000. *Chlorogalum p. purpureum* occurs in the rain shadow of the Santa Lucia Range on Fort Hunter Liggett, south Monterey Co., and on Camp Roberts, north San Luis Obispo Co. *Chlorogalum p. reductum* occurs in the rain shadow of the La Panza Range in central San Luis Obispo Co., mostly on Los Padres National Forest and with potential for a substantially larger occupied area on private land. We review and enhance the existing knowledge of *C. purpureum*, in particular its life history and ecology, distribution, population sizes, threats, current management and conservation status. In 2012, invasive plants are the primary threat to *C. purpureum*.

## Introduction

The genus *Chlorogalum* (Agavaceae, Bolger et al. 2006) comprises five plant species inhabiting western North America from southern Oregon, USA, to Baja California, Mexico (Jernstedt 2012). One species, purple amole *Chlorogalum purpureum*, is listed as threatened under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service [USFWS] 2000). *Chlorogalum purpureum* is a bulbous, perennial soap plant and the only member of the genus with purple or blue flowers, the other species having white or pink flowers (Hoover 1940, Jernstedt 2012). It is endemic to central California (Figure 1), with two varieties recognized (Hoover 1964): purple amole *C. purpureum purpureum* (25 to 40 cm tall), and Camatta Canyon amole *C. purpureum reductum* (10 to 20 cm tall, Jernstedt 2012).

At Federal listing in 2000, *C. p. purpureum* was known from three occurrences on Fort Hunter Liggett (a training installation of the U.S. Army; 35°54′4.37″N, 121°10′40.33″W), Monterey Co., with an estimated population of ≈ 13,450 plants (USFWS 2000). Primary threats were loss of plants and habitat by military activities, and displacement by invasive grasses. In 2000 after listing, a population estimated at 10,000 plants was discovered on

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Camp Roberts (a training installation of the California Army National Guard; 35°45′35.29″N, 120°50′3.91″W), San Luis Obispo Co. (USFWS 2001), which was estimated in 2001 to comprise > 200,000 plants (California Army National Guard in USFWS 2002). *Chlorogalum p. reductum* was known from three occurrences in the La Panza region in central San Luis Obispo Co. at listing: on Los Padres National Forest (35°24′2.69″N, 120°16′49.01″W), and two nearby private properties. Population estimates ranged from ≈ 1,300 to 300,000 plants on ≈ 4 ha. Primary threats were illegal vehicle trespass on national forest land, road maintenance, displacement by invasive grasses, and cattle grazing (USFWS 2000). The State of California had previously listed *C. purpureum reductum* as rare under the California Endangered Species Act in 1978 (California Department of Fish and Game 2012b). Our purpose is to review and enhance the existing knowledge of *C. purpureum*, in particular its life history and ecology, distribution, population sizes, threats, current management and conservation status.

## Methods

In the literature, the common name purple amole has been used for the species *C. purpureum* and also for the nominate variety. To avoid confusion, hereafter we use purple amole only for *C. p. purpureum*. Throughout this paper, "we" refers to all or any one of the authors. We summarize the knowledge of the species, including current threats and management, and analyze the conservation status in 2012. The expressed views are solely ours and not the official position of any agency.

We managed purple amole on Fort Hunter Liggett (66,773 ha) from 1998 to 2012 and on Camp Roberts (17,314 ha) from 2001 to 2012. At Fort Hunter Liggett, we have maintained a database since 2000 with attributes of the population that we update as new information is obtained by annual monitoring of life history parameters and by additional analyses. We mapped 880 patches from 1997 to 2012, established transects in some patches, mapped and numbered (marked) some individual plants, and estimated the number of plants in most patches: 1 to 10, 11 to 50, 51 to 100, 101 to 200, 201 to 500, 501 to 1,000, 1,001 to 2,000, 2,001 to 5,000 or > 5,000. At Camp Roberts, we censused the population during May to June 2001 by demarcating the occupied area into quadrats (each 25 × 100 m) and then counting (using a clicker counter) the number of plants in each quadrat, stopping at 5,001 (> 5,000). Our counts are only for plants with above-ground structures, which excludes the bulbous stage. For Camatta Canyon amole, we conducted three site visits (2010, 2011, 2012), communicated with relevant persons and examined soil maps. In addition, we reviewed the literature. We consider a location as a separate occurrence only if it is > 0.4 km from the nearest occurrence (California Department of Fish and Game 2012a).

## Review of the Species

The species inhabits a semiarid environment with hot dry summers and cool wet winters. Both varieties grow in gravelly clay soil in open areas with a light cover of native plants in grassland, blue oak savanna (*Quercus douglasii*) and blue oak woodland. Records for purple amole account for 97% (≈ 429 ha) of the known occupied area, and for Camatta Canyon amole 3% (≈ 12 ha, our current estimate). Both varieties sometimes grow in association with cryptogamic crusts (cyanobacteria, lichens, mosses and fungi on the soil surface; E.L. Painter in USFWS 2000, Guretzky et al. 2005, pers. obs.). Cryptogamic crusts are important elements of arid and semiarid ecosystems (Beymer and

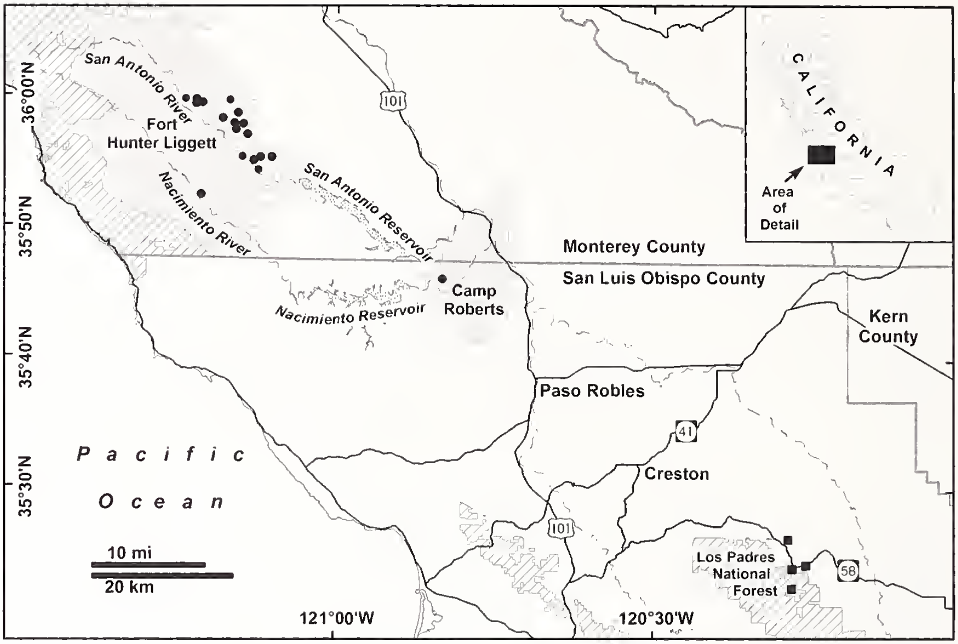


Fig. 1. Distribution of the threatened *Chlorogalum purpureum* (Agavaceae) in central California. Black dots, purple amole *C. p. purpureum*; black squares, Camatta Canyon amole *C. purpureum reductum*.

Klopatek 1992) because they stabilize soil against erosion, fix atmospheric nitrogen, form organic matter (Eldridge and Greene 1994), retain soil moisture, discourage weed growth (Belnap et al. 2001) and provide favorable sites for growth of native plants (e.g., Lesica and Shelly 1992). New *C. purpureum* become established almost entirely by seed (Hoover 1940). Purple amole in a screen house flowered 3 to 4 y after planting as seed, and most died 5 to 7 y after germination (D. Wilken, Santa Barbara Botanic Garden, California, pers. comm.). Camatta Canyon amole planted on site as seed required at least 12 y to flower (Koch and Hillyard 2009). Purple amole emerge above ground Nov. to Dec., with inflorescences developing during early spring, and flower and fruit during May to June. Camatta Canyon amole flower and fruit during Apr. to June. As fruits mature, the leaves wither and inflorescences dry and turn brown. We observed purple amole bulbs entering dormancy during summer, and some marked plants remained dormant for multiple years.

### *Purple Amole*

Purple amole is now known to occur on two properties: 17 occurrences on Fort Hunter Liggett, and one occurrence on Camp Roberts (Figure 1). It is endemic to the Santa Lucia Range in south Monterey Co. and north San Luis Obispo Co., occurring in the rain shadow at lower elevations (213 to 390 m) on the east side. The Coast Ridge rises to 1,000 m west of Fort Hunter Liggett, and Pine Mountain rises to 1,095 m west of Camp Roberts. Mean annual rainfall is 485 mm at Fort Hunter Liggett (Cantonment, primarily Nov. to Apr.; National Park Service 2007) and 285 mm at Camp Roberts (primarily Oct. to May, White et al. 2000). All known occurrences are in the San Antonio and Nacimiento River valleys. Construction of Lake Nacimiento and Lake San Antonio in 1961 and 1965, respectively, may have submerged some occupied areas.

The land comprising Fort Hunter Liggett has been settled and used by EuroAmericans since 1771, which has affected current distribution. Purple amole is nearly absent from areas previously ripped/disked for cultivation, and most abundant in areas not previously ripped/disked including some used for intensive military training since 1941. The taxon occupies ≈ 341 ha on Fort Hunter Liggett, occurring in hundreds of discontinuous patches at mean density up to 11 plants/$m^2$ in grassland, blue oak savanna and open areas of blue oak woodland. Using our cumulative data since 1997, we estimate the population comprises 315,000 to 700,000 plants. Records on Fort Hunter Liggett are at 270 to 390 m elevation. Surveys along the east boundary suggest it likely occurs also on adjacent private land (Wilken in USFWS 2002), for which the USFWS (2002, 2003) designated critical habitat (620 ha; an area with essential characteristics).

Purple amole on Fort Hunter Liggett occurs on both deep and thin soils, most of which are loamy and underlain by clay with fine gravel (generally < 0.5 cm diameter) on the surface. Most occupied areas (78%) are level or near-level (slope < 10%), including a few on ridge top terraces (Wilken in USFWS 2001). It generally grows where other vegetation is sparse (Guretzky et al. 2005) and in association with low-growing annual plants, including: natives—rusty popcornflower *Plagiobothrys nothofulvus*, miniature lupine *Lupinus bicolor* and California goldfields *Lasthenia californica*; and invasives—soft brome *Bromus hordeaceus* and stork's bill *Erodium* sp. Purple amole and cryptogamic crusts co-occur in 50% of the survey plots, and density of purple amole is positively correlated ($P <$ 0.05) with cryptogamic crusts ($r$ = 0.271) and other native plants ($r$ = 0.199, Guretzky et al. 2005). Niceswanger (2002) reported Botta's pocket gophers *Thomomys bottae* eating purple amole (stems, leaves, flowers) on Fort Hunter Liggett. We observed Botta's pocket gophers displacing bulbs and causing extensive disturbance to the habitat. Since 2010, feral pigs *Sus scrofa* are also disturbing the habitat.

In 2003, the U.S. Army used a ball and chain to clear chaparral (Kucera and Mayer 1999) at several sites presumably not occupied by purple amole. However, one of these sites (≈ 78 ha) now likely has the highest density on Fort Hunter Liggett. At another site, fire burned a study plot before seed maturation, with apparent loss of all seeds (Niceswanger 2002). The following year, the number of plants at the burned site increased by 175%. These observations suggest purple amole may respond favorably to removal of potentially competitive species (invasives and natives) and to fire at certain times of the year. We are testing the potential of prescribed fire to remove invasive plants and benefit purple amole, with several areas already burned in 2011.

Over 7 y at Fort Hunter Liggett, we observed 26% of monitored plants (range 13 to 63% per y) attempting reproduction (produced stalks, flowers, capsules or seeds), with 12% (range 5 to 26% per y) actually producing seeds. Flowering was correlated with total rainfall in the preceding few months (Guretzky et al. 2005). Numbers of seeds ranged up to 386 per plant (mean = 28, Niceswanger 2002). We observed many marked plants in dormancy as bulbs for 1 to 3 y, and one marked plant remained dormant for 6 y and another 5 y. Guretzky et al. (2005) estimated the dormancy rate as 23% of the population per y and the mortality rate as 10% of the population per y.

Since Federal listing, the U.S. Army has included purple amole in its natural resources management plan at Fort Hunter Liggett and annually monitors life history parameters. In 2005, 2007 and 2010, the U.S. Army consulted with the USFWS regarding its ongoing activities and effects on purple amole. In accordance with biological opinions issued under the U.S. Endangered Species Act, cumulative loss of occupied areas by ground disturbance does not exceed 0.4 ha/y. The U.S. Army terminated cattle grazing on Fort

Hunter Liggett in 1991 because of adverse effects to natural resources, and it is not likely to resume in the occupied areas. Although the population appears stable on Fort Hunter Liggett, we identify invasive plants, Botta's pocket gophers, feral pigs and possibly lack of fire as threats in 2012 (Table 1).

Purple amole on Camp Roberts occupies ≈ 88 ha north of the Nacimiento River on the west side of the installation (213 to 274 m elevation), which is ≈ 31 km from the nearest occurrence on Fort Hunter Liggett. The most-recent census in 2001 recorded > 250,000 plants (our refined analysis). In June 2005, a hot wildfire burned ≈ 90% of the occupied area with loss of the seed crop. A dense layer of thatch (10 to 20 cm) had accumulated since cessation of sheep grazing. In 2006, we observed 10.4 plants/$m^2$ in survey plots during Mar. and 5.6 plants/$m^2$ during May. The decrease likely represented some plants entering dormancy without flowering. Although not tested and anecdotal, plants in the burned area appeared taller and with increased reproductive vigor (more flowers, fruits or seeds) than plants in the non-burned area, which suggests purple amole may respond favorably to fire at certain times of the year.

On Camp Roberts, purple amole occurs predominately in soil with a high concentration of gravel underlain by hard-packed clay, growing across the flat surface of an old alluvial fan primarily on northeast exposures with slope < 10%. The vegetation is predominantly grassland, with blue oak woodland on surrounding slopes. Here purple amole grows where there is sparse plant cover, seldom under oak canopies, and usually among low-growing native grasses (especially small fescue *Vulpia microstachys*) and herbaceous native plants. In particular, yellowflower tarweed *Holocarpha virgata* co-occurred in 95% of survey plots, annual agoseris *Agoseris heterophylla* in 82%, and bigflower agoseris *Agoseris grandiflora* in 79%. Together, yellowflower tarweed and bigflower agoseris comprised 75% of total plant cover in survey plots with purple amole. Invasive plants in the habitat include wild oat *Avena fatua*, soft brome and redstem stork's bill *Erodium cicutarium*. Feral pigs eat the bulbs of purple amole on Camp Roberts and previously caused extensive disturbance to the habitat. This threat has been reduced by controlled hunting elsewhere on the installation.

The California Army National Guard ceased training activities in areas occupied by purple amole in 2000 (except occasional road use), along with sheep grazing and hunting. The agency included the taxon in its natural resources management plan for Camp Roberts and annually monitors life history parameters. The California Army National Guard consults with the USFWS regarding its activities and effects on purple amole. Consequently, limited military activities resumed in occupied areas in 2011. We identify the following threats on Camp Roberts in 2012: invasive plants, feral pigs and possibly lack of fire (Table 1). We are considering several actions that may benefit purple amole, including prescribed fire and controlled sheep grazing to remove invasive plants.

### *Camatta Canyon Amole*

Camatta Canyon amole is now known from four occurrences on four properties (Figure 1), ≈ 61 km southeast of purple amole on Camp Roberts and ≈ 92 km southeast of purple amole on Fort Hunter Liggett. It is endemic to the La Panza Range in central San Luis Obispo Co., occurring in the rain shadow at intermediate elevations (570 to 633 m) on the east side. Black Mountain rises to 1,104 m immediately to the west. Based on data for La Panza Ranch (≈ 10 km eastward and therefore drier), mean annual rainfall at the occupied area is > 156 mm (likely by several cm), along with rain primarily from Oct. to Apr. (http://www.worldclimate.com 2011).

Table 1. Status of the threatened *Chlorogalum purpureum* (Agavaceae) at listing in 2000 and since listing to 2012. Invasive plants are now the primary threat. CR denotes Camp Roberts. FHL denotes Fort Hunter Liggett. LPNF denotes Los Padres National Forest. USFWS denotes U.S. Fish and Wildlife Service.

| | Purple amole *C. p. purpureum* | | Camatta Canyon amole *C. purpureum reductum* | |
|---|---|---|---|---|
| Attribute | At listing in 2000 | Since listing to 2012 | At listing in 2000 | Since listing to 2012 |
| Occupied area (≈ number of ha) | Unknown FHL | 429 (341 FHL, 88 CR) | 4 | 12 |
| Mean density (≈ number of plants/$m^2$) | Not known | 11 FHL, 10.4 CR | 10.7 (1988) | up to 5.3 (2012) |
| Population estimate (≈ number of plants) | 13,450 FHL | 315,000 to 700,000 FHL; > 250,000 CR | 1,300 to 300,000 | 20,000 to 500,000 |
| Number of populations | 1 FHL | 2 (1 FHL, 1 CR) | 1 | 1 |
| Number of occurrences | 3 FHL | 18 (17 FHL, 1 CR) | 3 | 4 |
| Threat | At listing in 2000 | Since listing to 2012 | At listing in 2000 | Since listing to 2012 |
| Loss of plants and habitat by military activities | Ongoing FHL | Reduced by consultation with USFWS FHL CR | | |
| Invasive plants | Ongoing FHL | Reduced by management FHL, ongoing CR | Ongoing | Ongoing |
| Alteration of fire cycle | Suspected FHL | Reduced by management FHL, suspected CR | Not a threat | Suspected |
| Cattle grazing | Potential FHL | Removed FHL | Ongoing | Ongoing |
| Sheep grazing | | Removed CR | | |
| Habitat conversion to chaparral | Not a threat FHL | Ongoing FHL | Not a threat | Suspected |
| Predation/disturbance by gophers | Not a threat FHL | Ongoing FHL | Not a threat | New LPNF (2010) |
| Predation/disturbance by feral pigs | | New FHL (2010), reduced by management CR | | |
| Off-highway vehicle recreation | | | Ongoing LPNF | Removed LPNF |
| Road maintenance | | | Ongoing LPNF | Ongoing LPNF |

The primary occupied area is on a ridge top ≈ 200 m east of the south end of Camatta Canyon, which is immediately south of the junction of State Highway 58 and Red Hill Road. The population as currently known is mostly on Los Padres National Forest, extending also onto both sides of State Highway 58 in the right-of-way (1.2 m beyond each shoulder), north onto private property (also likely east), and 3.3 km south of State Highway 58 on private property. The right-of-way of State Highway 58 is managed by the California Department of Transportation, which designated the right-of-way as a botanical management area. This agency gives greater environmental review when planning work here (T. Edell, California Department of Transportation, pers. comm.). The private property immediately north of State Highway 58 is a cattle ranch. The private property south of State Highway 58 appears to be a residential property, and it was registered with The Nature Conservancy in a land protection program (California Department of Fish and Game 2007). The extent of the population across the four properties is not precisely known. However, the occupied area was estimated to comprise 3.2 ha on national forest land, 0.1 ha on the private land south of State Highway 58 (USFWS 2000, 2002), and 0.5 ha on the right-of-way of State Highway 58 (California Department of Fish and Game 2007). Records of the California Department of Fish and Game (2007) state the occupied area comprises 51 ha.

Abundance estimates for Camatta Canyon amole on national forest land have ranged from tens of thousands to ≈ 500,000 plants (California Department of Fish and Game 2007). The private property south of State Highway 58 contained an estimated several hundred plants (A. Koch in USFWS 2002). In the right-of-way of State Highway 58, 213 and 306 plants were observed in 2000 (J. Luchetta in USFWS 2001) and 2005 (T. Edell, California Department of Transportation, pers. comm.), respectively. On the private property north of State Highway 58, we were able to observe Camatta Canyon amole only from the right-of-way in May 2011. We counted ≈ 60 plants from one strategic point, observing predominantly tall grasses in the habitat and an absence of grazing. Mean densities in 10 random plots on national forest land in 1987 and 1988 were 6.5 plants/m$^2$ and 10.7 plants/m$^2$, respectively (Magney 1988). During May 2011, we observed a general absence of Camatta Canyon amole among taller invasive plants (≈ 30 to 46 cm height) that were especially dense in vicinity of blue oak trees. In contrast, a previous staging area for off-highway vehicles (≈ 929 m$^2$) with relatively few invasive plants contained 3.2 Camatta Canyon amole/m$^2$. In addition, we observed Botta's pocket gophers causing extensive disturbance to the habitat in 2011 and 2012, especially where invasive plants were abundant. In May 2012, the mean density of Camatta Canyon amole in the most densely populated part of the occupied habitat (18 quadrats, each 0.5 × 50 m) was 5.3 plants/m$^2$ (L. Simpson, U.S. Forest Service, pers. comm.).

Some authors reported Camatta Canyon amole on serpentine soil (e.g., Hoover 1964), with Safford et al. (2005) reporting it as a strict endemic. We correct and clarify by stating that Camatta Canyon amole on Los Padres National Forest occurs on an alluvial terrace in soil with a red sandy matrix dominated by gravel, all derived from sandstone and shale with no serpentine (D. Chipping, California Polytechnic State University, pers. comm.; Natural Resources Conservation Service 2003). In the vicinity of Red Hill Road, this particular soil type (Arbuckle sandy loam with slope < 10%) comprises ≈ 11 ha on Los Padres National Forest and ≈ 96 ha on private land immediately north of State Highway 58 (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx, 2010). Potential exists for the occupied area on private land immediately north to be substantially larger than on national forest land. The USFWS (2002, 2003) designated critical habitat for Camatta Canyon amole on 1,324 ha of private land immediately north.

On Los Padres National Forest, Camatta Canyon amole grows in open areas predominantly in annual grassland and blue oak savanna, and often co-occurring with cryptogamic crusts. Native plant associates include crown brodiaea *Brodiaea coronaria*, winecup clarkia *Clarkia purpurea*, sand pygmyweed *Crassula erecta*, bluedicks *Dichelostemma capitatum*, sanicle *Sanicula* spp., California goldfields, sky lupine *Lupinus nanus* and gilia *Gilia* sp. (Magney 1988, Service 2002). Along State Highway 58, it typically grows in hard-packed soil and away from dense grasses, either among low-growing plants or in open areas around chamise *Adenostoma fasciculatum* (T. Edell, California Department of Transportation, pers. comm.).

The occupied area on national forest land is in the Pozo-La Panza Unit, which is best known for off-highway vehicle recreation, and it is bisected by a dirt road. In 2010, 2011 and 2012, we observed that the occupied area was effectively protected from off-highway vehicles by fencing, signs and ranger patrols. The adverse effects of road maintenance (in particular grading) appeared to be ongoing, but which we consider a lesser threat. It is also in the Navajo Allotment where a permittee usually grazes cattle from Feb. to May, which overlaps in time with flowering and fruiting of Camatta Canyon amole (Apr. to June). Cattle can cause physical damage by trampling, along with soil compaction and erosion, damage to cryptogamic crusts, reducing presence of native plants and increasing presence of invasives (Fleischner 1994, DiTomaso 2000, Belnap and Eldridge 2001). In 2010, we observed the relatively flat soil surface to be imprinted with hoof depressions where cattle had been when the soil was soft and wet. In 2011 and 2012, the allotment had not been grazed. In each year we observed potential competition with invasive plants (e.g., red brome *Bromus rubens*, slender oat *Avena barbata*, soft brome) and also possibly native chamise, along with buildup of thatch. Germano et al. (2001) previously recommended grazing as a tool for managing invasive grasses and helping to conserve declining native species in California. In consideration of all factors, controlled cattle grazing at the right density and timing may benefit Camatta Canyon amole by reducing the presence of invasive plants and thatch. In summary, we identify the following threats to Camatta Canyon amole in 2012: invasive plants, Botta's pocket gophers, uncontrolled cattle grazing, road maintenance, and possibly lack of fire (Table 1). The USFWS and U.S. Forest Service are discussing management of Camatta Canyon amole on national forest land.

*Conservation Status*

The USFWS (2008) reviewed the status of the species in 2008 and recommended no change in its listing status of threatened. Although more information is now available, a five-factor analysis using USFWS criteria is beyond the scope of this paper. Nonetheless, using the best available information and international standards (IUCN 2001, 2010), *C. purpureum* in 2011 does not meet IUCN criteria for placement on its red list as critically endangered, endangered or vulnerable: extent of occurrence, 931 km$^2$; area of occupancy, 4.41 km$^2$; quality of the habitat, declining; and number of occurrences, 22. Nor does *C. p. purpureum* meet IUCN criteria for listing: extent of occurrence, 310 km$^2$; area of occupancy, 4.29 km$^2$; quality of the habitat, declining; and number of occurrences, 18. However, *C. purpureum reductum* meets IUCN criteria for placement on its red list as endangered: extent of occurrence, 2.3 km$^2$; area of occupancy, 0.12 km$^2$; quality of the habitat, declining; and number of occurrences, 4. With these attributes, *C. purpureum reductum* faces a very high risk of extinction.

## Conclusions

Since Federal listing in 2000, purple amole is now known to occur in substantially greater numbers, occupy a substantially greater area and occur on two properties, which are managed as separate populations: 17 occurrences on Fort Hunter Liggett, and one on Camp Roberts (Table 1). Unknown occupied areas may possibly occur in the San Antonio and Nacimiento river valleys between the two populations, especially in designated critical habitat (USFWS 2002, 2003). Camatta Canyon amole is known from only four occurrences within a small area: mostly on Los Padres National Forest, two private properties, and the right-of-way of State Highway 58 at Red Hill Road. Based on landscape characteristics (Arbuckle sandy loam and slope $< 10\%$), potential exists for a substantially larger occupied area on private land north of State Highway 58, especially in designated critical habitat (USFWS 2002, 2003).

The U.S. Endangered Species Act is the primary Federal law protecting the species, although it has limited ability to protect listed plants on private land. Camatta Canyon amole is also listed under the California Endangered Species Act (California Department of Fish and Game 2007); however, grazing and other agricultural activities on private land are exempt. Invasive plants are now the primary threat to *C. purpureum*. Invasives may be able to displace it by outcompeting and monopolizing limited resources (e.g., space, sunlight, nutrients, water; Stephenson and Calcarone 1999), and by producing thatch, which can prevent growth and recruitment and also alter the natural fire regime (Brooks et al. 2004). In addition, based on our observations on Fort Hunter Liggett and Los Padres National Forest, some native plants (climax chaparral) may be able to displace *C. purpureum*, possibly in the absence of fire.

We are considering several management actions that may benefit purple amole on Fort Hunter Liggett (prescribed fire) and Camp Roberts (prescribed fire, controlled sheep grazing) by removing invasive plants and thatch. Also, the species may respond favorably to fire in ways not yet known. For example, the wavyleaf soap plant *C. pomeridianum* exhibits fire-stimulated flowering and produces seeds only in the first year after fire (Borchert and Tyler 2009). However, caution must be exercised because fire can destroy the flowers and seeds of purple amole and also benefit some invasive plants (Klinger et al. 2006). We encourage controlled cattle grazing on Los Padres National Forest and the relevant private land to remove invasive plants and reduce thatch, so long as consideration is given to stock density, the life cycle of Camatta Canyon amole and soil conditions. The effects of the grazing regime should be thoroughly considered.

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# Developmental Mode in Opisthobranch Molluscs from the Northeast Pacific Ocean: Additional Species from Southern California and Supplemental Data

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*Abstract.*—We document development type for 33 species of benthic opisthobranch gastropods – 15 for the first time – collected mainly from the Southern California Bight. Fourteen of the newly examined species had planktotrophic development, while the dorid nudibranch *Atagema alba* had capsular metamorphic development, the first example of direct development in a non-dendrodoridid nudibranch known from the northeast Pacific Ocean. For the remaining 18 species our new data are either consistent with earlier determinations of development type, or confirm previous inferences. The new data also broaden geographic coverage for some species, and for the sacoglossan *Stiliger fuscovittatus* and the nudibranch *Melibe leonina*, suggest that egg size is inversely related to temperature. We correct the previous erroneous identification of nephrocysts as eyespots in the hatching planktotrophic larvae of the nudibranchs *Tritonia festiva* and *Janolus fuscus*. These results further highlight the predominance of planktotrophic development in benthic opisthobranchs from the northeast Pacific Ocean.

## Introduction

Mode of development has been determined for approximately two-thirds of the over 300 species of opisthobranch molluscs known from the northeast Pacific Ocean (Goddard 2004, 2005; Goddard and Hermosillo 2008). Small eggs and planktotrophic development predominate among these species; so far, only 14 species from the region are known to hatch from their egg coverings as either lecithotrophic larvae or juveniles (Goddard and Hermosillo 2008). The four species of nudibranchs known to bypass a free-living larval stage and hatch as juveniles all belong to a single family, the Dendrodorididae (Goddard, 2005).

Developmental mode in opisthobranchs is most reliably documented when based on observations of the morphology of hatching veliger larvae - particularly the presence or absence of eyespots and propodium - accompanied by measurements of egg size, embryonic period and temperature, and size and type of shell at hatching (Bonar 1978; Goddard 2004). However, these parameters are not always readily measured or reported in the literature, and developmental mode has previously been inferred for some species based on subsets of the above information. For example, Goddard (2004) characterized as planktotrophic the development of the nudibranchs *Polycera tricolor* Robilliard, 1971 and *Dirona picta* MacFarland in Cockerell & Eliot, 1905, based on, respectively, (1) a comparison of the embryonic period reported for *P. tricolor* by Robilliard (1971) with those of congeners of known developmental type, and (2), qualitative observations, combined with a measurement of the preserved embryos reported by Marcus and Marcus (1967). As

Table 1. Collection localities.

| Site | GPS coordinates | Depth (m)/habitat |
|---|---|---|
| Whittier, Alaska | 60.7778, −148.6903 | Floating docks |
| Monterey Bay | 36.6088, −121.8797 | Subtidal, 16 m |
| Monterey Harbor | 36.6043, −121.8912 | 5 m, dock pilings |
| Asilomar, Pacific Grove | 36.6272, −121.9408 | Rocky intertidal |
| Sand Dollar Beach, Monterey Co. | 35.9217, −121.4717 | Rocky intertidal |
| Cayucos | 35.4478, −120.9100 | Rocky intertidal |
| Hazard Canyon, Montana de Oro State Park | 35.2897, −120.8839 | Rocky intertidal |
| Naples, Santa Barbara Co. | 34.4339, −119.9514 | Rocky intertidal |
| Naples Reef | 34.4218, −119.9523 | Subtidal, 15 m |
| Santa Barbara Harbor | 34.4067, −119.6892 | Floating docks |
| Tarpits Reef, Carpinteria | 34.3869, −119.5164 | Rocky intertidal |
| Laguna Beach | 33.5429, −117.7906 | Rocky intertidal |
| La Jolla | 32.8549, −117.2680 | subtidal, 17 m |
| South Casa Reef, La Jolla | 32.8434, −117.2814 | Rocky intertidal |
| Bird Rock, La Jolla | 32.8144, −117.2739 | Rocky intertidal |
| San Clemente Island | 32.8134, −118.3626 | subtidal, 20 m |
| Mission Bay, San Diego | 32.7642, −117.2172 | Floating docks |
| Point Loma, San Diego | 32.6664, −117.2450 | Rocky intertidal |
| Punta Rosarito, Baja California | 28.5672, −114.1597 | Rocky intertidal |
| El Tomatal, Baja California | 28.4869, −114.0694 | Rocky intertidal |

opportunities have arisen, we have endeavored to fill some of these gaps in the available embryological data, as well as sample across more of the geographic range of some species. Aside from providing confirmation or not of previous inferences, this will enable more robust comparative studies, help distinguish closely related species, and increase our understanding of geographic variation in the life history traits of opisthobranchs.

Here we document mode of development for species not previously examined, most of which are from southern California, and fill existing gaps in the embryological data for others. We include species rarely observed or mainly subtidal in distribution, two undescribed species, and document a new example of rare direct development in a nudibranch from the northeast Pacific Ocean. We discuss discrepancies between our observations and those reported in the literature and also correct the previous erroneous identification by the senior author of the paired larval structures known as nephrocysts (e.g., Thompson 1976; Bonar 1978) as eyespots in the hatching larvae of two common planktotrophic species.

## Collection Sites and Methods

Adult opisthobranchs, or portions of their egg masses in the process of being deposited, were collected by hand from subtidal and intertidal sites along the Pacific coast of North America (Table 1). Adults were held in containers (250 to 1000 ml) of unfiltered seawater at near ambient ocean temperatures until they laid egg masses. Recently laid egg masses were examined using a compound microscope equipped with an ocular micrometer. If first cleavage had not commenced, the diameters of a random sample of 10 zygotes were measured in each egg mass; otherwise, an upper limit on zygote size was estimated by measuring the dimensions of a few randomly selected embryos at or before the gastrula stage. We then isolated individual egg masses, or approximately 1 cm long sections of larger egg masses, into separate, labeled vials (20 ml) and changed and gently swirled the seawater in these once or twice daily. We examined the egg masses daily until hatching and then measured the longest dimension of their shells and assigned mode of development (planktotrophic, lecithotrophic or direct) and larval shell type (coiled type 1 or egg-shaped, inflated type 2) as in Goddard (2004). After obtaining the above egg masses, adult specimens were relaxed in 7.5% $MgCl_2$, fixed in 70% ethanol, and deposited as voucher specimens in the California Academy of Sciences. Some of these vouchers included pieces of egg masses and were supplemented by digital images of adults. We used an underwater data logger (StowAway Tidbit, Onset Computer Corp.) to record temperature at 10 min. intervals in our holding containers.

For the dorids *Geitodoris mavis* Marcus & Marcus, 1967 and *Taringa aivica* Marcus & Marcus, 1967, we examined preserved specimens originally collected in 1994 and 2000, respectively, and following Goddard (2004), inferred their mode of development based on the relatively small size of their embryos. For the chromodorid *Felimare californiensis* (= *Hypselodoris californiensis*) (Bergh, 1879) we inferred mode of development based on estimates of embryonic period and egg size. We estimated the latter by measuring the zygotes in an image of an adult laying its egg ribbon (Figure 2A) and assuming an egg ribbon width of 6 mm (adjusted to 4.243 mm to account for the approximately 45° viewing angle of the segment of the egg ribbon containing the zygotes we measured), based on the measurement reported by Ingram (1935). Craig Hoover (personal communication to JG, 30 Sept 2012) provided information on the embryonic period of *F. californiensis*, based on subtidal observations he made in September 2012 of three egg masses laid by *F. californiensis* in Big Fisherman Cove, Santa Catalina Island.

JG identified the egg mass of *Atagema alba* (O'Donoghue, 1927) from Bird Rock, La Jolla (see Table 2) based on original 35 mm slides, including close-ups of sections of egg ribbon, in the James R. Lance collection at the California Academy of Sciences (CAS) in San Francisco.

We follow the taxonomic nomenclature of Behrens and Hermosillo (2005), and for the Chromodoridae, Johnson and Gosliner (2012).

## Results

We obtained results on the development of 33 species, 15 for the first time (Table 2). Eleven of these 15 laid small eggs and developed into hatching planktotrophic larvae (Table 2). Planktotrophic development was inferred for an additional three of them (*Geitodoris mavis*, *Felimare californiensis*, and *Flabellina pricei*), based on the small size of their embryos, and for *Felimare californiensis*, the length of its embryonic period as well (Table 2). Finally, *Atagema alba* from La Jolla developed from relatively large eggs and had capsular metamorphic development (Table 2, Figure 1). The juveniles of this species exited their shells while leaving the egg capsules, and one day after hatching had rhinophore buds and an oval notum reinforced by calcareous spicules and edged with secretory glands (Figure 1B & C). Five days after hatching, the juveniles had two to three notal caryophyllidia (papillae surrounded by crowns of spicules; Figure 1D). A radula with three pairs of hammate teeth was visible two days after hatching (Figure 1F) and appeared to have approximately six rows of teeth after seven days (Figure 1E).

Of the remaining 18 species examined, hatching planktotrophic larvae were observed in 15, and this same mode of development was inferred for the remaining three based on the small size of their embryos (Table 2).

## Discussion

Thirty-two of the 33 total species we examined were found to have planktotrophic development, consistent with prior compilations of developmental mode in benthic

Table 2. New data on embryonic development of opisthobranch molluscs from California. Mode of development: P = planktotrophic, CM = capsular metamorphic, with modes inferred based solely on size of zygotes or early embryos in parentheses. An asterisk (*) preceding a species name indicates a species whose mode of development has not previously been determined, and a dash (—) indicates no data. Values for egg diameter and shell length at hatching are means ± 1 SD, and sample size (n).

| Taxon | Egg Diameter (μm) | # eggs per capsule | Embryonic period (days) | Temp. (°C) | Shell type | Shell length at hatching (μm) | Eyespots at hatching | Mode of Development | Locality |
|---|---|---|---|---|---|---|---|---|---|
| **Sacoglossa** | | | | | | | | | |
| *Stiliger fuscovittatus* Lance, 1962, CASIZ 182713 | 58.8 ± 1.1 (10) | 1 | 4.5 | 15–20 | 1 | 104.3 ± 3.3 (22) | no | P | Mission Bay |
| | 60.9 ± 0.9 (10) | 1 | 4.5 | 15–20 | 1 | 108.3 ± 2.8 (22) | no | " | Mission Bay |
| | 59.6 ± 2.1 (9) | 1 | — | — | 1 | — | — | " | Monterey Harbor |
| | — | 1 | — | — | 1 | 102.7 ± 6.1 (11) | no | " | Monterey Harbor |
| **Anaspidea** | | | | | | | | | |
| *Aplysia vaccaria* Winkler, 1955, CASIZ 189306 | — | >50 | 19+ | — | 1 | 143.8 ± 3.1 (5) | no | P | Laguna Beach |
| **Nudipleura: Pleurobranchidae** | | | | | | | | | |
| *Berthella strongi* (MacFarland, 1966), CASIZ 182722 | 89.3 ± 0.8 (10) | 1 | 16 | 12–16 | 1 | 137.0 ± 3.1 (10) | yes | P | El Tomatal |
| | — | 1 | — | — | 1 | 137.1 ± 7.9 (5) | yes | " | Naples |
| **Nudipleura: Doridina** | | | | | | | | | |
| **Acanthodoris lutea* MacFarland, 1925 | 69.5 ± 1.1 (10) | 1 | 8 | 15 | 1 | 132.4 ± 4.0 (10) | no | P | Monterey Bay |
| **Ancula lentiginosa* Farmer *in* Farmer & Sloan, 1964, CASIZ 182719 | <60 | 1–2 | 10 | 13–18 | 1 | 99.3 ± 3.1 (10) | no | P | Naples |
| **Atagema alba* (O'Donoghue, 1927), CASIZ 186493 | 156.6 ± 1.7 (3) | 1 | >>14 | 18–20 | 1 | 210–218[a] | yes | CM | Bird Rock, La Jolla |
| *Doriopsilla albopunctata* (Cooper, 1863) | — | 1–3 | — | — | 1 | 193.0 ± 7.0 (5) | no | P | Cayucos |
| **Doris pickensi* Marcus & Marcus, 1967, CASIZ 189305 | 77.2 ± 1.2 (10) | 1 | 13 | 14–20 | 1 | 132.6 ± 2.2 (10) | no | P | Naples |
| **Felimare californiensis* (Bergh, 1879) | ≈100[b] | — | >7, <12[c] | 17–19[c] | — | — | — | (P) | Santa Catalina Island |
| **Geitodoris mavis* Marcus & Marcus, 1967, CASIZ 186482 | <85[d] | 1 | — | — | — | — | — | (P) | Punta Rosarito |
| *Okenia rosacea* (MacFarland, 1905) | — | 1 | — | — | 1 | 129.8 ± 1.0 (10) | no | P | Point Loma |

Table 2. Continued.

| Taxon | Egg Diameter (μm) | # eggs per capsule | Embryonic period (days) | Temp. (°C) | Shell type | Shell length at hatching (μm) | Eyespots at hatching | Mode of Development | Locality |
|---|---|---|---|---|---|---|---|---|---|
| *Palio dubia* (M. Sars, 1829), CASIZ 182721 | <75[d] | 1 | — | — | | — | — | (P) | Whittier, Alaska |
| *Polycera tricolor* Robilliard, 1971 | 78.0 ± 1.7 (10) | 1 | 7 | 18 | 1 | 120.0 ± 5.5 (10) | no | P | San Clemente Island |
| *Taringa aivica* Marcus & Marcus, 1967, CASIZ 186481 | <70[d] | 4–6 | — | — | — | — | — | (P) | Punta Rosarito |
| **Thordisa bimaculata* Lance, 1966, CASIZ 182715 | 79.6 ± 2.0 (5) | 1 | 9 | 15–19 | 1 | 122.8 ± 6.3 (10) | no | P | Point Loma |
| *Triopha maculata* MacFarland, 1905, CASIZ 184514 | 70.1 ± 1.1 (10) | 1 | 11 | 12–17 | 1 | 116.5 ± 1.8 (10) | no | P | Naples |
| **Nudipleura: Dendronotina** | | | | | | | | | |
| *Dendronotus subramosus* MacFarland, 1966 CASIZ 184512 | — | 1 | 8 | 10–20 | 2 | 223.2 ± 9.6 (10) | no | P | Asilomar |
| *Doto Columbiana* O'Donoghue, 1921, CASIZ 186483 | 73.6 ± 1.9 (5) | 1 | 7 | — | 1 | 120.1 ± 2.7 (10) | no | P | Hazard Canyon |
| *Melibe leonine* (Gould, 1852), CASIZ 186815 | 70.4 ± 1.6 (10) | 2–5 | 4 | — | 1 | 120.9 ± 3.6 (10) | no | P | Santa Barbara Harbor |
| **Nudipleura: Arminina** | | | | | | | | | |
| *Dirona picta*, MacFarland *in* Cockerell & Eliot, 1905, CASIZ 182714 | 70.1 ± 1.5 (10) | 4–5 | 4 | 15–21 | 1 | 114.7 ± 3.5 (10) | no | P | Point Loma |
| **Janolus anulatus* Camacho-Garcia & Gosliner, 2006, CASIZ 189420 | 66.7 ± 1.4 (10) | 1 | 6–7 | 12–18 | 1 | 110.7 ± 2.7 (10) | no | P | Tarpits Reef |
| *Janolus barbarensis* (Cooper, 1863), CASIZ 184513 | 95.4 ± 1.3 (10) | 15–20 | 8 | 16–24 | 1 | 187.1 ± 5.3 (10) | no | P | San Diego |
| **Nudipleura: Aeolidina** | | | | | | | | | |
| **Anstraeolis stearnsi* (Cockerell, 1901), CASIZ 186486 | 81.4 ± 2.2 (10) | 1 | 7 | 18 | 1 | 122.0 ± 7.3 (10) | no | P | La Jolla |
| **Babakina festiva* (Roller, 1972), CASIZ 182204 | 72.2 ± 2.2 (10) | 1 | 7.5 | 13–17 | 1 | 115.8 ± 1.1 (10) | no | P | Naples |

Table 2. Continued.

| Taxon | Egg Diameter (µm) | # eggs per capsule | Embryonic period (days) | Temp. (°C) | Shell type | Shell length at hatching (µm) | Eyespots at hatching | Mode of Develop-ment | Locality |
|---|---|---|---|---|---|---|---|---|---|
| *Cuthona lagunae* (O'Donoghue, 1926), CASIZ 182716 | 94.9 ± 1.1 (10) | 1 | 8 | — | 2 | 262.1 ± 2.5 (7) | yes | P | Hazard Canyon |
| *Cumanotus* sp. CASIZ 191891 | <80 | 1 | — | — | — | — | — | (P) | Santa Barbara Harbor |
| **Eubranchus* sp. 2 of Behrens & Hermosillo (2005), CASIZ 189422 | <100 | 1 | 6 | 12–19 | 2 | 210.4 ± 6.4 (10) | yes | P | South Casa Reef, La Jolla |
| **Flabellina cooperi* (Cockerell, 1901), CASIZ 186489 | 65.4 ± 2.0 (10) | 1–6 | 5 | 18 | 1 | 101.0 ± 6.9 (10) | no | P | La Jolla |
| | — | 2–4 | — | — | 1 | 105.9 ± 4.2 (12) | no | " | La Jolla |
| **Flabellina goddardi* Gosliner, 2010, CASIZ 182590 | 65.2 ± 0.5 (10) | 1 | 7 | 11–21 | 1 | 102.4 ± 2.3 (10) | no | P | Tarpits Reef |
| *Flabellina iodinea* (Cooper, 1862), CASIZ 182717 | — | 1–2 | — | — | 1 | 155.0 ± 4.3 (3) | no | P | Sand Dollar Beach |
| | — | 1–2 | — | — | 1 | 157.2 ± 3.2 (6) | no | P | Naples Reef |
| **Flabellina pricei* (MacFarland, 1966), CASIZ 186485 | 64.2 ± 1.0 (10) | 1 | — | — | | — | — | (P) | La Jolla |
| *Flabellina trilineata* (O'Donoghue, 1921), CASIZ 182718 CASIZ 189421 | — | — | — | — | 1 | 103.7 ± 1.9 (10) | no | P | Naples |
| | — | 1 | 7.5 | 12–19 | 1 | 105.6 ± 2.8 (10) | no | " | Naples |
| | 64.0 ± 2.5 (20) | 1–2 | — | — | 1 | — | — | (P) | Santa Barbara Harbor |
| **Flabellina* sp. (cf *F. trilineata*), CASIZ 182720 | 62.8 ± 2.2 (10) | 1 | 8 | 9–15 | 1 | 107.6 ± 2.0 (10) | no | P | Naples |
| | — | 1 | 8 | 9–15 | 1 | 110.8 ± 2.2 (10) | no | " | Naples |
| | 63.8 ± 1.5 (6) | 1 | 5.5 | 13–17 | 1 | 112.4 ± 3.8 (8) | no | " | Naples |
| | — | 1 | 5 | 13–17 | 1 | 108.7 ± 1.3 (10) | no | " | Naples |
| | — | 1 | 6 | 13–17 | 1 | 110.2 ± 1.5 (10) | no | " | Naples |

[a] Shells left behind while hatching from egg capsules.

[b] Estimate based on image of egg ribbon (see Methods and Figure 2A).

[c] C. Hoover, personal communication to JG, 30 Sept 2012.

[d] Measurements of early embryos preserved in 70% ethanol.

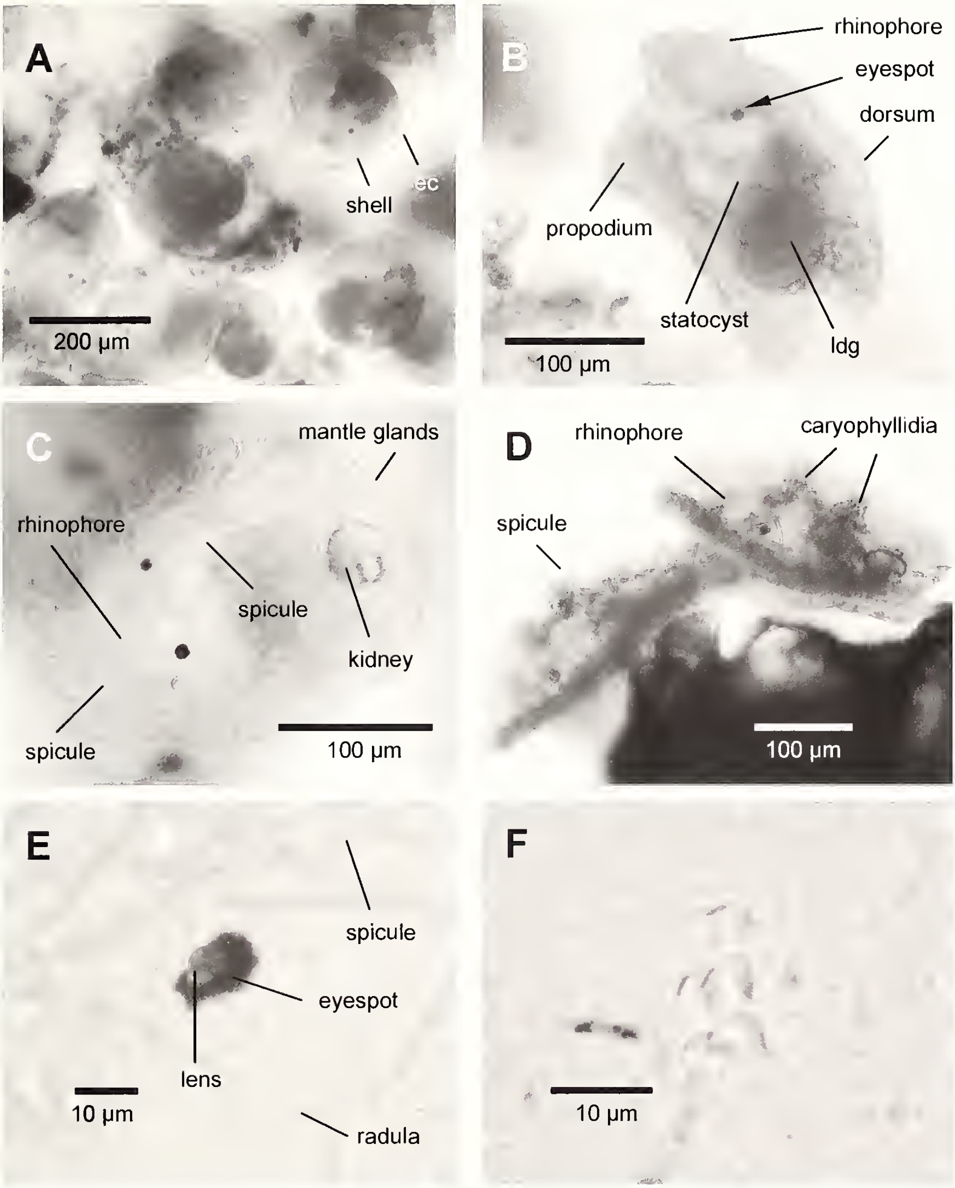


Fig. 1. Live embryos and newly hatched juveniles of *Atagema alba* from Bird Rock, La Jolla. **A**. Embryos, still encapsulated, on day of hatching. **B**. Juvenile, left lateral view, one day after hatching. **C**. Juvenile, dorsal view, one day after hatching. **D**. Two juveniles, five days after hatching. **E**. Eyespot, with overlying lens, and radula from juvenile, 7 days after hatching. **F**. Radula from juvenile, two days after hatching. Note three pairs of hammate teeth. E and F from squashed specimens. Abbreviations used in figure: ec = egg capsule; ldg = left digestive gland; rhinophore = rhinophore bud.

opisthobranchs from both the temperate and tropical northeast Pacific Ocean (Goddard 2004; Goddard and Hermosillo 2008). *Atagema alba*, with capsular metamorphic development, was the only species we observed in this study with non-feeding development. It represents the first example of direct development in a non-dendrodoridid nudibranch from the region. For each of the 18 species previously

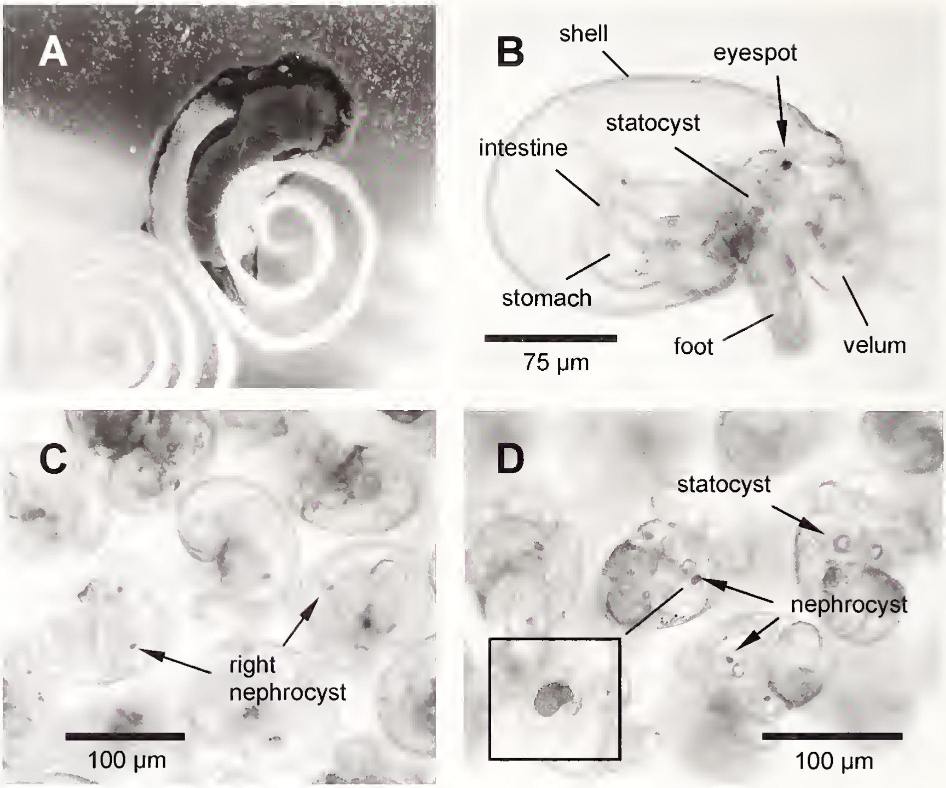


Fig. 2. Nudibranch egg masses and veligers. **A**. *Felimare californiensis* laying an egg ribbon in the laboratory at the USC Marine Laboratory on Santa Catalina Island, September 1972. Image by John Engle. **B**. Newly hatched veliger larva of *Eubranchus* sp. 2 of Behrens and Hermosillo (2005), right lateral view. **C**. Near-hatching veligers of *Tritonia festiva* from Cape Arago, Oregon, July 1987. **D**. Near-hatching veligers of *Janolus anulatus*, showing (inset) higher magnification of a nephrocyst.

examined, including *Polycera tricolor* and *Dirona picta*, our new data either support earlier determinations of development type, or confirm previous inferences (see Goddard 2004, Table 1). Below we (1) discuss individual species, including discrepancies with previously reported embryological data, and (2) correct the previous erroneous identification by one of us (JG) of nephrocysts as eyespots in two species.

*Stiliger fuscovittatus* Lance, 1962

Case (1972) studied this diminutive sacoglossan in San Francisco Bay and reported an uncleaved egg diameter of 70 μm and shell-size at hatching of 110 μm, similar to the values reported here for specimens from San Diego and Monterey. In contrast, Strathmann (1987) reported values of 95 μm and 150 μm for eggs and hatching larvae, respectively, from specimens from the San Juan Islands, Washington. A similar size discrepancy exists between our values for the eggs and larvae of *Melibe leonina* (Gould, 1852) from Santa Barbara (Table 2) and those reported by Strathmann (1987) for this species from the Washington and British Columbia. These size discrepancies are consistent with the inverse relationship between temperature and egg and larval sizes known for some marine invertebrates (discussed by Moran & McAlister 2009), and might be worth investigating experimentally.

*Atagema alba* (O'Donoghue, 1927)

The egg mass of this species was found under an intertidal cobble at Bird Rock, La Jolla. The egg mass was a fairly stout ribbon 3 mm high, coiled in 1.3 turns, with a simple (not wavy) free edge and a total diameter of 6.5 mm. The zygotes and embryos were white. Compared to the images in the Lance collection at CAS of an egg mass laid in captivity by an *A. alba* collected intertidally in San Diego in July 1969, the egg mass we found had one less turn, but was otherwise virtually identical in appearance, including the relatively large size and spacing of the embryos. In the northeast Pacific Ocean, only *Dendrodoris behrensi* Millen & Bertsch, 2005 deposits a similar egg mass, but its embryos are significantly larger than those of *A. alba*, are deposited in thicker-walled capsules, and undergo ametamorphic direct development (Goddard 2005). Our voucher specimens (CASIZ 186493) of *A. alba* consist of post-metamorphic juveniles as pictured in Figure 1D.

*Doris pickensi* Marcus & Marcus, 1967

This species, previously known only from the northern Gulf of California to Costa Rica (Behrens and Hermosillo 2005; Camacho-Garcia et al. 2005), laid its egg ribbon flat, rather than on edge like most other dorids. The yellow ribbon, pictured in Goddard (2012a), measured up to 2.3 mm wide and was laid in a loose coil of three turns.

*Felimare californiensis* (Bergh, 1879)

Our estimate of 100 µm for the egg diameter of this species is based on Ingram's (1935) measurement of a single egg ribbon, applied to Figure 2A, and therefore depends on variability in egg ribbon width in *F. californiensis*, which is unknown. However, the estimate is similar to the 95 µm egg size of another chromodorid, the sympatric *Felimida macfarlandi* (Cockerell, 1902), a known planktotroph (Goddard 2004), as well as planktotrophic representatives in the northeastern Pacific Ocean of the closely related genus *Cadlina* (Goddard 2004).

Based on *in situ* observations by Craig Hoover of three egg masses in Big Fisherman Cove, Santa Catalina Island, *F. californiensis* developed to hatching at 17–19°C in at least seven days, but not more than 12 days (Table 2). At these temperatures, this range in embryonic period falls within that typical of dorid nudibranchs with similarly sized eggs and planktotrophic development and is also at least a week shorter than embryonic periods known for species with non-feeding modes of development in the NE Pacific Ocean (Hadfield and Switzer-Dunlap 1987; Goddard 1996; Goddard and Hermosillo 2008). We therefore conclude that *F. californiensis* has planktotrophic development. Based on an image in (Kopp 2008), a smaller congener of *F. californiensis*, *F. porterae* (Cockerell, 1901) also lays relatively small eggs and likely has planktotrophic development.

Although the information we present here on the development of *F. californiensis* is incomplete and less precise than for other species, we have included it to help assess the cause of the loss of this species from the mainland of southern California. *Felimare californiensis* was once common throughout the Southern California Bight, but in contrast to other Californian nudibranchs in the region, has not been sighted on the mainland in over three decades (M. Miller *in* Behrens 2001; Goddard et al. 2013).

*Palio dubia* (M. Sars, 1829)

The size of the embryos from Alaska is consistent with measurements of the eggs and embryos of this species from the North Atlantic Ocean (Hamel et al. 2008; Goddard 2011a).

*Triopha maculata* MacFarland, 1905

Mulliner (1972) reported that an 80 mm long *Triopha grandis* MacFarland 1966 "produced 400,000 eggs per egg-mass" and hatched after 6 days (at an unspecified temperature) into "free swimming, planktotrophic veligers." Because both the large brood size and short hatching time are entirely consistent with planktotrophic development, Goddard (2004) followed Mulliner's (1972) determination of developmental mode for this species, which was synonymized, along with *Triopha occidentalis* (Fewkes, 1889), with *T. maculata* by Ferreira (1977). Behrens (1991) and Goddard (2004) followed Ferreira (1977), but not McDonald (1983, 2007), who considers *T. grandis* a junior synonym of *T. occidentalis*, separate from *T. maculata*. Our finding that the eggs deposited by a 50 mm long *T. maculata* were encapsulated singly (Table 2) contrasts with Mulliner's (1972) report of an average of 18 eggs per capsule for *T. grandis*. This large difference between egg masses in the number of eggs per capsule suggests that *T. grandis* may indeed be separate from *T. maculata*, as argued by McDonald (1983, 2007).

*Doto columbiana* O'Donoghue, 1921

This species feeds on hydroids of the genus *Aglaophenia* and has previously been referred to by the senior author as *Doto* form B (Goddard, 1996, 2004). The sizes of the eggs and hatching larvae reported here from Hazard Canyon are similar to those reported from northern California by Goddard (1996).

*Janolus anulatus* Camacho-Garcia & Gosliner, 2006

The cream to white egg strings of this species (see Goddard 2012b) contained embryos encapsulated singly. This contrasts with other species of *Janolus* known from the northeast Pacific Ocean, including *J. barbarensis* (Cooper, 1863), with 15 to 20 embryos per capsule (present study, Table 2), and *J. fuscus* O'Donoghue, 1924, with an average of 66 embryos per capsule (Wolf and Young 2012). The zygotes and hatching larvae of *J. anulatus* were also significantly smaller than those of the above two congeners (Goddard 2004; Wolf and Young 2012; present study, Table 2).

*Cumanotus* sp.

Following Behrens (1991), Goddard (2004) referred to this species, which feeds on *Ectopleura crocea* (Agassiz, 1862) in bays and harbors, as *Cumanotus fernaldi* Thompson & Brown, 1984. However, as pointed out by S. Millen (personal communication to JG, 8 Jan 2012), Thompson and Brown (1984) in their brief description of *C. fernaldi* were referring to the larger, soft-sediment dwelling species studied by Hurst (1967) that is ecologically and morphologically similar to the north Atlantic *C. beaumonti* (Eliot, 1906). Hurst (1967) used the name *C. beaumonti* for her specimens from Washington and reported that they laid corkscrew shaped egg masses with 4–14 eggs per egg capsule. *Cumanotus* sp. consistently has one egg per capsule (Goddard 1992; present study, Table 2), is ecologically and morphologically similar to the north Atlantic *C. cuenoti* Pruvot-Fol, 1948, and is undescribed (S. Millen, personal communication to JG, 8 Jan 2012). It is pictured as *C. fernaldi* in Behrens and Hermosillo (2005, species number 244), but that name actually applies to species number 245 in Behrens and Hermosillo (2005). (S. Millen, personal communication to JG, 8 Jan 2012).

Unaware that two species of *Cumanotus* exist in the northeast Pacific Ocean, Goddard (2004, Table 1) lumped development data for both species. The complete and correct breakdown is as follows. Based on Hurst (1967), *C. fernaldi* (as *C. beaumonti*) deposits corkscrew-shaped egg masses with 4–14 eggs per capsule that hatch after 10 days at 8–11°C with type 1 shells averaging 119 µm long. Based on Goddard (1992, 2011b) and the present study, *Cumanotus* sp. also deposits corkscrew-shaped egg masses, but with one egg (averaging 73 µm in diameter) per capsule, hatching after 9–10 days at 12–16°C with type 1 shells averaging 130 µm long.

*Cuthona lagunae* (O'Donoghue, 1926)

The egg masses and embryonic development of specimens of *C. lagunae* collected from Hazard Canyon in central California were virtually identical to those described by Goddard (1991) for specimens from northern California and southern Oregon, including the extrusion from the zygotes of unusually large, yolk-filled polar bodies.

*Eubranchus* sp. 2 of Behrens and Hermosillo (2005)

This species laid small, C-shaped egg masses characteristic of the genus. The embryos developed into planktotrophic veligers with type 2 shells, a small foot, eyespots, and minimal yolk reserves (Figure 2B).

*Flabellina goddardi* Gosliner, 2010

The developmental data for this species in Table 2 were obtained from the coiled and secondarily looped, white egg string and near-hatching veligers pictured without size or scale information in Gosliner's (2010) original description of this distinctive species. Since finding the first specimen in May 2008, we have found 14 additional specimens of *F. goddardi*, all in May and June at Tarpits Reef in Carpinteria, California, the type locality of this species.

*Flabellina trilineata* (O'Donoghue, 1921)

Two specimens found feeding on *Ectopleura crocea* in the Santa Barbara Harbor in January 2012 each laid egg strings with most capsules containing 2 eggs (Table 2). Previously, only one egg per capsule has been recorded for this species, including for specimens from the outer coast of Santa Barbara County (Bridges and Blake 1972; Strathmann 1987; Goddard 1992; present study).

*Flabellina* sp.

Adults were collected intertidally at Naples, on the south coast of Santa Barbara County. They closely resembled *F. trilineata* collected from the same locality in overall shape, but had smooth to slightly wrinkled rhinophores, more irregular white lines on the body, and white cnidosacs. Instead of a thin white line down the middle of the notum as in *F. trilineata*, some of our specimens of *Flabellina* sp. had a notum mostly covered with white pigment. *Flabellina* sp. deposited egg masses similar to those of *F. trilineata* collected from the same locality, but the ribbons of *Flabellina* sp. had a smaller diameter. The eggs were similar in diameter to those of *F. trilineata*, but the shells of the hatching veligers were slightly larger (Table 2). Preliminary genetic evidence suggests *Flabellina* sp. is distinct from *F. trilineata* (R. Johnson, personal communication to JG, 23 June 2010).

In his description of *Coryphella piunca*, Marcus (1961, Fig. 163) illustrated smooth to lamellate rhinophores. Steinberg (1963) synonymized *C. piunca* with *C. trilineata* O'Donoghue, 1921, and later, Roller (1970) synonymized *C. fisheri* MacFarland, 1966 with *C. trilineata*. Because both MacFarland's (1966) description of *C. fisheri* and

O'Donoghue's description of *C. trilineata* only mention annulate or lamellate rhinophores, it appears that Marcus's *C. pinnca* likely included specimens of both *F. trilineata* and *Flabellina* sp. as recognized here.

Goddard (1984, Table 1) reported that dendronotid *Tritonia festiva* has eyespots at hatching, and Strathmann (1987, p. 291) and Goddard (2001b, Appendix A) repeated this. Reexamination of JG's original notes from 1981 and photomicrographs taken by JG in 1987 of the hatching larvae of this species revealed the paired structures were not eyespots, but rather nephrocysts (see Thompson 1976; Bonar 1978; Bickell and Kempf 1983) containing unusually large and dense, irregularly shaped, semi-translucent granules. At low magnification and certain angles of view and illumination, these structures can appear to be eyespots (Figure 2C). However, larval eyespots in opisthobranchs consist of thin patches of opaque black pigment, develop an overlying hyaline lens, and are located anterior to the nephrocysts (Thompson 1976; Bonar 1978). Goddard (1992, 2001b) also mistook dense nephrocysts for eyespots in the arminid nudibranch *Janolus fuscus*, but these have also been confirmed to be nephrocysts in both this species (Wolf and Young 2012; pers. obs.), as well as its congener, *J. anulatus* (present study, Figure 2D).

The combined presence of eyespots and a propodium is a reliable indicator of metamorphic competence in opisthobranchs (Bonar 1978), and most planktotrophic nudibranchs hatch without eyespots (Bonar 1978; Hadfield and Switzer-Dunlap 1984; Goddard 2004). However, exceptions are known from the northeast Pacific Ocean, including species of Eubranchidae and Tergipedidae (Hurst 1967; Strathmann 1987; Goddard 1991; present study, Figure 2B) and the dorid *Aegires albopunctatus* MacFarland, 1905, which has unusual larval development (Goddard 2001a).

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# Small Mammal Use of the Burn Perimeter Following a Chaparral Wildfire in Southern California

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*Abstract.*—Wildfires in southern California chaparral burn at high intensities and often cover thousands of hectares. Some small mammals survive the fire, while others colonize from scattered unburned islands and from intact vegetation bordering the main fire perimeter. For ten years (2002–2011) we live-trapped two grids and used the number of captures to examine post-fire small mammal use of a narrow 65-m zone straddling the high-contrast edge between burned and unburned chaparral on the perimeter of a high-intensity wildfire. Results indicate that agile kangaroo rats (*Dipodomys agilis*) were captured more often in open, burned areas than in unburned chaparral. Deer mice (*Peromyscus maniculatus*) were captured equally in burned and unburned chaparral but did not show an affinity for either habitat or the edge of the burn. Pinyon mice (*Peromyscus truei*) were captured most often in unburned chaparral throughout the study but were prevalent on the burn edge in years one and four. In the first year post-fire, California mice (*Peromyscus californicus*) were captured more frequently in unburned than burned chaparral but in years four and five, captures shifted toward the edge and then into the burn areas in year nine. We did not find evidence that any of the four species were dedicated edge specialists in this study. Neither pinyon mice nor California mice appeared to be permanent residents of the burns in the first ten years post-fire. We suggest that future research on post-fire small mammal succession in chaparral would benefit from chronosequence studies that give a more comprehensive, long term picture of succession.

## Introduction

Chaparral wildfires in southern California, especially those driven by hot, dry Santa Ana winds in the fall, spread quickly, burn at high intensities, and have the potential to reach thousands of hectares in size. Post-fire temporal and spatial patterns of burn-area re-colonization by small mammals depend on a several factors, but primarily on the number of animals surviving the fire *in situ* (Banks et al., 2011) and on animals re-entering the burn from refugia (*e.g.*, unburned brush, rock outcrops, riparian zones). Since chaparral fires usually do not leave vegetation mosaics, unburned islands within large (thousands of hectares) burns often are few in number, vary greatly in size, and tend to be widely scattered (Quinn 1990; Borchert et al., 2003). Compared to unburned islands, intact chaparral bordering the fire perimeter offers a more dependable source of colonists and is more likely to harbor the full contingent of small mammal species, and in greater numbers, than vegetation islands (Longland and Bateman, 2002).

Management strategies for conserving faunal diversity after wildfires depend on a multi-scale understanding of fire effects (Di Stefano et al., 2010). The earliest post-fire small mammal studies in chaparral focused on the colonization of individual sites in burned and unburned chaparral (Lawrence 1966; Wirtz 1977; Wirtz et al., 1988; Wirtz 1995). Often, however, proximity of burn trapping grids to the nearest unburned refugia was not stated and it was assumed that the rate of re-occupation was not dispersal-limited (Rosario and Mathias, 2007). More recently, research on small mammal succession has shifted to much larger scales (Schwilk and Keeley, 1998; van der Ree and Loyn, 2002; Brehme et al., 2011; Diffendorfer et al., 2012). Trapping grids in these studies were placed in both unburned vegetation as well as in the burned area at varying distances from known refugia. Results of these studies have provided a more complete picture of the considerable variability in small mammal re-colonization that can occur at the landscape scale.

A conspicuous feature of all chaparral wildfires is the high-contrast, hard edge along the burn perimeter and at the margins of unburned islands. While there is extensive literature on the effects of edges on small mammals in unburned habitats (e.g., Murcia 1995; Lidicker 1999), few studies have addressed small mammal use of fire-induced edges, even though edges play an important role in the recovery of the fauna in burned areas (Larrivée et al., 2008; Santos et al., 2009; Tasker et al., 2011). For example, we know of only three studies on small mammal use of fire-induced edges (Figueiredo and Fernandez, 2004; Pires et al., 2005; Diffendorfer et al., 2012).

The habitat accommodation model (Fox 1982) has been proposed to explain small mammal succession in burned areas. This model relates small mammal re-colonization to post-fire changes in vegetation structure and composition, which also makes the model applicable to small mammal use of fire-caused edges. More recently, Ries and Sisk (2004) proposed a specific model to predict faunal distributions at edges of all types. Their model focuses on resource differences between the two juxtaposed habitats and the edge that separates them. In addition to creating sharp differences in vegetation, the edge separates habitats with markedly different food resources, risks of predation and abiotic factors. For example, in burned chaparral the early post-fire flora produces an abundance of seeds that may be missing, or occur at low densities, in unburned chaparral (Tyler and Borchert 2002). Moreover, as obligate seeding shrubs re-establish in the burn area, supplemental seeds may be abundant for several decades. On the other hand, unburned chaparral provides better protection from predators, especially in the early post-fire years. This asymmetry in resources creates conditions in which small mammals may increase their use of the edge because they can readily access an abundant food supply in the burn and at the same time find protection from aerial predators and carnivores in adjacent unburned chaparral.

In this study, we focused on small mammal use of a narrow zone (65 m) straddling burned and unburned chaparral on the main fire perimeter of a wildfire. Based on the Ries and Sisk model, we expected small mammals to increase their activity at the burn edge, especially in the early post-fire years when the seed supply increased in the burn area. However, as the edge softened in later years, and burned vegetation became increasingly similar to the unburned chaparral, we expected the attraction to the edge to be less pronounced, or to disappear altogether. Therefore, our objectives were (1) to describe small mammal use of a high-contrast edge over a 10-year period, and (2) to compare edge and burn-area use to existing studies of small mammal succession in burned chaparral at greater distances from the burn perimeter.

## Methods

### *Study Area*

In June 2002, the 8,100-ha Wolf Fire burned the two study sites situated on an extensive (~ 40 ha), old river terrace 30 m above Sespe Creek at 955 m elevation in Los

Padres National Forest. The study area is located 15 km NNE of Ojai, CA. The trapping grids were ~ 560 m NNW of the Sespe Trailhead (34° 33′ 38″ N, 119° 9′ 52″ W). Before the fire, the study area was dominated by 70-year-old chamise (*Adenostoma fasciculatum*) chaparral, with widely scattered dead chaparral whitethorn (*Ceanothus leucodermis*). Climate of the study area is Mediterranean consisting of cool wet winters and long dry summers. Average annual precipitation for Ojai, CA is 539 mm. From 2002–2010 precipitation was above average in five years and below average in four years.

The fire burned at unusually high intensity through the entire study area but was extinguished on the flat terrace ~ 120 m before reaching Sespe Creek. At the locations of the trapping grids, the boundary between burned and unburned chaparral was sharply defined because a 5-m wide bulldozer line was constructed as part of the fire suppression effort. On one side of the dozer line was a linear edge of unburned chaparral and on the burned side of the line a narrow (0.5 m–1.0 m) partially burned strip of vegetation left by the dozer we termed the "fringe". Beyond the narrow fringe was the expansive, denuded burn area. In the early years after the fire the cleared dozer line was sparsely vegetated but by nine years chamise cover was ~40%.

### *Small Mammal Trapping*

We established two 8 × 12 trap grids 110 m apart. At each site, a row of 12 traps spaced 10 m apart was placed along the linear edge of the chaparral. Another row of traps was placed along the fringe five meters opposite the edge traps. Additional rows of traps were arrayed in the burn areas 15, 25 and 35 m perpendicular to the edge traps and 10, 20 and 30 m in the interior of the unburned chaparral. We used a single, large Sherman trap (10 cm × 12 cm × 38 cm) at each station.

We opened traps in the afternoon the first day and trapped for five days (four trap nights). Traps were baited with sunflower seeds and pieces of peanuts and walnuts. Cotton balls served as bedding. We checked traps each morning. Captured animals were marked at the base of the tail with a permanent marking pen, weighed, sexed, and assessed for reproductive condition. We used weight and pelage color to distinguish adult from sub-adult animals.

Trapping began in July 2002, one month after the fire. We trapped both grids in the spring (May–July) and fall (September–November) for the first five years post-fire (2002–2006). At the end of five years, several species lacked a sustained presence in the burned areas so we delayed trapping until the spring of 2008 and again in the spring of 2011 to monitor changes in their status in the burn areas.

### *Vegetation Methods*

For each grid we estimated the cover of shrubs, herbs, forbs and grasses to the nearest 5% within 7-$m^2$ (radius 1.5 m) plots using the trap station as plot center. Cover was sampled at burn stations one, three and eight years post-fire and at the unburned stations one and eight years post-fire. To measure the vertical stratification of foliage at all the stations, we randomly chose 1 $m^2$ within each 7-$m^2$ macro-plot. We first estimated the total shrub cover and height in the 1-$m^2$ plot after which we placed a 2.5-m pole alternately banded in 50 cm increments at the plot center. The estimated cover of the 1-$m^2$ plot was partitioned among the 50-cm intervals marked on the pole.

### *Rodent Abundance*

We used the Schnabel capture-recapture model to calculate the number of rodents per hectare in each trapping session. Densities are presented for the two grids combined

Table 1. Vegetation percent cover in burned chaparral in 2003, 2005 and 2010 and in unburned chaparral in 2003 and 2010. Values are means ± 1 SE.

| | 2003 | | 2005 | 2010 | |
|---|---|---|---|---|---|
| | Unburned | Burned | Burned | Unburned | Burned |
| Herbs, forbs, and grasses | 0 | 31.4 ± 2.8 | 14.0 ± 2.7 | 0 | 0 |
| *A. fasciculatum* | 71.2 ± 1.8 | 19.7 ± 2.7 | 35.8 ± 3.4 | 69.5 ± 1.9 | 42.9 ± 2.2 |
| *C. leucodermis* | 0 | 0 | 2.0 ± 3.4 | 0 | 16.9 ± 2.1 |

which summed to 1.43 ha. Because animals were batch-marked, densities could not be calculated separately for burned and unburned areas.

### *Statistical Analysis*

We spread fourteen trapping sessions over nine years. Sessions were lumped to create yearly intervals for analysis. For example, sessions at 1 and 6 months were combined for the early post fire period (year 0). Yearly intervals with their corresponding sessions are as follows: year one (11 and 14 months), year two (18, 22 and 24 months), year three (34 and 40 months), year four (46 and 51 months), year five (58 months), year seven (85 months) and year nine (107 months).

We used captures of each species to analyze the use of the four habitats over time: burned, fringe, edge and unburned. We analyzed habitat use by calculating the mean captures per trap (total captures in 4 nights) for 72 traps in the burned areas, 24 fringe traps, 24 edge traps and 72 traps in the unburned areas. Captures for the two grids were combined for the analyses since they were identical in rodent species composition and combining them increased the sample size. Because capture data were zero-inflated and failed to meet the assumptions of normality, we used Kruskal-Wallis analysis of variance to test for differences in captures per trap among the habitats for each of the eight years.

## RESULTS

### *Vegetation Structure*

The high-intensity fire completely denuded the burn area. All that remained immediately after the fire were exposed chamise burls with short (~15 cm), charred stems. Post-fire annual cover was highest in 2003 and was composed almost entirely of the annual short-lobed phacelia (*Phacelia brachyloba*) (Table 1). By 2005 the cover of annuals and short-lived perennials had all but disappeared in the burn.

Living chaparral whitethorn was absent in unburned chaparral but after the fire, seedling production by this shrub was prolific so that by 2005 cover had reached 2% (Table 1). Between 2005 and 2010 the cover and height of chaparral whitethorn increased rapidly and by 2010 it comprised 17% of the burn area shrub cover (Table 1). Chamise both resprouted and produced seedlings after the fire; its height and cover increased steadily in the burned area. After eight years, average total shrub cover did not differ significantly between burned and unburned stations (69.5% burned vs. 59.8% unburned, $t_{82} = -1.07$, $P = 0.29$) although shrubs still were taller in the unburned vs. the burned areas (178.5 cm unburned vs. 142.2 cm burned, $t_{81} = 6.02$, $P \leq 0.001$).

The vertical foliage distribution was markedly different between burned and unburned vegetation eight years post-fire (Fig. 1). Compared to unburned chaparral, higher percentages of shrub foliage in the burned areas were in the 0–50 and 51–100 cm classes

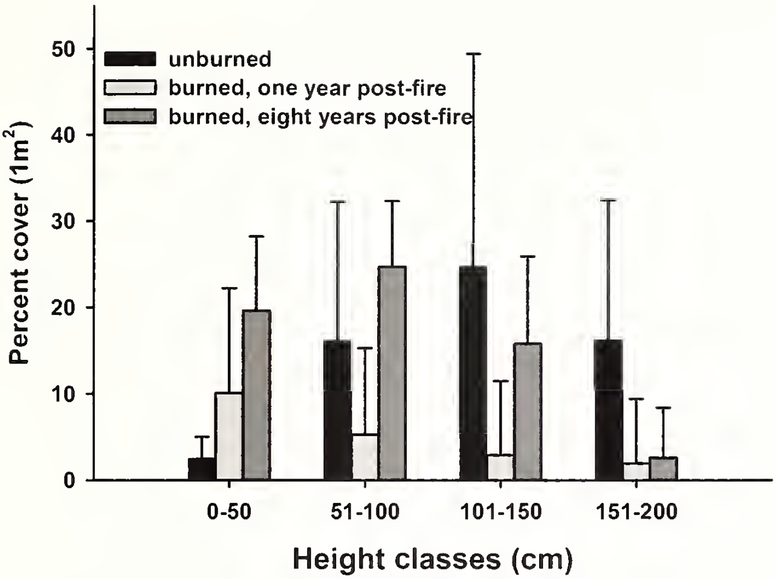


Fig. 1. Vertical stratification of shrub cover in 50-cm intervals for burned and unburned chaparral in the trapping grids. Unburned values are for one (2003) and eight years (2010) post-fire combined, and for burned chaparral one (2003) and eight (2010) years post-fire. Cover values are means ± 1 SE.

(Fig. 1). After nine years, the burn area remained more open with much of the foliage of the young shrubs concentrated in the lower strata. In unburned chaparral higher percentages of foliage were in the 101–150 and 151–200 cm classes but, unlike the burned stations, foliage was sparse in the near-ground stratum (0–50 cm) (Fig. 1). In the tallest layers of unburned chamise foliage and branches often formed a continuous, interlocking canopy.

### *Trapping Results*

Between July 2002 and April 2011, 10,752 trap nights yielded a combined total of 778 captures of eight rodent species on the two grids. Based on the number of captures four species were relatively common and included: agile kangaroo rats (*Dipodomys agilis*) (224 captures), pinyon mice (*Peromyscus truei*) (218 captures), deer mice (*Peromyscus maniculatus*) (156 captures), and California mice (*Peromyscus californicus*) (170 captures). We also captured four Merriam's chipmunks (*Eutamias merriami*), four California ground squirrels (*Otospermophilus beecheyi*), one big-eared woodrat (*Neotoma macrotis*) and one brush mouse (*Peromyscus boylii*).

### *Agile Kangaroo Rats*

Agile kangaroo rats initially were present in low numbers (Fig. 2a). At two years, density increased dramatically, primarily because juveniles made up half of the total. Density declined in the following years and remained relatively stable (Fig. 2a).

Captures were highest in the burn areas for three of the eight years (Fig. 3a). In the other five years captures were evenly distributed among the four habitats although burn-area captures slightly exceeded the other three habitats in each year (Fig. 3a). Kangaroo rats treated the fringe like the burned areas in the first three years. Captures in the burn areas peaked four and five years post-fire (Fig. 3a). Even though shrub cover increased

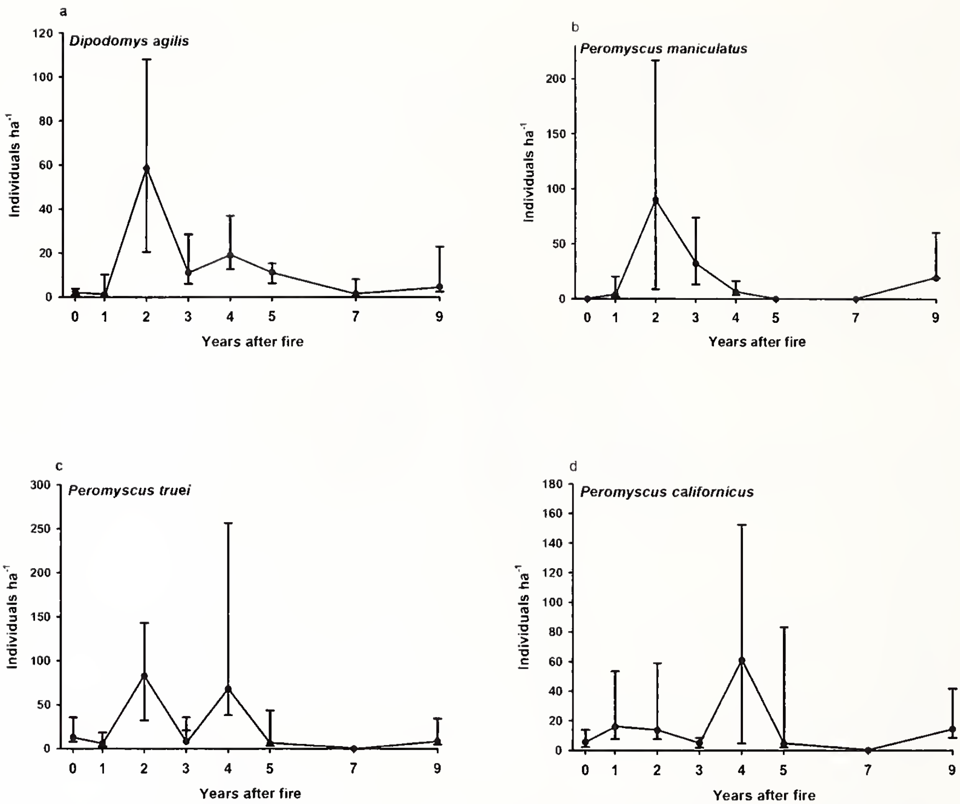


Fig. 2. a. *Dipodomys agilis* (agile kangaroo rat) density, b. *Peromyscus maniculatus* (deer mouse) density, c. *Peromyscus truei* (pinyon mouse) density, and d. *Peromyscus californicus* (California mouse) density. Values are for the total area of the grids: 1.43 ha. Error bars are the 95% confidence limits of the means.

and ground cover decreased after the fire, agile kangaroo rat captures remained relatively high in the burn areas until the conclusion of the study (Fig. 3a). Of the 50 sub-adult captures, 64% were in the burned areas, which was similar to adult captures (62%).

### *Deer Mice*

Deer mice were not captured in three of the eight years making them the most variable of the three cricetids in terms of changes in density (Fig. 2b). Captures showed no significant difference among any of the habitats during the study (Fig. 3b). Adult and sub-adult males comprised 68% of the 68 captures in the burns.

### *Pinyon Mice*

Pinyon mouse densities peaked in years two and four (Fig. 2c). Of the four species, pinyon mice consistently showed the highest mean captures in unburned chaparral in all eight years (Fig. 3c) and were least likely to enter the burn, although there was one short-lived increase in year two (Fig. 3c). Mean captures at the edge were highest in year 4 and were relatively high, but not statistically significant, in years zero, one, four, seven and nine (Fig. 3c). Of the 22 captures in the burns, 68% were adult and sub-adult males.

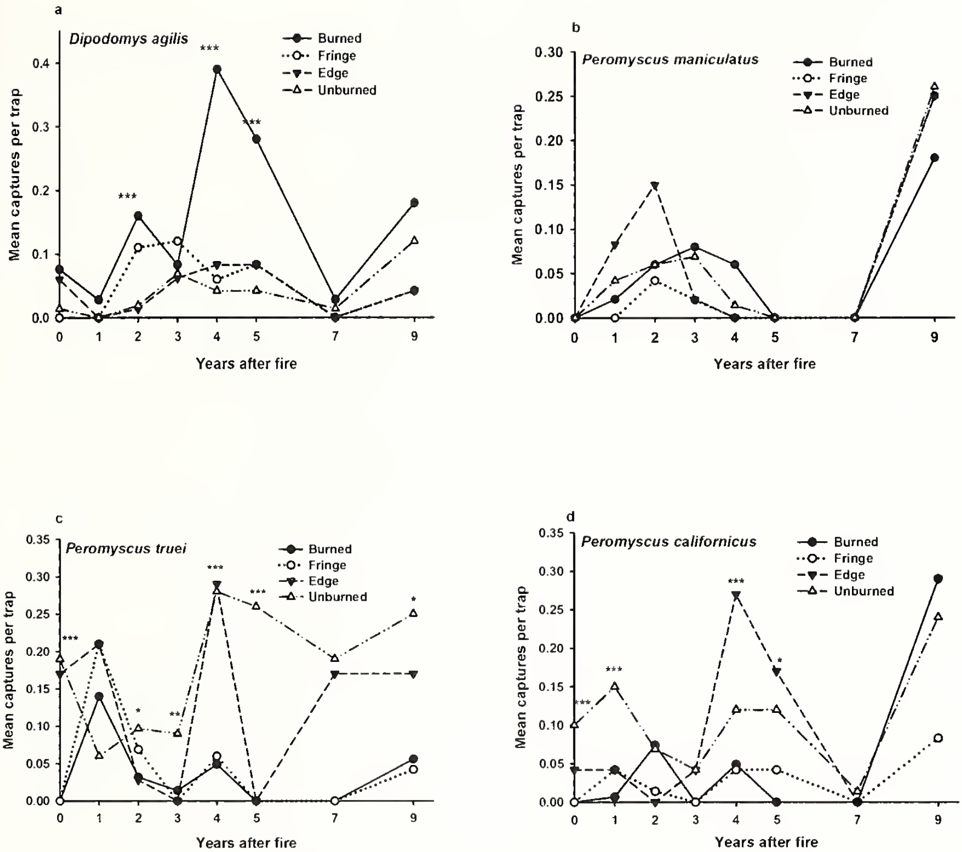


Fig. 3. a. Mean captures per trap for *Dipodomys agilis* (agile kangaroo rat) in the burned areas (solid circle), fringe (open circle), edge (inverted solid triangle) and burned areas (open triangle), b. Mean captures per trap of *Peromyscus maniculatus* (deer mouse) for the four habitats, c. Mean captures per trap of *Peromyscus truei* (pinyon mouse) for the four habitats, and d. Mean captures per trap of *Peromyscus californicus* (California mouse) for the four habitats. Confidence intervals of the means have been removed for clarity. Asterisks indicate a significant difference in captures among the four habitats using Kriskal-Wallis ANOVA. Statistical significance is indicated as follows: * $p<0.05$, ** $p<0.01$ and *** $p<0.001$.

## *California Mice*

The density of California mice was highest in year four (Fig. 2d). In the early years, California mouse captures were most prevalent in unburned chaparral but shifted to the edge in years four and five (Fig. 3d). Burn-area captures were highest in year nine. Of the 35 burn captures, 68% were adult males while just 2% were sub-adults.

## Discussion

Based on what was known about the response of the four species to fire at the onset of this study, we expected them to enter the burns relatively quickly and, in fact, all appeared by 18 months post-fire, perhaps in response to seed production by post-fire herbs and forbs (Morris and MacEachern 2010; Plavsic 2011) . Agile kangaroo rats were captured most frequently in the burn areas (Fig. 3a). Deer mice, in contrast, were habitat generalists and were captured in all the habitats (Fig. 3b). Pinyon mouse captures were concentrated in in unburned chaparral throughout the study (Fig. 3c) although they showed significant use of the edge in year four. California mouse captures were mostly confined to interior chaparral stations in the early years but shifted to edge and burned stations in years four and five (Fig. 3d).

In this study, kangaroo rats were strongly attracted to the open, burned areas. The prevalence of agile kangaroo rats in the burned areas was expected since it is a well-known early successional specialist (Wirtz 1977; Price et al., 1995; Quinn 1990; Schwilk and Keeley, 1998). Indeed, many *Dipodomys* spp. prefer open, newly burned habitats in a variety of vegetation types (Halford 1981; Brehme et al., 2011; Monasmith et al., 2010; Horn et al. 2011; Litt and Steidl, 2011).

Deer mice also readily occupied the burn area (Fig. 3b). This species is a habitat generalist and was edge-neutral. Deer mice are somewhat arboreal in chaparral (Laakkonen 2003) and are well-known for their ability to rapidly re-occupy burned areas (Quinn 1990; Price et al., 1995; Brehme et al., 2011). Indeed, deer mice are often the most abundant early burn rodents in an array of vegetation types (Larsen et al., 2007; Zwolak and Forsman, 2008; Fuhlendorf et al., 2010; Kirchner et al., 2011). In burned conifer forests, for example, deer mice populations increased soon after fire and became self-sustaining (Zwolak and Forsman, 2008). In fact, animals dispersed from burned into unburned habitats. In this study, deer mice trapped in unburned chaparral also may have come from populations in the burn area.

Based on Lawrence's findings (1966) for pinyon mice in northern California chaparral, we expected this species to enter the burn areas quickly in high numbers or perhaps to concentrate their activity at the edge where they had ready access seed produced by the post-fire annuals and short-lived perennials (Tasker et al., 2011). Instead, pinyon mice consistently were captured in unburned chaparral with only one notable increase (year one) in the burned areas (Fig. 3c). Edge use was significant in year four but also was relatively high in years zero, one, seven and nine (Fig 3c). Although frequently captured on the edge, pinyon mouse was not an edge specialist; it appeared to treat the edge as if it were unburned chaparral.

California mice are late-seral chaparral inhabitants (Merritt 1978; Quinn 1990) and have a negative response to fire (Lawrence 1966; Wirtz et. al., 1988; Brehme et al., 2011). We did not expect California mice to enter the burn early like pinyon mice, but we thought they might occupy the edge, or even the fringe, perhaps to take advantage of the early post-fire seed resource, and in later years, show an increase in the burn areas in response to increasing shrub cover, height and seed production.

Early in the study California mice captures were concentrated in unburned chaparral (Fig. 3d). However, by years 4 and 5 California mouse captures increased markedly at the edge, although they also continued to be relatively high in unburned chaparral (Fig. 3d). In those two years this species may have been an edge specialist. If so, it is not clear why since *Ceanothus leucodermis*, which began to produce seeds in the burned areas in year four, was absent in the space between the edge and fringe. Finally, burn-area occupation by California mice was intermittent (years two, four and nine), supporting other studies that have reported the irregular appearance of California mice in the early post-fire years (Quinn 1990), especially after high severity fires (Wirtz 1995). California mice in burned chaparral were more abundant near unburned vegetation than at sites farther from refugia (Schwilk and Keeley, 1998; Diffendorfer et al., 2012).

Small mammal re-occupation of burns is often closely linked to structural vegetation recovery (Fox et al., 2003; Di Stefano et al., 2010) as well as seed production (Suazo et al., 2013). According to the habitat accommodation model (Fox 1982), small mammals sequentially re-enter disturbed habitats when their species-specific vegetation requirements are met, *e.g.*, when its optimum height or cover values are attained. As the optimum vegetation requirements of a species develop, its abundance increases, but then declines as the vegetation moves away from its optimum (Monamy and Fox, 2000; Fox et al., 2003). In this study, agile kangaroo rats increased in the open burn areas (its optimum) but are expected to decrease as the cover and complexity of late-seral chaparral returns (Quinn 1990).

In contrast, the habitat distributions of California mice and pinyon mice suggest the vegetation structure in the burn has yet to reach their re-occupation optima. Both species are highly arboreal in late-seral shrublands (Meserve 1972; Laakkonen 2003). Although we did not trap the shrub canopies, it is possible that a more permanent presence of these species in the burned areas depends on the development of a more complex shrub canopy, *i.e.*, one more conducive to arboreal activity. The tall canopy layers and intermingled branches characteristic of late-seral chamise chaparral have yet to fully develop in the burns after ten years (Fig. 1).

Studies of post-fire succession of small mammals in chaparral have been relatively short in duration, lasting one to seven years (Wirtz 1995; Schwilk and Keeley, 1998) and have focused primarily on the first arrival of species in burn areas. For some species, however, the early post-fire years may be only the beginning stage of a much longer period of re-occupation. In a chronosequence study of small mammal succession in Australian tree mallee, Kelly et al. (2011) showed that colonization of recovering burns occurred rapidly for some species but required many decades for others. For example, house mice (*Mus domesticus*) quickly re-occupied (< five years) burns dominated by bare ground. However, this initial surge in abundance was followed by a decline until it was rare in burns older than 20 years. In contrast, the late successional southern ningaui (*Ningaui yvonneae*) was missing from recent (<14 months) burns. Instead, males attained their maximum abundance at ~25 years post-fire and females did not peak until ~30 years. Most notably, breeding females did not reach a maximum until ~45 years. In this study, agile kangaroo rats and deer mice quickly occupied the burns and appeared to have a sustained presence there over the ten years. In contrast, pinyon mice and California mice mainly inhabited unburned chaparral and only intermittently entered the burns. Throughout the study, males dominated burn captures of the latter two species suggesting they were still in the early phases of re-occupation (Southerland and Dickman, 1999).

Because we studied a small portion of the burn perimeter, our results have limited application to the rest of the burn. Nevertheless, one of our main conclusions is that previous studies of chaparral small mammal succession may have described only the earliest phases of post-fire re-occupation by late-seral small mammals and that there is a need to address longer time periods perhaps using a chronosequence approach. After a decade, pinyon mice and California mice have yet to regularly occupy the burns and most early colonists of these species were males. Clearly, studies lasting < 10 years may not be long enough to describe the complete re-entry of these species. Trapping chaparral burns of different ages offers the opportunity to gather both demographic and habitat requirement data over a longer time period. Using this approach, it would be possible to examine how the proportion of males and females occupying recovering chaparral changes over time, as well as to determine when reproductive females become permanent members of the small mammal community.

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# *Cetorhinus* cf. *C. maximus* (Gunnerus) (Lamniformes: Cetorhinidae), A Basking Shark from the Late Miocene Empire Formation, Coos Bay, Oregon

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*Abstract.*—The family Cetorhinidae Gill includes one extant genus, *Cetorhinus* Blainville, and a single living species, the basking shark, *C. maximus* (Gunnerus). Basking sharks are coastal pelagic to oceanic with circumglobal distribution in boreal to warm-temperate waters of the continental and insular shelves. Second only in size to the whale shark, *Rhincodon typus*, basking sharks attain a maximum total length of 12 to 15 m (although generally not exceeding 9.8 m), and are planktivorous, feeding by filtering copepods, barnacles, decapod larvae and fish eggs from the water. The first Tertiary records of undisputed cetorhinids are from the middle Eocene of Antarctica, possibly the middle Eocene of Russia, and the late Eocene of Oregon. Eocene cetorhinids are referred to *Keasius taylori*, and Oligocene through early Miocene basking sharks are traditionally assigned to *Keasius parvus*. The earliest occurrence of *Cetorhinus* in the northeastern Pacific is early Miocene, and fossils attributed to this genus are relatively common in middle Miocene through Pleistocene marine sediments of Oregon, California, and Baja California, Mexico. Late Miocene and younger *Cetorhinus* are conventionally placed in the extant species, *C. maximus*. Late Miocene fossils of a basking shark from the Coos Conglomerate Member of the Empire Formation, Oregon, were collected in 1972 by students from the University of California, Berkeley. Associated vertebrae and gill rakers compare favorably in size and overall morphology with those of adult Recent *C. maximus*. Based on correlations of vertebral and gill raker dimensions with the total length for Recent *C. maximus*, the Empire basking shark is estimated to have been between 4.5 and 5.75+ m in total length. Although gill rakers and vertebrae from the Empire Formation compare favorably with those of *C. maximus*, a definitive identification requires dentition. The occurrence of *Cetorhinus cf. C. maximus* in the late Miocene of Oregon is consistent with other late Miocene records of this species in California and Chile. *C. maximus* may range no earlier than late Miocene in the eastern North Pacific.

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## Introduction

The Family Cetorhinidae Gill, 1862, includes one extant genus, *Cetorhinus* Blainville, 1816, and a single living species, the basking shark, *C. maximus* (Gunnerus, 1765) (Springer and Gilbert, 1976; Compagno, 1984, 2001). Basking sharks are among the largest living neoselachians, exceeded only in size by the whale shark *Rhincodon typus* (Smith, 1828), attaining a maximum total length of 12.2 to 15.2 m, although generally not exceeding 9.8 m in total length (Compagno, 2001). *Cetorhinus maximus* is also characterized by having large gill slits that nearly encircle the head, numerous long, filamentous dermal denticle gill rakers lining the anterior and posterior sides of each branchial arch, a strongly pointed snout and large subterminal mouth with numerous small, monocuspid teeth, strong lateral keels on the caudal peduncle and a large lunate caudal fin (Compagno, 2001).

The living basking shark is coastal pelagic to oceanic with a circumglobal distribution in boreal to warm-temperate waters of the continental and insular shelves; it occurs both offshore and in shallow coastal waters and enters enclosed bays (Compagno, 2001). In the northeastern Pacific, *Cetorhinus maximus* ranges from the Gulf of California, northern Mexico to the Gulf of Alaska and perhaps the Aleutian Island chain (Mecklenburg et al., 2002; Lamb and Edgell, 2010). Basking sharks are planktivorous, feeding by filtering copepods, barnacles, decapod larvae, and fish eggs from the water (Compagno, 2001). They feed, while swimming slowly with their mouths wide-open, allowing water and plankton to pass through the buccal cavity, into the pharynx and across the branchial arches, which are lined with numerous gill rakers (1260 gill rakers per gill: Bigelow & Schroeder, 1948, p. 150; Matthews and Parker, 1950, p. 564). Plankton are sieved out as the water passes between the gill rakers and is expelled through external gill openings. Matthews and Parker (1950) suggest that mucous excreted along the base of the gill rakers aids in the capture of food.

The Family Cetorhinidae includes two extinct genera, *Pseudocetorhinus* Duffin, 1998, and *Keasius* Welton, 2013. Teeth and gill rakers of *P. pickfordi* Duffin, 1998, were originally described from the Rhaetian of England and also occur in the Late Triassic of France (Cuny et al., 1994; Cuny, 1995; Cuny et al., 2000), Belgium (Cuny et al., 1994) and Luxembourg (Godefroit et al., 1998). According to Duffin (1998), *P. pickfordi* may represent the earliest known cetorhinid and the first filter-feeding shark. Allocation of *Pseudocetorhinus* to the Cetorhinidae is not particularly convincing, and probably has no phylogenetic relationship with Tertiary and Recent Cetorhinidae. A gap in the fossil record of the Cetorhinidae exists from the Early Jurassic through early Eocene, with the first Tertiary records of undisputed cetorhinids in the middle Eocene of Antarctica (Cione and Ruguero, 1998), the Eocene of Oregon (Welton *in* Cappetta, 1987, p. 107; Welton, 2013), and possibly the middle Eocene of Russia (Malyshkina, 2006).

There are approximately six nominal extinct cetorhinid species, ranging in age from the middle Eocene to late Pleistocene (Cappetta, 2006; Welton, 2013). Of these six species, three (*Cetorhinus duponti* (Hasse, 1882) and *C. selachoides* (Hasse, 1882), both from the early Pliocene of Anvers, Belgium, and *C. glauconiticus* (Noetling, 1885), from the upper Rupelien (Oligocene) of Russia) are based on vertebrae. Two species (*Keasius parvus* (Leriche, 1908), from the upper Rupelian (Oligocene) Boom Clay of Belgium, and *C. auratus* (Van Beneden, 1871, from the early Pliocene of Anvers, Belgium) are based on gill rakers, and *K. taylori* Welton, 2013, was recently described from an associated skeleton with teeth, vertebrae and gill rakers. The validity of *C. glauconiticus* and *C. selachoides* is questionable (Cappetta, 2006), and *C. duponti* and *C. auratus* are junior synonyms of *C. maximus* (Woodward, 1889; Leriche, 1908, 1921; Cappetta, 2006). *Keasius parvus* is a valid Oligocene through perhaps early Miocene species, and *K. talyori* is known from the middle and late Eocene.

Conventionally, almost all late Miocene and younger cetorhinids are referred to *Cetorhinus maximus*, and early Miocene and Oligocene basking sharks are assigned to *Keasius parvus*. A proximal gill raker referred to *Cetorhinus* sp. from the middle Eocene La Meseta Formation of Seymour Island, Antarctica (Cione and Reguero, 1998), was referred to *C. parvus* by Hovestadt and Hovestadt-Euler (2011), and has subsequently been assigned to *K. taylori* (Welton, 2013).

Oligocene occurrences of *Keasius parvus* include Germany (Weiler, 1922, 1928, 1931; Leriche, 1948; Muller, 1976, 1983; Von Der Hocht, 1978a, 1978b; Pfeil, 1981; Freess, 1991, 1992; Reinecke et al., 2001, 2005; Haye et al., 2008; Gille et al., 2010; Hovestadt et al., 2010; Hovestadt and Hovestadt-Euler, 2011; De Pietri et al., 2010), Belgium (Leriche, 1908, 1910; Herman, 1979; Van Den Bosch, 1984; Baut and Genault, 1999), Switzerland (Frohlicher and Weiler, 1952), France (Dutheil, 1991; Baut, 1993; Genault, 1993; Pharisat, 1998; Merle et al., 2002), and questionably identified from a placoid scale from South Carolina, U.S.A. (Cicimurri and Knight, 2009). *Cetorhinus* sp. has been reported from the late Oligocene of Japan (Uyeno et al., 1984; Yabumoto and Uyeno, 1994), and Baja California, Mexico (Gonzalez-Barba and Thies, 2000). Indeterminate fragmentary cetorhinid gill rakers occur in the Oligocene Kirker Formation of California (Welton, unpublished data).

Miocene occurrences of *Keasius parvus* include Germany (Kruckow, 1961; Barthelt et al., 1991; Bracher and Unger, 2007; Reinecke et al., 2008, 2011), Switzerland (Bolliger et al., 1995), Austria (Brzobohaty and Schultz, 1978; Schultz, 1978; Schmid et al., 2001), and France (Vialle et al., 2011).

Unidentified Oligocene species of *Cetorhinus* are reported from Romania (Jonet, 1947), Poland (Van Den Bosch, 1981; Bienkowska-Wasiluk and Radwanski, 2009), and Japan (Kikuchi and Takaoka, 1979; Tomita and Oji, 2010). Early to middle Miocene basking sharks are quite diverse, largely unstudied, and usually referred to *Cetorhinus* sp. (Applegate *in* Mitchell and Tedford, 1973; Domning, 1978; Karasawa, 1989; Yabumoto and Uyeno, 1994; Bolliger et al., 1995; Gottfried, 1995; Purdy et al., 2001; Gonzalez-Barba and Thies, 2000) or are variously assigned to *C. maximus* (Brzobohaty and Schultz, 1978; Karasawa, 1989; Uyeno et al., 1983; Yabumoto and Uyeno, 1994; Long, 1994). Jordan and Hannibal (1923, p. 31, pl. III-B and I, but not C-F, L-M, Q, W, and CC) figure two *Cetorhinus* teeth from California (most likely from the middle Miocene – Barstovian, Round Mountain Silt) under the genus *Gyrace* Jordan, 1923, a junior synonym of *Galeocerdo* Muller and Henle, 1837. Gonzalez-Barba and Thies (2000) report *Cetorhinus* sp. from the Tortonian of Baja California, Mexico and *Cetorhinus* sp. occurs in the late Miocene-early Pliocene of Holland (Wijnker et al., 2008), and the late Miocene (Stewart, 1997; Barnes, 2008) and Pliocene (Applegate, 1978) of Baja California, Mexico. Almost all late Miocene through Pleistocene basking sharks are included in *C. maximus,* with occurrences in Belgium (Herman et al., 1974; Herman, 1979; Nolf, 1986; Van Der Brugghen, 2005), Italy (Lawley, 1876; Landini, 1977; Marsili, 2008; Cigala-Fulgosi et al., 2009), France (Cappetta and Nolf, 1991), Japan (Uyeno and Matsushima, 1974), the Czech Republic (Schultz et al., 2010), Chile (Long, 1993), California (Kanakoff, 1956; Fitch, 1970; Langenwalter, 1975; Long, 1994; Boessenecker, 2011), Oregon (Long, 1994; Welton, unpublished data), and Baja California, Mexico (Long, 1994).

In the summer of 1972, students of the University of California at Berkeley, Summer Institute, discovered associated skeletal elements of a basking shark in the Coos Conglomerate Member of the Empire Formation at Fossil Point, Coos Bay, Oregon (Fig. 1). The specimen was collected in a calcareous sandstone concretion and consists of three vertebrae and 11 fragmentary gill rakers. This paper describes the Empire Formation *Cetorhinus* fossils and compares them with vertebrae and gill rakers of the recent basking shark *C. maximus*. This paper is the second in a series of studies to document the taxonomy and stratigraphic distribution of Tertiary eastern North Pacific cetorhinids.

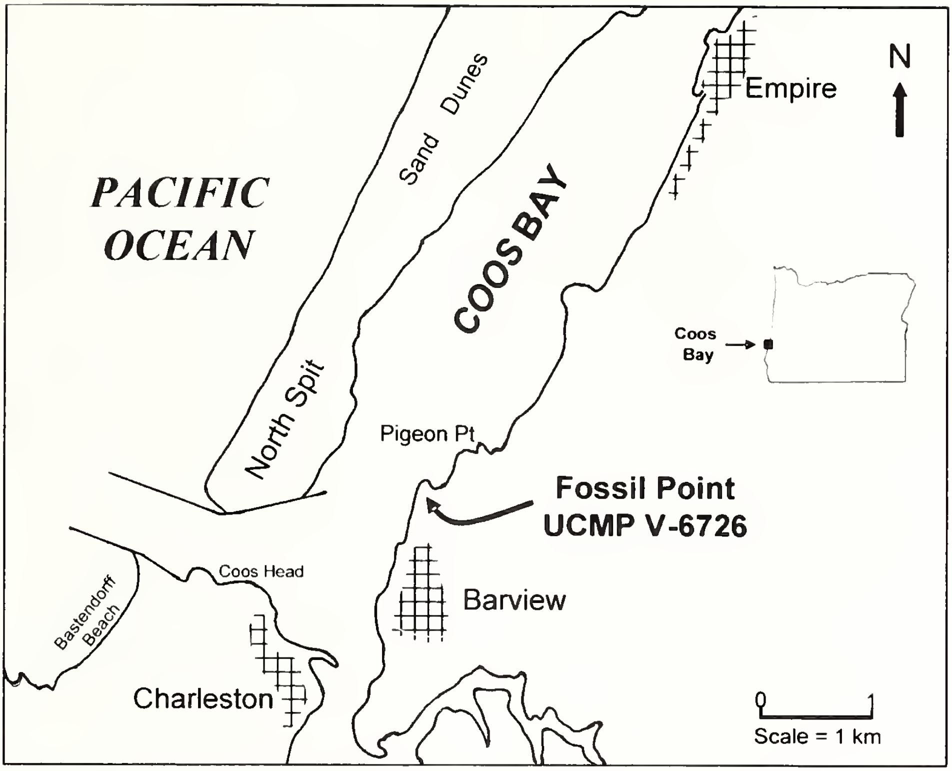


Fig. 1. Map of Coos Bay, Oregon showing location of Fossil Point and UCMP locality V-6726, in the Coos Conglomerate Member of the late Miocene Empire Formation.

## Material and Methods

Modern and fossil specimens described or referenced in this study are housed in scientific institutions in the United States and the Netherlands as indicated by the following acronyms:

KBIN - Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussels, Belgium

LACM - Natural History Museum of Los Angeles County, Los Angeles, California, U.S.A.

UCMP - University of California, Museum of Paleontology, Berkeley, California, U.S.A.

The terminology for individual gill rakers (Fig. 2) has been modified from Hovestadt and Hovestadt-Euler (2011), and follows Welton (2013). Anatomical terms for vertebral centra and their internal calcifications are derived from Ridewood (1921), Wintner and Cliff (1999), Wintner (2000).

The fossils of *Cetorhinus* cf. *C. maximus* (UCMP 77642, locality UCMP V-6726), are catalogued and housed in the Museum of Paleontology, University of California, Berkeley, and precise locality data for this specimen may be obtained from the same institution. Detailed descriptions and illustrations of gill rakers of extant *C. maximus* are found in Van Den Bosch (1984), Hovestadt-Hovestadt-Euler (2011), and Welton (2013). Comparisons with the Empire basking shark are also based on examination of the following specimens: *C. maximus*, LACM 35876-1, wet-preserved gill arch with gill

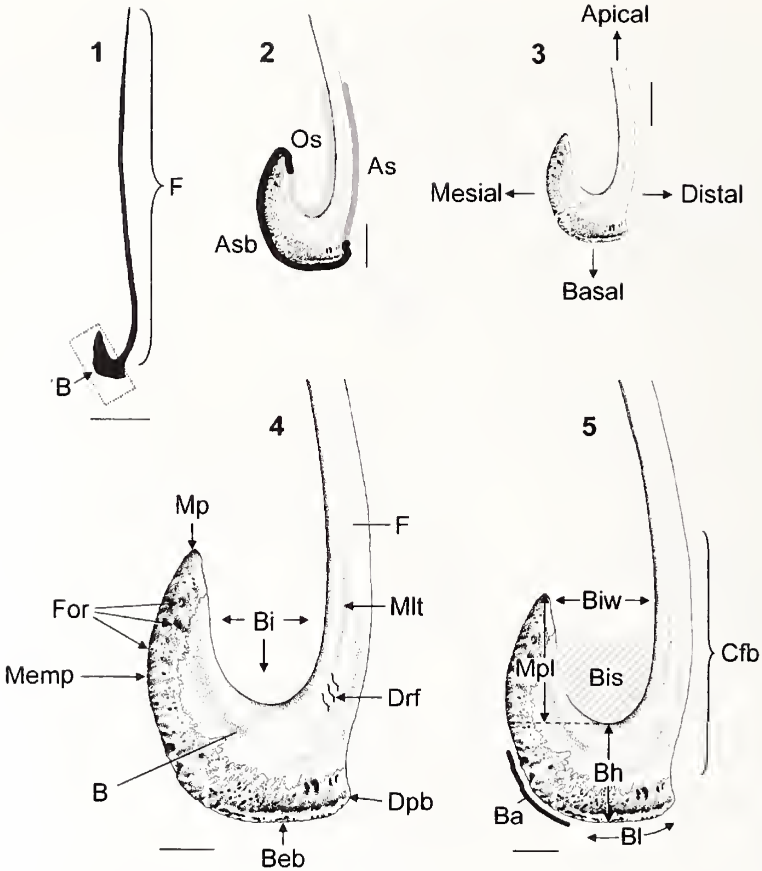


Fig. 2. Cetorhinid gill raker terminology. *Cetorhinus maximus*, LACM 35876-1, adult male, 6.0–6.7 m (TL). (1) Major gill raker components. (2) Gill raker surfaces; oral surface - light gray, aboral surface – dark gray, attachment surface of base – black. (3) Gill raker orientation terms. (4) Gill raker morphologic terms. (5) Gill raker measurements. **Abbreviations**: **As** – aboral surface; **Asb** – attachment surface of base; **B** – base of gill raker; **Ba** – base angle; **Beb** – basal edge of base; **Bh** – base height; **Bi** – bight; **Bis** – bight shape; **Biw** – bight width; **Bl** – basal length of base; **Cfb** – curvature of filament base; **Dpb** – distal protuberance of base; **Drf** – diagonal ridges on filament; **F** – filament; **For** – foramina of attachment surface; **Memp** – mesial edge of medial process; **Mlt** – median longitudinal trough; **Mp** – medial process; **Mpl** – medial process length; **Os** – oral surface. Scales: (1) = 5 mm; (2–3) = 4 mm; (4–5) = 2 mm.

rakers, adult male, 6.0–6.7 m total length (TL), collected off Morro Bay, San Luis Obispo, California, 30 June 1976. Descriptions and illustrations of gill rakers belonging to the Oligocene *Keasius parvus* are found in Leriche (1910) and Hovestadt-Hovestadt-Euler (2011). Comparisons were also made with *K. parvus* gill rakers based on LACM 154925, 20 gill rakers from LACM Locality 3813, Oligocene (Rupelien), U. Meeressand, Weinheim bei Alzey Steinbruch an der Neumuhle.

The associated skeletal elements are preserved in a calcareous concretion, and were initially prepared by etching in a weak (5%) acetic acid solution to expose gill rakers and calcified vertebral cartilages. Additional preparation was done with an air abrasive unit. All artwork and photographs are by the author. The illustrations in Figures 2 and 6 were drawn using a Wild M5 stereomicroscope and camera-lucida attachment.

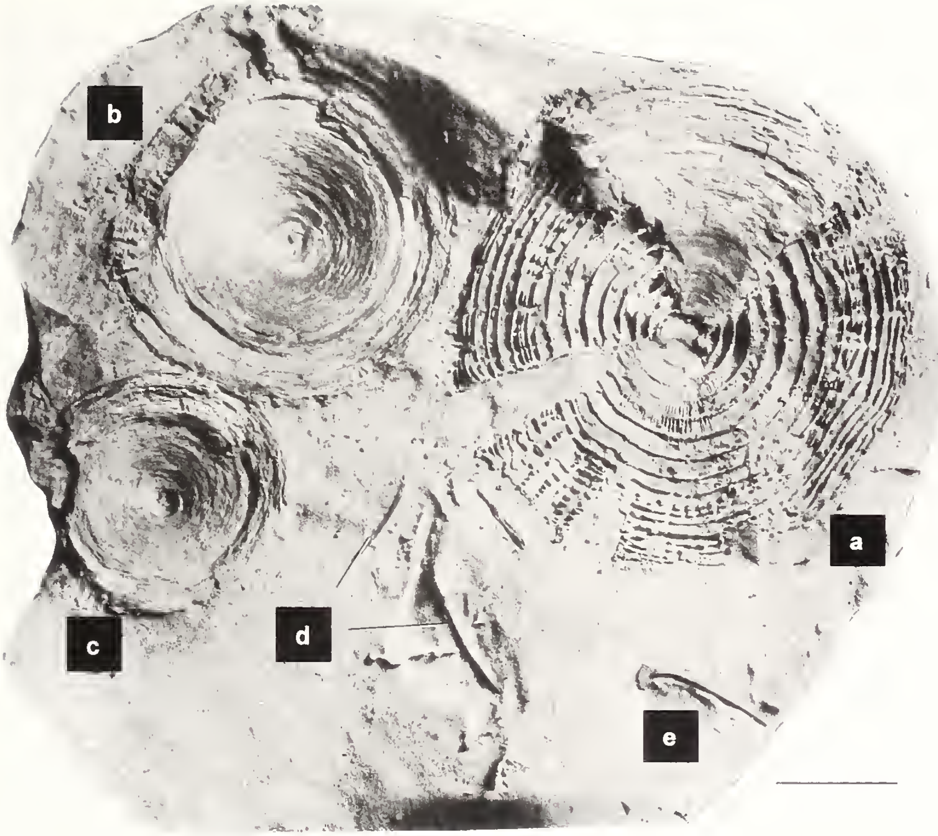


Fig. 3. Acid etched calcareous concretion from the Coos Conglomerate Member of the Empire Formation (UCMP Locality V-6726, Fossil Point, Coos County, Oregon) with exposed vertebrae and gill rakers of *Cetorhinus* cf. *C. maximus* (UCMP 77642). a, transverse section of abdominal or trunk vertebra showing concentric calcifications of intermedialia; b, axial view of intermediate sized vertebra showing the corpus calcareum and radial calcifications on broken surface (upper left margin of centrum); c, axial view of caudal? vertebra with exposed radial calcifications; d, fragmentary gill raker filaments; e, incomplete gill raker with a well preserved base. Scale = 2 cm.

## Systematic Paleontology

Class Chondrichthyes Huxley, 1880

Superorder Galeomorphii Compagno, 1973

Order Lamniformes Berg, 1958

Family Cetorhinidae Gill, 1862

Genus *Cetorhinus* Blainville, 1816

*Cetorhinus* cf. *C. maximus* (Gunnerus, 1765)

Figs. 3a-e, 4–6a-d

**Referred Specimen**—UCMP 77642, three vertebrae, and 11 fragmentary gill rakers (Figs. 3–6).

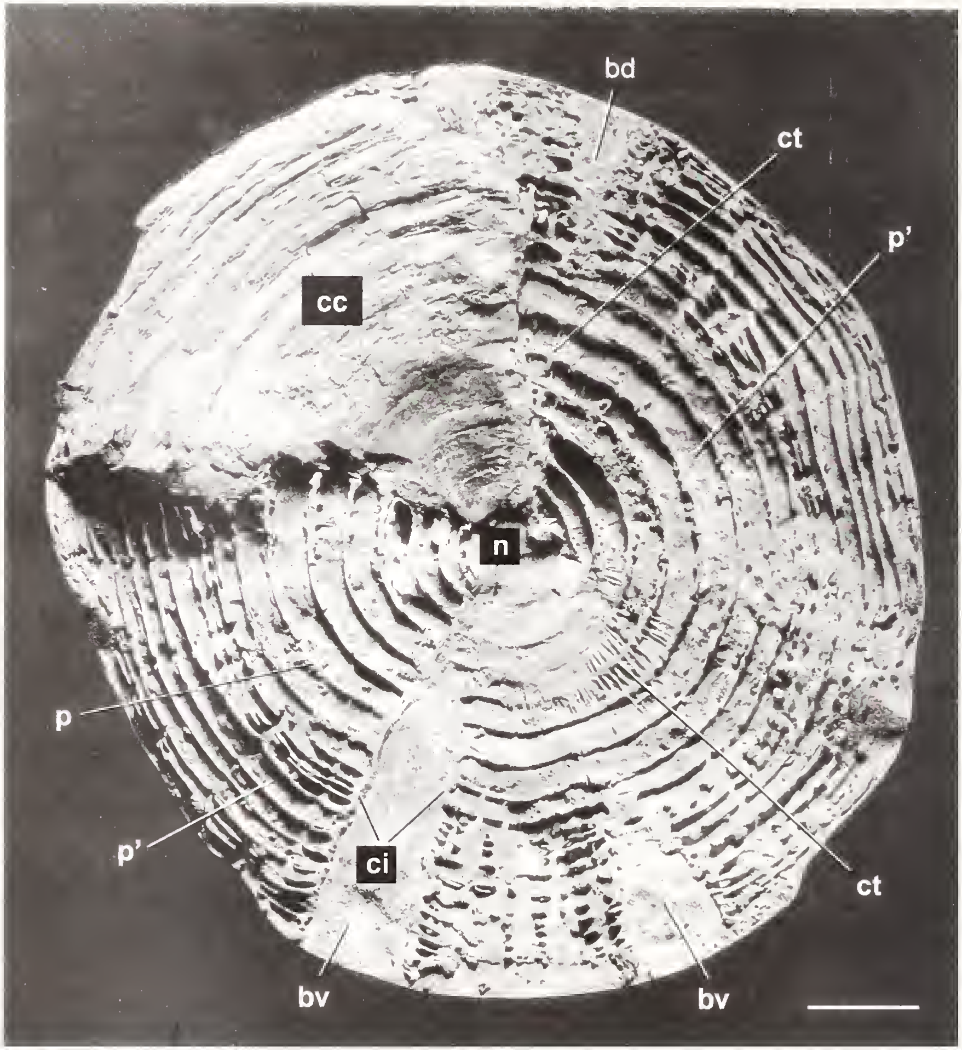


Fig. 4. Acidized transverse section through largest vertebra of *Cetorhinus* cf. *C. maximus* (UCMP 77642), showing calcifications of the intermedialia. **Abbreviations**: **bd** - basidorsal insertion; **bv** - basiventral insertion; **cc** - corpus calcareum; **ci** - calcified wedge face of intermediale; **ct** - calcified tube; **n** - passage of notochord; **p** - uncalcified cartilaginous part of the intermediale; **p'** - calcified concentric lamellae of the intermediale. Scale = 1 cm.

**Locality**—UCMP V-6726, Fossil Point, Coos County, Oregon, approximately 900 meters southwest of Pigeon Point and about 2400 meters north of Charleston, Coos County, Oregon (Fig. 1).

**Formation**—UCMP 77642 was collected from the Coos Conglomerate Member of the Empire Formation (Diller, 1896; Dall, 1898, 1909; Howe, 1922; Weaver, 1945; Armentrout, 1973, 1980). The Coos Conglomerate is composed of cobbles and boulders of fossiliferous lower Empire Formation sandstone, rounded beach pebbles and cobbles of chert, basalt, quartzite, and reworked Empire Formation fossils mixed with contemporaneous shallow water fauna (Armentrout, 1973, p. 4). Dall (1909) was able

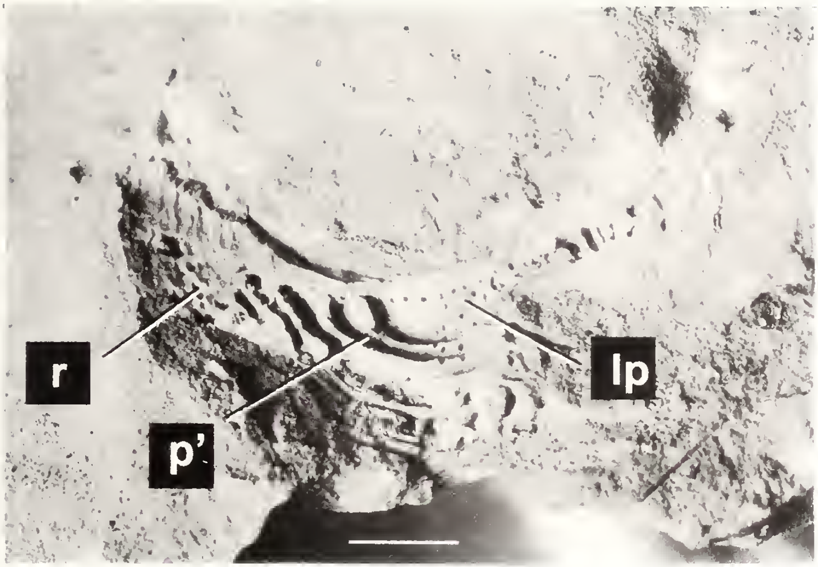


Fig. 5. Exposed concentric lamellae (p') along broken section of *Cetorhinus* cf. *C. maximus* vertebrae (UCMP 77642, Fig. 3c) showing numerous perforations (lp), and radial calcifications (r). Scale = 1 cm.

to make a distinction between fossils derived from the underlying Empire Formation sandstone and those deposited contemporaneously with the Coos Conglomerate by carefully noting color and matrix composition. The *Cetorhinus* skeletal elements are contained in a fine to medium grained, gray, calcareous sandstone nodule, surrounded by a matrix of basalt and quartzite pebbles up to 5.0 mm in diameter. Based on similarities in lithology, this nodule was probably reworked from lower Empire Formation sandstone.

**Age**—Late Miocene, *Thalassiosira antiqua* and possibly the *Nitzschia reinholdii* northeastern Pacific Diatom Zones (Barron and Armentrout, 1980; Barron, 1981, addendum p. 123, p. 124, fig. 7; Armentrout 1981, p. 142, annotations 50 and 51, p. 143, fig. 2), Wishkahan Molluscan Stage (Addicott, 1976, 1981), early part of the Hemphillian North American land-mammal "age" (Repenning *in* Armentrout, 1981, p. 141, annotation 25), and between 6.5 and 8.5 Ma (Armentrout, 1981, p. 143, fig. 2; Armentrout et al., 1983).

**Description**—The skeletal elements of *Cetorhinus* were first recognized in the field as a series of associated, but disarticulated, calcified centra and gill rakers, weathering *in situ* from the Coos Conglomerate Member of the Empire Formation. The skeleton is preserved in a single calcareous sandstone concretion (Fig. 3), and the association is assumed to represent one individual for the following reasons: 1) all skeletal elements belong to the same taxon; 2) all gill rakers are within a size range found on a single gill arch (Hovestadt and Hovestadt-Euler, 2011, p. 79, fig. 9m-u; Fig. 6), and the three associated centra are within the size range for one individual (Natanson et al., 2008). Evidence of some postmortem transport is indicated by the juxtaposition of vertebrae from different positions along the vertebral column, in combination with scattered gill rakers in the matrix.

**Vertebrae**—The largest vertebra (Figs. 3a, 4) is seen in transverse section broken midway between the anterior and posterior ends of the centrum. A wedge-shaped section of the corpus calcareum is preserved (Fig. 4) and covers one of the wedge cartilages. The

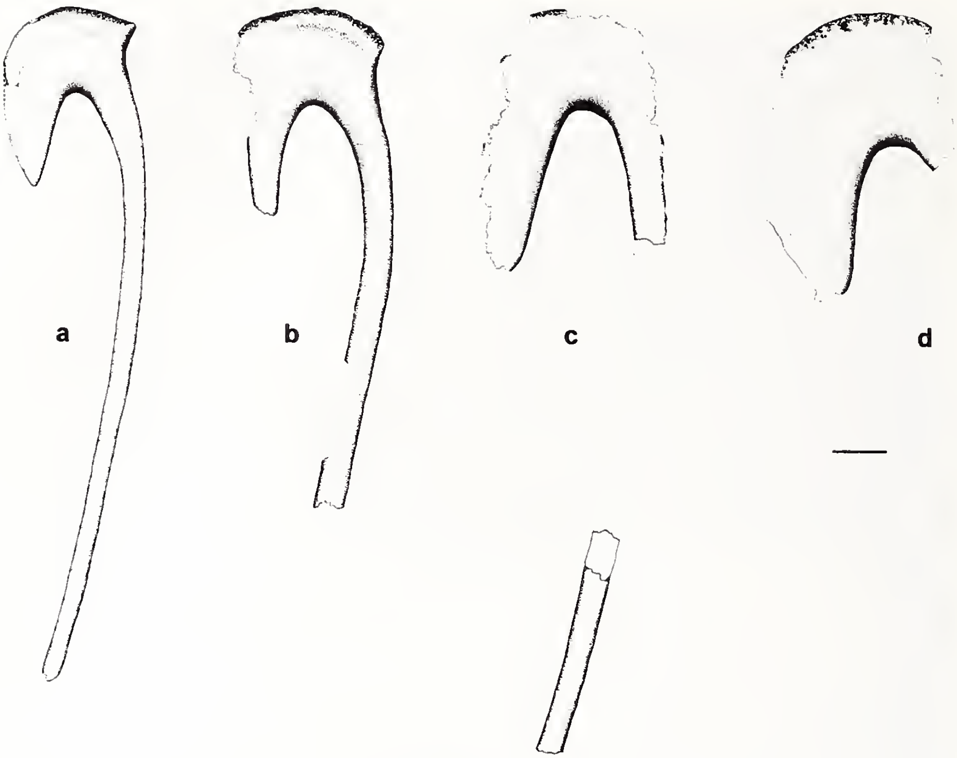


Fig. 6. Incomplete gill rakers of *Cetorhinus* cf. *C. maximus* (UCMP 77642), from the Coos Conglomerate Member of the late Miocene Empire Formation, Coos County, Oregon (UCMP locality V-6726). The gill raker sequence **a** through **d** approximates distal-most to central-most positions on the gill arch. Scale = 2 mm.

centrum is readily differentiated into four intermedialia by the basidorsal and basiventral insertions for the neural and haemal arch cartilages (Fig. 4). Outer zone cartilage of the intermedialia (Ridewood, 1921) contain approximately 20 calcified concentric lamellae, the innermost calcifications being the oldest and the outermost thinner lamellae being most recently calcified. Each lamella bears many sieve-like perforations (Fig. 5) in the lamellar wall, connected to each adjacent concentric lamellar wall by a calcified tube, which during life transmitted a blood vessel (Ridewood, 1921). Each interlamellar tube originates near the innermost concentric lamellae and grows radially toward the perimeter of the centrum. Isolated nodules that occur in the uncalcified wedges of the neural and haemal arch cartilage as seen in modern vertebral cross sections (island or isolated nodules or calcified cartilage of Ridewood, 1921, p. 361) are absent in this specimen. The wedge faces, i.e., the faces which are in contact with arch cartilage are well calcified, a feature that Ridewood (1921:360) suggests is an adult characteristic. Radiating lamellae are absent. The greatest diameter of the centrum, measured to the outside of the last lamellar calcification is approximately 80 mm.

The corpus calcareum of the intermediate-sized vertebra is exposed in axial view. Poorly preserved growth band pairs of alternating ridges and troughs are visible in Figure 3b. Radial calcifications are exposed along the broken perimeter of the centrum. The centrum is 58 mm in transverse width. The smallest centrum is partially broken along one side revealing numerous lamellar perforations (Figs. 3, 5) and radial calcifications. The radii extend from the perimeter of the centrum, inward toward the notochord for a distance of one-half the radius. The centrum is approximately 42 mm in transverse width and 27 mm in anteroposterior length.

**Gill Rakers**—Eleven fragmentary gill rakers are preserved, four of which have bases (Fig. 6), and the remainder consist of filament sections. The longest incomplete gill raker (Fig. 6c) is 26+ mm. The filaments are gently curved medially, taper apically, are laterally thin, and may have either a weak median longitudinal trough developed just above the point at which the filament connects with the base (Fig. 2), or this surface is flat to weakly convex. The oral and aboral filament surfaces are rounded, and the filaments are widest and most strongly curved at their junction with the base. The base of one gill raker (Fig. 6a) has a well developed distal projection, and basal edges range from flat to moderately rounded (Fig. 6 a, b, d). The medial process is long in all gill rakers, tapers apically with a broad base, and ranges from narrow (Fig. 6b) to somewhat triangular in shape (Fig. 6a). The mesial edge of the medial process is straight (Fig. 6b) to rounded (Fig. 6a, d) and the intersection of the basal edge of the base and the mesial edge of the medial process ranges from angular (Fig. 6b) to subangular (Fig. 6a, d). A narrow, rugose basal attachment surface is continuous from the distal basal projection to the apical tip of the medial process. The bight is subangular in all gill rakers, and the basal height, as measured at the point of greatest bight curvature (Figs. 2, 6) is relatively wide. Except for the basal attachment surface, all gill raker surfaces are covered by smooth to very finely textured enameloid. Broken filament cross sections show a hollow pulp cavity that persists medially throughout the length of the gill raker.

## Discussion

**Vertebrae**—Calcifications in the centra in Recent *Cetorhinus maximus* have been described by Hasse (1882), Ridewood (1921), and illustrated by Natanson et al. (2008, p. 272, fig. 1). The calcifications found in the Empire basking shark (Figs. 3–5) compare favorably with those of *C. maximus* in sharing the following attributes: centrum nearly oval in axial view; diagonal lamellae absent in large trunk vertebrae and present in much small caudal centra; intermedialia weakly calcified with well-developed concentric lamellae; basidorsal and basiventral insertions for the neural and haemal arch cartilages well developed with moderately calcified wedge faces; small tubes radiate from the centrum focus (Wintner and Cliff, 1999), passing through concentric lamellae and extend to the margin of the centrum; primary double cone angle, measured from the focus to the anterior or posterior margin of the corpus calcareum, is high; length of centrum much greater than other lamniforms.

According to Ridewood (1921, p. 361–362), ventral intermediale in trunk vertebrae are wider than the dorsal intermediale. In the cloacal region, they are about equal, and the ventral intermediale continue to narrow in the caudal region. Natanson et al. (2008, p. 272, fig. 1) figured a series of *Cetorhinus maximus* vertebrae representing cranial, abdominal and trunk vertebrae, illustrating a trend from ventrolaterally directed basopophyses in cranial vertebrae, increasing lateral direction in abdominal vertebrae, and a reverse of the trend in trunk vertebrae. The trends noted above are potentially useful in determining the relative position of isolated vertebrae in the vertebral column. Unfortunately, as pointed out by Ridewood (1921), it is not possible with certainty to determine the dorsal orientation of an isolated centrum. As an alternative, one can infer relative position based on vertebral size, if the sample represents an association from one individual. Applying the above criteria, the presence of concentric lamellae and lack of radii in the largest Empire centrum (Figs. 3a, 4) suggests this vertebra is from the trunk region. Although one basopophyses is hidden by a fragment of the corpus calcareum, it appears that one pair is more ventrolaterally directed than the other. On this basis, the centrum illustrated in Figure 4 is oriented with the most laterally directed basopophyses in the ventral position. The smallest Empire centrum (Fig. 3c) possesses radial calcifications on the external surface of the outermost concentric lamellae. A caudal position for this centrum is indicated by its small size, in combination with the presence of radial calcifications.

There are currently no studies documenting individual, ontogenetic, or geographic variations in the vertebrae of Recent *Cetorhinus maximus*. In the absence of these data, it is not possible to define specific attributes of their morphology that can be used to identify interspecifc differences between fossil and Recent vertebrae. In addition, there are no valid extinct species of *Cetorhinus* with vertebrae, to serve as a basis for comparison with extant *C. maximus*.

**Gill Rakers**—Gill rakers are modified mucous membrane denticles (Peyer 1968). The base is fixed to the branchial arch by connective tissues and perforated by nutrient canals along the entire basal edge. Vascular canals filled with dentinal tubes and surrounded by interosteal tissue form the base. A median vascular canal arising from the base runs up the center of the filament. Dentinal tubes, originating along the outer margin of the pulp cavity, penetrate a thick layer of pallial dentine, which, with the exception of the basal attachment surface, covers the entire gill raker. A thin pigment layer overlain by enameloid covers the outermost surface of the gill raker.

Gill rakers in *Cetorhinus maximus* are present on both sides of each of the five branchial arches. From the inner edge of each arch extends a 10-cm diameter strip of mucous membrane (LACM 35876-1), and to either side of this lies a single continuous row of gill rakers with their free ends (filaments) directed towards the mouth. The semilunar base of each gill raker is attached to the mucous membrane of the gill arch. The longest gill rakers occur near the center of the arc and are about 9 cm long in the LACM specimen. They are spaced at about 12–13 per centimeter and decrease in length toward either end of the gill arch. Bigelow & Schroeder 1948:150) estimated the number of gill rakers in one series on one branchial arch to be 1260. Matthews and Parker (1950:564) estimated the total number to be from 1200 to 1300 on the anterior larger gill arches and from 1000 to 1100 on the shorter arches.

Van Den Bosch (1984), Hovestadt and Hovestadt-Euler (2011), and Welton (2013) figure gill rakers from Recent *Cetorhinus maximus*, representing central through distal positions along the gill arch, from individuals of both sexes, and a range of body lengths. Comparison of *C. maximus* gill rakers having the same relative position on the gill arch, but from individuals ranging in size from 360 cm (TL) to greater than 600 cm (TL), shows a morphologic (ontogenetic) trend with increasing body length (Hovestadt and Hovestadt-Euler, 2011). Ontogenetic changes in the morphology of *C. maximus* gill rakers from a central position on the gill arch, include: an increase in gill raker length, a shift in the basal angle from rounded to subangular, an increase in length of the medial process, and development of a concave mesial edge to the medial process. Variable attributes include degree of filament curvature at its base, basal width, and bight angles that range from curved to angular. It is possible that sexual dimorphism, or individual variation, might explain some differences in gill raker morphology; however, the sample size is too small to test this hypothesis.

Large adult *Cetorhinus maximus* gill rakers exceed 20 cm in total length (TL), whereas the most complete Empire gill raker is 2.6 +cm (Fig. 6c). Comparing the Empire gill raker bases (Fig. 6a-d) with the approximately equal sized *C. maximus* gill raker bases shown in the series illustrated by Hovestadt and Hovestadt-Euler (2011, p. 79, fig. 9, m-u, from a 672 cm (TL) female) I estimate that the Empire gill rakers shown in Figure 6, if complete, would have total lengths ranging from a minimum of five cm (Fig. 6a) to a maximum of about eight cm (Fig. 6d). These estimates are derived using a ratio of base height to gill raker length, established on the Hovestadt and Hovestadt-Euler (2011) figured gill rakers (fig. 9m-u), and applied to the Empire specimens. The Empire gill rakers (Fig. 6a-d) compare favorably with those adult *C. maximus* (Hovestadt-Hovestadt-Euler, 2011, p. 79, fig. 9m-u) in having moderately to strongly curved filament bases, and relatively flat to weakly convex distal protuberances. The basal margins are moderately long, and the medial processes are very long and narrow with weakly concave to weakly convex medial edges. Basal heights are moderately high, and basal angles are rounded to subangular. Bights are moderately wide and all appear to be subangular. Trends from a distal to central position on the gill arch include increasing curvature of the filament base, increasing basal length, increasing length of the medial process, development of a concave mesial edge of the medial process in the most central gill rakers, and an increase in gill raker length, with the longest gill rakers either in the central-most position on the gill arch (Hovestadt and Hovestadt-Euler, 2011) or just distal to the central position (Welton, 2013, fig. 12, LACM 35876-1). The Empire gill rakers differ from those of LACM 35876-1 (Welton, 2013, fig. 12) in having subangular rather than rounded bights, less curvature at the filament base, and in some gill rakers, and a less rounded mesial edge of the medial process. The gill raker sequence illustrated in Figure 6a-d approximates distal-most to central-most positions on the gill arch.

The Empire *Cetorhinus* gill rakers and vertebrae differ significantly from those of the *Keasius taylori* (Welton, 2013) and *K. parvus* (Hovestadt and Hovestadt-Euler, 2011; LACM 154925), by having much larger gill rakers, from *K. parvus* in having less curvature at the filament just above it attachment with the base, and from both *K. parvus* and *K. taylori* in having a less robust base with a much longer and narrower medial process, a more horizontal basal edge of the base, a subangular to rounded basal angle, subangular to rounded bight, and relatively short basal height. The Empire vertebrae are large and have well developed concentric lamellae. The vertebrae of *K. taylori* and *K. parvus* are much smaller and lack concentric lamellae (Welton, 2013).

**Estimated Total Length of the Empire Formation Basking Shark**—The total length of the Empire basking shark can be estimated using vertebral size (Natanson et al., 2008) and gill raker length (Hovestadt and Hovestadt-Euler, 2011). In the absence of a complete Empire skeleton, maximum vertebral dorsoventral heights and gill raker lengths in this individual are unknown. Assuming there were larger vertebrae and gill rakers in the shark, total length estimates based on the preserved vertebrae and gill rakers are conservative. The largest Empire centrum measures about 80 mm in dorsoventral height. According to a graph correlating vertebral dimensions to total length for Recent *Cetorhinus maximus* (Natanson et al., 2008, p. 272, fig. 2), the Empire basking shark has an estimated total length of about 450 cm. Using a correlation of gill raker length to total length of *C. maximus* (Hoevestadt and Hovestadt-Euler, 2011, p. 80, fig. 11), an 80 mm Empire gill raker (TL estimated above) correlates with a 575 cm (TL) shark.

**Comments on the Use of Vertebrae, Gillrakers and Teeth in Fossil Cetorhinid Taxonomy**—All nominal fossil species of *Cetorhinus* are based on gill rakers or vertebrae.

The issues related to the use of vertebrae in defining new species have been noted above, and most of the same problems apply to the use of gill rakers in taxonomy. Recent studies of extant *C. maximus* (Van Den Bosch, 1984; Hovestadt-Hovestadt-Euler, 2011; Welton, 2013) provide significant new data on gill raker morphology, and especially changes in their shape with age and position on the gill arch. However, additional work is needed to document individual, ontogenetic, perhaps sexual, and geographic variation in gill raker morphology. The use of gill rakers in fossil cetorhinid taxonomy is further complicated by the fact that some undescribed Neogene *Cetorhinus* have gill rakers very much like Recent *C. maximus*, but teeth that are distinct and warrant assignment to a new species (Welton, unpublished data).

Identification of the Empire *Cetorhinus* would have been greatly facilitated with oral teeth, but none were found with the fossil, and to my knowledge, no teeth of *Cetorhinus* have been collected from the Coos Conglomerate. Although gill rakers and vertebrae from the Empire Formation compare favorably with those of the Recent basking shark *C. maximus*, a definitive identification requires dentition.

**Fossil Record of the Genus *Cetorhinus* in Oregon and California**—The fossil record of the genus *Cetorhinus* in Oregon and California ranges from early Miocene through Pleistocene (Long, 1994; Welton, unpublished data). Based primarily on teeth, and to a lesser extent gill rakers and vertebrae, early and middle Miocene *Cetorhinus* from the eastern North Pacific are morphologically distinct from *C. maximus*, and represent undescribed species (Welton, unpublished data). The occurrence of *Cetorhinus* cf. *C. maximus* in the late Miocene of Oregon (Long, 1994; this study) is consistent with other late Miocene records of the species in California (Long, 1994) and Chile (Long, 1993).

## Conclusions

1. A calcareous sandstone concretion containing three vertebrae and 11 fragmentary gill rakers belonging to the genus *Cetorhinus* Blainville, 1816, was collected from the Coos Conglomerate Member of the late Miocene Empire Formation, Coos County, Oregon.
2. Taphonomic data suggest the vertebrae and gill rakers represent an associated but disarticulated skeleton from one individual. The skeleton shows evidence of transport prior to deposition.
3. The Empire *Cetorhinus* gill rakers and vertebrae differ significantly from those of the *Keasius taylori* and *K. parvus*, and compare favorably with those of the Recent basking shark *C. maximus*.
4. The total length of the Empire basking shark is estimated to be between 4.5 and 5.75+ m based on correlations of vertebral and gill raker dimensions with the total length for Recent *C. maximus*.
5. Although the gill rakers and vertebrae from the Empire Formation compare favorably with those of the Recent basking shark *Cetorhinus maximus*, a definitive identification requires dentition.
6. Based primarily on teeth, and to a lesser extent gill rakers and vertebrae, early and middle Miocene *Cetorhinus* from the eastern North Pacific are distinct from *C. maximus* (Welton, unpublished data). The occurrence of *Cetorhinus* cf. *C. maximus* in the late Miocene Empire Formation of Oregon (Long, 1994; this study), is consistent with other late Miocene records of the species in California

(Long, 1994) and Chile (Long, 1993), and suggests that *C. maximus* may range no earlier than late Miocene in the eastern North Pacific.

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# 106[TH] ANNUAL MEETING

## *SOUTHERN CALIFORNIA ACADEMY OF SCIENCES*

## May 3–4, 2013

*California State University, Long Beach*

*Long Beach, CA*

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# FRIDAY ABSTRACTS IN PROGRAM ORDER

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## 1. HABITAT SELECTION AND UTILIZATION OF THE WHITE CROAKER (*GENYONEMUS LINEATUS*) IN THE LOS ANGELES AND LONG BEACH HARBORS

**B.J. Ahr**, M.R. Farris, and C.G. Lowe. California State University Long Beach, Department of Biological Sciences, Long Beach, CA, 90840.

Sediment contamination within the Los Angeles-Long Beach Harbors has been an environmental concern since pollutants entered the harbors through historical wastewater discharge. Contaminants such as DDT and PCBs are of particular concern in the harbors as it negatively affects marine organisms and can be harmful to humans if consumed. White croaker (*Genyonemus lineatus*) are a sentinel fish species for contamination because of their susceptibility to pollutants and their direct interaction with contaminated sediments through their benthic foraging behavior. Acoustic telemetry was utilized to determine fine and coarse scale movements of white croaker within the LA-LB Harbors in order to determine habitat preference and utilization. Benthic infauna data (provided by the ports) was coupled with fish movement data. Preliminary data suggests prey density is not the sole driver for habitat selection for white croaker. White croaker spent relatively equal amounts of time in each one of the four prey density categories (ranging from lowest to highest concentrations in the harbors). White croakers spent 20% in the highest tier (47.5–59 benthic individuals/0.1 $m^2$) and spent the most time (32%) in the second highest tier (35.9–47.4 benthic individuals/0.1 $m^2$) of benthic infauna. White croaker exhibit a diet shift in depth distribution, occupying deeper depths and a wider range of depths during the day than during the night. This study will continue to investigate the relationship of white croaker movements and prey density and depth. This study will also continue to determine which abiotic and biotic factors are drivers for white croaker habitat selection.

## 2. MOVEMENT PATTERNS AND BEHAVIOR OF WHITE CROAKER (*GENYONEMUS LINEATUS*) IN THE LOS ANGELES AND LONG BEACH HARBORS

**M.R. Farris**, B.J. Ahr, and C.G. Lowe. California State University, Long Beach, Department of Biological Sciences, Long Beach, CA 90840.

Acoustic telemetry techniques were used to study both the fine scale and coarse scale movements of white croaker (*Genyonemus lineatus*) in the Los Angeles (LA) and Long Beach (LB) Harbors. Understanding the movements of *G. lineatus* in the Harbors is of particular importance due to the fact that it is commonly caught by recreational and subsistence anglers, and is highly contaminated with organochlorine pollutants in this region. Individual *G. lineatus* tagged for coarse scale tracking within the inner Harbors ($n = 49$) exhibited greater site fidelity than those tagged in the outer Harbors ($n = 50$), and the highest degree of connectivity was observed between directly adjacent regions of the Harbors. Individual *G. lineatus* tagged for fine scale tracking ($n = 18$) exhibited an average daily area use of 156533 $m^2$ ± 229865 $m^2$ (±SD); average daily area use in the outer Harbors (264735 $m^2$ ± 319920 $m^2$) was significantly greater than in the inner Harbors (75382 $m^2$ ± 54424 $m^2$) ($p = 0.019$). Data from this study indicate that an area in the inner LA Harbor, known as the Consolidated Slip, may be an area of particular importance to *G. lineatus* within the Harbors as individuals tagged in this area exhibit higher site fidelity than fish in other areas of the Harbors. This is noteworthy as the Consolidated Slip is also known to contain the highest concentrations of organochlorine pollutants in sediments within the Harbors.

## 3. SITE FIDELITY, HOME RANGE, AND SPAWNING MIGRATION OF BARRED SAND BASS (*PARALABRAX NEBULIFER*) ON THE PALOS VERDES SHELF

**G.N. Teesdale**, B. Wolfe, and C.G. Lowe. California State University Long Beach, Department of Biological Sciences, Long Beach, CA 90840.

Barred sand bass (*Paralabrax nebulifer*, "BSB") are an important gamefish in southern California, commonly targeted during summer spawning aggregations. Understanding the timing of individual

migrations to these aggregations is essential for effective management of this species. Acoustic transmitters were surgically implanted in 55 BSB on the Palos Verdes Shelf near Los Angeles County Sanitation District's (LACSD) Whites Point outfall. A passive acoustic receiver array of 42 VR2W receivers combined with vessel deployment of 10 mobile receivers monitored the movements of tagged fish from July 2010–October 2012. Coarse scale detections (individual receiver) of BSB demonstrated a high degree of non-spawning season site fidelity (65.8% of days at liberty (September–May)) to specific inshore areas (20 m to 40 m). Fine scale trilaterated positions rendered from multiple receiver detections were used to calculate kernel utilization distributions (KUDs). Overall areas (95% KUDs) averaged (29,187 ± 5,559 $m^2$) and core areas (50% KUDs) averaged (2,834 ± 392 $m^2$). GIS analysis revealed that BSB exhibit high affinity to rocky ballast along outfall pipes and adjacent areas of natural rocky reef while making brief forays into surrounding habitats. Spawning migration was documented through periods of absence from PV and subsequent detections in the Huntington Flats area (late-May through late-September) up to 29.9 km from the array. These results are consistent with short-term acoustic studies documenting small home ranges in close proximity to ecotones and long-term traditional tag-recapture studies documenting general distance and direction of migrations. This is the first study to determine the long-term site fidelity and timing of spawning related migrations of BSB.

## 4. PRELIMINARY TRENDS: RESPONSES OF FISHING EFFORT AND BOATING TO NEWLY ESTABLISHED MPAS ALONG THE MAINLAND COAST OF SOUTHERN CALIFORNIA

**T.K. Ford**. Santa Monica Bay Restoration Commission, Center for Santa Monica Bay Studies, Loyola Marymount University, Los Angeles, CA, 90045.

Aerial Surveys of the mainland coast of southern California from Point Conception to the U.S. Mexican border were initiated in 2008. The surveys use light aircraft to fly-over all vessels encountered within California State Waters, (from the coast out to three miles). The observers in the aircraft record the location, and define the type and activity of the vessels when encountered using a georeferenced database in a computer onboard the aircraft. Using this methodology we are able to collect an accurate, fishery independent, fine spatial scale dataset on recreational and commercial fishing activities, as well as other vessels, from kayaks to oil tankers (margin of error +/− 188 meters). Preliminary results suggest: higher rates of noncompliance within the recreational fishing community than commercial sectors. Fishing vessels are not displaying compaction in response to the new MPAs. Commercial fishing effort has shifted away from the boundaries of the new MPAs rather than closer, "fishing the line". For boating more generally preliminary trends suggest: a reduction in boat activity during the spring of 2012 compared to previous years. A consistent spatial trend has been a significantly higher density of boats operating off the mainland coast of San Diego, Orange and southern Los Angeles Counties compared to northern Los Angeles, Ventura and Santa Barbara Counties.

## 5. STATUS AND TRENDS IN THE SOUTHERN CALIFORNIA SPINY LOBSTER FISHERY AND POPULATION: 1980–2011

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The California spiny lobster (*Panulirus interruptus*) fishery in southern California ranked amongst the most economically important fisheries in California. An analysis of commercial harvest data confirms that the fishery was indeed landing near-record catches in recent years. The commercial catch per trap pulled declined 15%/year in years after the introduction of a new rigid-style hoop net in the recreational fishery. Fishery-independent data sourced from power plant marine life monitoring recorded increased California spiny lobster abundance after 1989 with evidence of increased larval settlement in 1989. This coincided with a documented oceanographic regime shift in the Pacific Ocean. Power plant abundance indices derived for lobsters one year away from recruiting into the fishery as well as young-of-the-year each significantly predicted the commercial harvest at index-appropriate temporal lags, i.e. one year for next year's fishery recruits. Predictability of both indices was apparently reduced in years since the introduction of the new rigid hoop net in the recreational fishery. The population data confirms that, at this point, the fishery appears healthy but warns of the collapse that may occur if oceanographic conditions shift to a new

regime less favorable to California spiny lobster than present conditions. These analyses also indicate the urgency of monitoring the recreational fishery harvest.

## 6. KELP AND SHALLOW ROCK ECOSYSTEMS: MPA BASELINE DATA COLLECTION FOR THE SOUTH COAST REGION (2011–2012); AN OVERVIEW

**L.A. Zahn**, J.T. Claisse, J.P. Williams, C.M. Williams, and D.J. Pondella, II. Vantuna Research Group, Occidental College, Department of Biology, Los Angeles, CA, 90041.

Data collection for the Kelp and Shallow Rock Ecosystems assessment of the South Coast MPA Baseline Monitoring Program was completed in 2012. The overall goal of this project was to describe the ecological condition of rocky reefs inside and outside of the new reserve boundaries. Data was collected using standardized CRANE methodology on scuba, assessing the abundance and distribution of fish, macroalgae and conspicuous invertebrates, reef characteristics including benthic cover and relief, and size structure data of all fish and selected invertebrate species (e.g., *Strongylocentrotus* spp.), throughout different depth zones of each site (inner, middle, outer, and deep). In total, 119 sites were surveyed in 2011 and 117 in 2012, assessing the ecological conditions inside and outside of 36 MPAs. Density and size structure of all the indicator or 'focal' species (as defined by the South Coast MPA Monitoring plan) were measured, which included giant kelp (*Macrocystis pyrifera*), kelp bass (*Paralabrax clathratus*), kelp and olive rockfishes, (*Sebastes* spp.), red and purple urchins (*Strongylocentrotus* spp.), spiny lobster (*Panulirus interruptus*), and abalones (*Haliotis* spp.), among many others. We plan to integrate the data with existing long-term datasets from the region to give the best picture of the status of these reefs at MPA implementation. Assessing the abundance and spatial distribution of these focal species region-wide, and integrating site-specific environmental data (e.g., sea surface temperature, reef substrate and relief) will help with the development of ecosystem indicators and provide information for future monitoring protocols.

## 7. THE CONSEQUENCES OF FISHING-INDUCED CHANGES IN PREDATOR SIZE FOR PREDATOR-PREY INTERACTIONS

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Even without selecting for large fish, the added mortality of fishing means fewer fish make it to larger sizes, leading to distributions shifted towards smaller individuals. The consequences of these shifts for single-species management have long been recognized. Because body size limits the sizes of prey a predator can eat, truncated size distributions may cause equally dramatic changes in predator-prey interactions. As a result, multispecies models based on biomass alone, without considering changes in size distributions, may over- or under-estimate predation rates. The potential trophic effects have largely been ignored when managing these fisheries, but will be critical to fulfilling the mandate for multispecies management. I developed a size-structured predator-prey model to evaluate how fisheries-induced changes in predator size distributions affect prey population dynamics. I parameterized this model within California kelp forests using observations of size-specific predation of California sheephead (*Semicossyphus pulcher*) on urchins (*Stronglyocentrotus* spp.). When predation success varied with predator size, and predators were size-selective, shifts in size distributions toward smaller predator sizes decreased overall prey mortality rates, with disproportionate reductions for larger prey, and increased prey densities. These patterns suggest changes in predator size structure will lead to previously unexpected changes in prey size structure and abundance.

## 8. FISH PRODUCTION OF THE OIL PLATFORMS OFF THE COAST OF CALIFORNIA

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To investigate the conservation and fisheries value of active and decommissioned oil platforms, standing stock biomass and production of fishes on oil platforms (and natural rocky reefs for comparison) off of southern California, USA were modeled using fisheries independent empirically-collected submersible and scuba survey data. All platforms and natural reefs included in the study were surveyed for at least 5 years. Standing stock biomass estimates incorporated depth-specific fish density and size structure with published weight-length relationships. Production of these fishes was then modeled over one year using von Bertalanffy growth function parameters and size-based species-specific estimates of natural mortality. Reproductive potential was also evaluated between platforms and natural reefs for species with published size-fecundity relationships (or other size-based measures of reproductive potential). Fish production estimates for oil platforms were high, often one to two orders of magnitude greater than rocky-reefs in the region. Per unit area of seafloor, oil platform fish populations also have significantly greater reproductive potential relative to those on rocky reefs. These results indicate that the potential contribution of oil platform habitat to biological resources in this region is substantial.

## 9. U.S. WEST COAST SEA TURTLE CONSERVATION AND MANAGEMENT

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Sea turtles found in the marine environment are managed under the jurisdiction of NOAA's National Marine Fisheries Service. The highly migratory nature of sea turtles presents a challenge for NMFS in recovering these endangered and threatened species, particularly since many of the threats to their survival, including impacts on nesting beaches or preferred foraging areas, are located in areas outside U.S. jurisdiction, including the high seas. Four sea turtle species inhabit waters off the U.S. west coast, including leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*), and green turtle (*Chelonia mydas*). Stranding records, fisheries bycatch data, and observations at sea provide valuable information on the seasonality and potentially important habitat for sea turtles off the west coast. In addition, analyses of life history data, genetics and satellite telemetry, including correlation with oceanographic and physical features, have refined our understanding of the origin of these turtles, important habitat, and their status regionally (e.g. North Pacific Ocean). Threats to sea turtles off the U.S. west coast include: fisheries interactions, boat collisions, power plant entrainments, marine debris, and illness, including a phenomena well known off the U.S. east coast termed "cold stunning." Domestic and international collaborative efforts have made positive strides in recovering sea turtle populations in the Pacific Ocean; however, major threats remain and the U.S. continues to serve as a leader in exploring solutions to reducing or mitigating these impacts.

## 10. TARGETING SWORDFISH DEEP DURING THE DAY TO REDUCE BYCATCH

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In recent years the management of Pacific swordfish (*Xiphias gladius*) fisheries have been shaped by concerns about bycatch of protected species rather than the sustainability of the target catch. An example comes from the California Drift gillnet fishery that targets swordfish off the U.S. West Coast. Due to concerns about leatherback sea turtle (*Dermochelys coriacea*) and marine mammal bycatch a series of gear modifications and time-area closures have been implemented. As a consequence, the fishing fleet and catch levels have declined dramatically with significant economic impacts. The diminishing landings may come at a greater cost in terms of bycatch if imports increase and foreign fisheries are not as tightly regulated. One way to reduce bycatch while allowing fishing is to take advantage of habitat separation between target and bycatch species. The habitat of swordfish and leatherbacks are separated vertically during the day; swordfish - deep, leatherbacks - shallow. This project examines the feasibility of targeting swordfish at depth using a deep-set longline and uses tagging technology to better characterize habitat separation. Two research cruises have been conducted targeting swordfish deep during the day. Working with fishermen, methods were developed to suspend the hooks below 200 m. Catch data were recorded on all sets. Catch are dominated by blue sharks (*Prionace glauca*) and opah (*Lampris* sp.) with few swordfish caught. There were no interactions with marine mammals or turtles. Additional efforts are planned for the fall of 2013.

### 11. EVALUATING POPULATION GENETIC STRUCTURE OF STRIPED MARLIN IN THE PACIFIC OCEAN

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Spatial genetic structure in the highly migratory striped marlin (*Kajikia audax*) was examined using nuclear (microsatellite) and mitochondrial (control region sequences) DNA markers. A multi-year concurrent sampling scheme was employed to collect tissue from 7 locations representative of the species' range in the Pacific: Japan, Hawaii, Southern California, Mexico, Central America, New Zealand and Australia. Mature and immature specimens were analyzed separately to evaluate life-stage specific population structure and movements. Microsatellite and sequence results revealed small, but significant overall spatial subdivision ($F_{ST}$ =0.0145 and $K_{ST}$ =0.06995, respectively). Pair-wise microsatellite analyses (n=1199) revealed 4 groups: 1) Japan/Immature Hawaii/Southern California 2) Mature Hawaii 3) Mexico/ Central America and 4) Australia/New Zealand. Mitochondrial sequence analysis (n=451) showed similar patterns; however, no significant differentiation was found between groups 1 and 2. Accounting for both spatial and temporal variation is crucial when interpreting genetic information for use in management strategies for striped marlin and other fisheries; therefore, temporal variation was also assessed in this study. Microsatellite data were used to calculate an unbiased estimate of temporal variance, Fs', which was corrected for overlapping generations. The magnitude of genetic drift ranged widely between consecutive age-classes, but did not alter the spatial patterns previously detected. This enhanced resolution of geographic genetic structure is important for understanding the complex migration patterns in this species. Moreover, the consistency among independent genetic studies on striped marlin provides strong support for management of at least 3 clearly delineated Pacific stocks.

### 12. RECENT ANALYSIS OF THE CALIFORNIA SEA CUCUMBER FISHERY

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In 2011, the California sea cucumber fishery reached a record high ex-vessel value of $3.4 million. This was double that of the previous record set in 2008 of $1.7 million. This dramatic increase in value has been primarily driven by increasing demands from foreign markets in China and Korea, with domestic markets also on the rise. The dive fishery targets the shallower occurring warty sea cucumber (*Parastichopus parvimensis*) while the trawl fishery targets the deeper giant red sea cucumber (*P. californicus*). Recent analysis of dive and trawl logs, have provided important information that we can use to better understand daily fishing behavior and how it has changed as this fishery has evolved. The results from independent monitoring groups have shown both decreasing and increasing densities of warty sea cucumber. The Department is currently evaluating these independent data sets as they relate to the commercial landing and log databases to determine if they can be used to better understand fishery trends. In addition, we have begun to monitor both inside and outside established MPAs to determine how distributions of warty sea cucumbers may be influenced seasonally. This understanding will be important in exploring the role that MPAs play as a fisheries conservation tool for sea cucumbers, and in assessing the various options that can be used to best manage this growing fishery.

### 13. STATUS OF THE FISHERIES - COASTAL PELAGIC SPECIES

**E.A. Hellmers**. California Department of Fish and Wildlife, Marine Region, San Diego, CA, 92123.

Populations of coastal pelagic species have long provided an important resource for the west coast of the U.S. In 1999 the Federal Coastal Pelagic Species Fishery Management Plan (CPS FMP) was adopted with

the intent to *prevent over-fishing while managing an increasing harvest capacity and maximizing yield. Under the FMP, take of all krill species is prohibited.* Northern anchovy (*Engraulis mordax*) and jack mackerel *(Trachurus symmetricus) are considered monitored species, while management of market squid, Doryteuthis (Loligo) opalescens is deferred to the State under the Department's Market Squid Fishery Management Plan. Populations of* Pacific sardine (*Sardinops sagax*) and Pacific mackerel (*Scomber japonicas*) are actively managed under the CPS FMP. For managed species, annual stock assessments are conducted, upon which the Pacific Fishery Management Council bases harvest guidelines (HG) for the following season. *One of the largest fisheries in California,* commercial sardine fishery catches were constrained by the HG in 2008 for the first time since the population was declared recovered in 1999. For the next four years, annual HG's had a restrictive trend due to declines in biomass estimates. In 2012, the HG was increased but not met, due to several possible factors. With a recent decline in the stock biomass estimates, the harvest guideline for Pacific sardine has again been reduced for the 2013 season from the previous year.

## 14. CALIFORNIA SHEEPHEAD (*SEMICOSSYPHUS PULCHER*) FISHERY REVIEW

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California sheephead (*Semicossyphus pulcher*) are protogynous, temperate reef fish that are targeted by size-selective recreational and commercial fisheries. Driven by the emergence of a trap fishery supplying the live fish market, the commercial sheephead fishery boomed in the 1990s when average annual landings for the decade were 106 metric tons; a 10-fold increase from average annual landings for the previous decade. In the early 2000s, regulatory actions including implementing minimum size limits and seasonal closures, and restricting access to the commercial fishery contributed to a decrease in landings. In 2001, optimum yield was determined and total allowable catch (TAC) was set to approximately half that of recent catches. Since 2005, commercial landings have been near or below the TAC set in 2001. Research has shown biological plasticity in sheephead in response to fishing and/or environmental factors. In some populations, sheephead reached first maturity and changed sex at smaller sizes, and sex ratios ranging from 1:1 to 15:1 (female:male) were reported. Recent studies also showed sheephead from some populations changed sex during the spawning season thereby forgoing spawning for some portion of the season. Changing sex during the spawning season suggests the reproductive potential of sheephead populations may be diminished where it occurs. In addition, spatial differences in population size structure show there is variable efficacy of the current minimum size limits across the sheephead's range. Although regulatory actions since the most recent boom have affected landings, modeling data from a recent study suggests that other regulations may increase fishery yield.

## 15. THE EFFECTS OF FISHING AND THE ENVIRONMENT ON THE LONG-TERM SUSTAINABILITY OF THE BARRED SAND BASS AND KELP BASS FISHERY IN SOUTHERN CALIFORNIA

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Unlike several boom-and-bust fisheries in other parts of the world, the recreational *Paralabrax* spp. (kelp bass/sand bass) fishery in southern California has endured several warm and cool oceanographic phases and nearly a century of increasing anthropogenic impacts. We examined regulatory changes and fishery-dependent and -independent data to investigate historical influences on the fishery and causes of dramatic catch declines in recent years. Our results reveal a complex relationship between harvest rules, fishery recruitment, kelp, ocean regimes, and fishing. Recent trends in larval abundance and lengths of harvested fish suggest population recruitment failure occurred during the last oceanographic regime shift coincident with peak exploitation. We believe this contributed to poor fishery recruitment, declines in catch-per-unit-effort, and a depressed population since the mid-2000s. Although long-standing regulations and periods of optimal environmental conditions appeared to have sustained the fishery, we recommend an adaptive management approach to mitigate the effects of fishing during unfavorable ocean conditions.

## 16. PROCEDURES AND SUCCSSES OF THE NMFS TUNA TRACKING AND VERIFICATION PROGRAM

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Since 2000, the National Marine Fisheries Service (NMFS) in Long Beach has implemented the National Oceanic and Atmospheric Administration's national Tuna Tracking and Verification Program (TTVP), reviewing and verifying imported and domestic tuna in the United States. Along with tracing tuna by harvest information, the TTVP verifies the status of dolphin-safe tuna claims, and oversees use of dolphin-safe tuna labels on consumer products. The dolphin-safe tuna label, designated in 1990, was the first label of its kind and remains an important tool for consumers who wish to know whether or not dolphins were seriously injured or killed during tuna harvest. Despite this long-standing history of tuna tracking by NMFS, this is the first formal description of the TTVP's internal review process for verifying dolphin-safe tuna.

## 17. DOLPHIN-SAFE TUNA LABELING IN THE UNITED STATES: WHERE DID IT COME FROM? WHAT DOES IT MEAN?

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Dolphin-safe logos are found on the vast majority of the tuna cans or pouches in U.S. retail markets. Tuna fishing practices, the role of fishery observers, U.S. statutes and regulations, and current issues are examined by the National Marine Fisheries Service, along with the impact these have had on dolphin-safe tuna labeling today. A review of the dolphin-safe program will be addressed.

## 18. PROTEOMIC CHARACTERISTICS OF THE REPRODUCTIVE STAGES OF THE POLYCHAETOUS ANNELID *NEANTHES ARENACEODENTATA*

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*Neanthes arenaceodentata* is the southern California member of the *Neanthes acuminata* complex. All the species in this complex are morphologically identical and have the same reproductive characteristics. Same sexes fight and opposite sexes lie side by side until egg laying. The female dies after laying eggs, and the male fertilizes the eggs and incubates the embryos for 3–4 weeks. The male can reproduce up to 9 times. Since this method of reproduction is unusual in polychaetes, the objective of this research was to determine if there is any set of proteins which influences this method of reproduction. Two-dimensional gel electrophoresis was used to identify differences between male and females proteins before and after reproduction. A total of 145 protein and 81 phosphoprotein spots were detected of which 36 proteins and 19 phosphoproteins were identified. The protein pattern was similar before and after fertilization in the male. Females lose about 75% of their weight following egg laying and are unable to resume feeding and either die or is eaten by the male. The protein structure is very different in the female as a result of spawning. There was a 44% and 16% decrease in the number of detected proteins and phosphoproteins in spent females, respectively. Identified proteins were actin-binding molecules involved in many cellular pathways regulated by multiple regulatory binding proteins and their modifications. Further, the down-regulation of muscle proteins and expression of specific set of actin isoforms after spawning suggested their regulatory role during reproductive period in *Neanthes* worms.

## 19. TEMPERATURE-MEDIATED VARIATION IN LARVAL TRAITS OF A SEASONALLY CLOSED ESTUARY SPECIALIST FISH: HOW MUCH DOES LATITUDE MATTER?

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Variations in the environment have been found to strongly influence the life history of many marine organisms that occur across with large latitudinal gradients. Species such as the endangered tidewater goby (*Eucyclogobius newberryi*) persist in estuaries along the California coast that are highly seasonally variable. This habitat preference may predispose them to local extirpation. This study investigates variations in the early life history of *E. newberryi* in relation to temperature trends found in ten estuaries spanning approximately eight degrees of latitude. Hourly temperature recordings were taken from July–October of 2011 using ibutton thermocron data loggers. Newly settled individuals were collected in order to determine how habitat variations affect pelagic larval duration (PLD), size at settlement, and post-settlement growth rates. Estuaries inhabited by *E. newberryi* showed high variability in temperature with no latitudinal trend, likely due to factors such as estuary size, amount of freshwater input, and duration of seasonal closure. Variations in all life history traits were found between high and low temperature sites. Fish that experienced colder temperatures had a longer PLD, slower post-settlement growth rates, and were larger at settlement.

## 20. BEHAVIOR OF JUVENILE WHITE SHARKS IN SOUTHERN CALIFORNIA

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The Southern California Bight is a known nursery for white shark (*Carcharodon carcharias*) of the eastern Pacific. Although birthing location is still unknown, young-of-the-year sharks (YOY) (< 1.75 cm TL) are incidentally caught in commercial gillnet fisheries and along coastal piers during summer and early fall months. Satellite and acoustic tagging data of YOY sharks caught in southern California during the summer indicate that sharks spend a majority of their time in coastal waters (< 200 m depth) then migrate south into Mexican waters during winter months when water temperatures go below 15.5°C. Some individuals have been shown to migrate back to southern California waters the following summer. Telemetry data indicate that YOY shark use approximately 600 $km^2$ during summer months. Areas showing the highest degrees of activity include Ventura Flats, Santa Monica Bay, Huntington Flats, and off Dana Point.

## 21. A TIME-CALIBRATED PHYLOGENY OF NORTH PACIFIC BAY GOBIES: ADAPTIVE CONVERGENCE, ECOLOGICAL DIVERSIFICATION, AND RELICTUAL ENDEMISM IN THE GULF OF CALIFORNIA

**R.A. Ellingson** and D.K. Jacobs. UCLA, Department of Ecology and Evolutionary Biology, Los Angeles, CA, 90095.

North Pacific bay gobies inhabit bays, beaches, and estuaries of temperate Asia and North America, but are absent from the northernmost latitudes of the central Pacific. Morphological characters have conventionally subdivided the clade into two informal groups – an elongate infaunal *Astrabe* group, and a deeper-bodied *Chasmichthys* group – each with a disjunct East-West (amphi-) Pacific distribution. A multi-locus phylogeny reveals basal divergence of the tree coincident with a dramatic global cooling event at the Eocene/Oligocene transition, with no evidence of subsequent trans-Pacific migration. These results suggest that several morphological characters previously used to define the *Astrabe* and *Chasmichthys* groups have arisen independently on both sides of the Pacific, revealing convergence of ecologically adaptive characters within a geographically divided clade. Inferences of vicariance via biogeographic events are used to time-calibrate this phylogeny. Divergence time estimates are used to compare and contrast potential mechanisms of bay goby diversification on either side of the Pacific. Speciation in the West Pacific has been driven largely by interstitial colonization of gravel beaches of varying grain size, and by invasion of freshwater streams around the Sea of Japan. In the East Pacific, diversification appears to be related to an intense upwelling regime combined with isolation in large Miocene-era embayments on the coast of California. Divergence times also provide strong evidence for relictual endemism in the Gulf of California, as speciation of three out of four Gulf-endemic gobies substantially predates tectonic formation of the Gulf itself.

## 22. A COMPARISON OF THE FREQUENCY OF MULTIPLE PATERNITY BETWEEN TWO POPULATIONS OF THE BROWN SMOOTHOUND SHARK, *MUSTELUS HENLEI*

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Multiple paternity was recently observed in a population of the brown smoothhound shark (*Mustelus henlei*) from Las Barrancas, Baja California Sur, Mexico with litters demonstrating the greatest percentage of multiple paternity for any shark species (0.93 of litters and an average number of sires = 2.3). To determine if this frequency is consistent elsewhere in the species' range, 4 polymorphic microsatellite loci were used to determine the frequency of multiple paternity in 18 litters of *M. henlei* from Santa Catalina Island, CA sampled in 2004, 2008, and 2012. Overall, multiple paternity was detected in 0.22 of litters with an average of 1.3 sires per litter. Multiple paternity varied among sampling periods with 2004 demonstrating multiple sires for 0.4 of sampled litters ($n = 10$) and 2008/2012 demonstrating a total lack of multiply sired litters ($n = 8$). Although multiple paternity was detected in this study, the frequency of occurrence is lower than that observed in the Mexican population. Based on these findings, investigators should take location into consideration when assessing the existence of multiple paternity in future studies of elasmobranch species.

## 23. A COMPARATIVE STUDY OF GENETIC DIVERSITIES AMONG EXPLOITED FLATFISHES OF THE CALIFORNIA SLOPE WITH EMPHASIS ON DOVER SOLE (*MICROSTOMUS PACIFICUS*)

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Dover sole (*Microstomus pacificus*) is a commercially important, slope dwelling flatfish of the northeast coast of the Pacific Ocean. Its genetic diversity is low relative to another commercially important flatfish, Pacific sanddab (*Citharichthys sordidus*). To provide a possible explanation, Dover sole nucleotide diversity and average pairwise differences are being compared to Pacific and longfin sanddab (*Citharichthys xanthostigma*), slender sole (*Lyopsetta exilis*), and the diamond turbot (*Hypsopsetta guttulata*) at Palos Verdes, Monterey, and Eureka, California. The rubynose brotula (*Cataetyx rubrirostris*), a non-flatfish, is being used as an outlier at Palos Verdes. Data from cytochrome oxidase subunit 1 (COI) sequences in Genbank (652 base pairs) suggested a trend where nucleotide diversity and average pairwise differences decrease with increasing depth. The shallow Pacific sanddab has an average pairwise difference of $1.65 \pm 1.04$ (mean $\pm$ standard deviation), while the deep slender and Dover sole have average pairwise differences of $1.20 \pm 0.82$ and $0.98 \pm 0.71$, respectively. Preliminary mitochondrial DNA control region data from specimens collected off Palos Verdes, using the highly variable 5′ domain, matches the COI sequences' depth trend. The shallow diamond turbot and longfin sanddab have an average pairwise difference of $15.98 \pm 7.80$ and $9.38 \pm 4.64$ (respectively), whereas the deeper dwelling Dover sole, slender sole, and rubynose brotula (overlapping depth ranges) have lower average pairwise differences of $3.67 \pm 2.33$, $4.28 \pm 2.24$, and $4.35 \pm 2.31$, respectively. These preliminary data suggest that the low genetic diversity of Dover sole may be related to the depth it inhabits.

## 24. BAY GOBIES IN CALIFORNIA AND THE GULF OF CALFORNIA – PHYLOGENY, SPECIATION PROCESS, CRYPTIC TAXA, ANTHROPOGENIC IMPACTS AND RESTORATION CONFLICTS

**D.K. Jacobs**, R. Ellingson, G. Dolby, and C.C. Swift. Ecology & Evolutionary Biology Dept. UCLA, Los Angeles, CA, 90095.

The primarily estuarine North Pacific "bay gobies" include approximately 17 eastern Pacific temperate and subtropical species. Diversity is high on the California Coast and higher still in the Gulf of California. These species prefer discrete types of estuarine habitat. The federally endangered tidewater goby (*Eucyclogobius newberryi*) is exclusive to the coast of California and strongly prefers seasonally closing habitat. Our recent work demonstrates that species within the group are phylogenetically subdivided East/West across the Pacific not on Ecological distinction relating to infaunality and blindness as had been previously argued. We also document that gobies endemic to the Gulf of California actually evolved prior to the tectonic formation of the Gulf, and that other subdivision within goby species may be a product of isolation of estuarine habitat at glacial low-stand. Moreover habitat specificity influences dispersal, genetic structure and endangerment. Cryptic diversity is evident including within the Gulf of California including the recently resurrected *Gillichthys detrusus* from the Colorado Delta. More generally a greater concern should be exhibited regarding local genetic variation relative to management action on the West Coast.

### 25. USING THE ROUND STINGRAY (*UROBATIS HALLERI*) AS A MODEL OF MATERNAL TRANSFER IN ELASMOBRANCHS

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Maternal offloading is one route by which animals may bioaccumulate persistent organic pollutants, such as DDT and PCBs. However, this process has not been well documented in elasmobranch fishes, despite the important roles they play in maintaining communities. The round stingray (*Urobatis halleri*) represents a good model to examine maternal offloading processes due to their high local abundance and use of contaminated nearshore systems. Ovulating and near-term pregnant female stingrays were sampled from several local estuaries in southern California and organic contaminants were measured in the ova and embryonic tissues and compared to levels measured in corresponding female livers to determine route of and extent of transfer. Total organic contaminant loads measured in ovulated ova were significantly lower than levels measured in embryos ($132.84 \pm 58.23$ ng/ova versus $438.66 \pm 301.64$ ng/embryo; $t_{25} = -3.9$, $p < 0.001$), indicating females have the ability to transfer contaminants throughout pregnancy. In addition, contaminant loads measured in pups showed a positive relationship with female contaminant concentrations ($F_{1,67} = 21.51$, $p < 0.001$). While females were demonstrated to maternally transfer contaminants, they offloaded relatively low percentages of their total contaminant loads ($1.5 \pm 1.7\%$) compared to other species. Therefore, variation in reproductive modes utilized by elasmobranchs will likely influence the extent to which females may maternally offload contaminants.

### 26. REGIONAL TAXONOMIC STANDARDIZATION AND INTERCALIBRATION: HOW TO ACHIEVE IT? THE GOALS AND ROLE OF SCAMIT

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California has some of the strictest environmental regulations in the US. The Southern California Bight has four major POTW's, three large ports, coastal bays and harbors, and open ocean which require marine environmental studies to insure their protection. As a result, there is a great amount of benthic sampling in coastal and ocean environments. That means taxonomic work! There are many government laboratories (municipal, county, state) and private consulting companies involved in producing benthic invertebrate community data (identification and abundance). A need for standardization and intercalibration of taxonomic name usage between Southern California laboratories was recognized and the Taxonomic Standardization Program was established by the Southern California Coastal Water Research Project in 1973. The demise of that program led to the formation of the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) in 1982. From the outset, the goal of SCAMIT was "promoting the study of marine invertebrate taxonomy in Southern California and developing a regionally standardized taxonomy". To accomplish this, SCAMIT provides a regular monthly forum to address problems in taxonomy, organizes taxonomic workshops, and hosts a discussion email list server. In addition, SCAMIT hosts a website, produces taxonomic aids, maintains a regional species list, and provides members with access to publication grant funds. A web based taxonomic database combining several information sources is in development. The organization's activities contribute to the scientific value of the many surveys of marine benthic invertebrate communities conducted in Southern California by assuring standardized taxonomy and compatibility between various taxonomic data sets.

### 27. THE SCAMIT TAXONOMIC DATABASE PROJECT: THE VISION AND THE REALITY

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In 2004 after a decade of successful use of SCAMIT's Taxonomic Species List of soft bottom invertebrates, an idea for an internet based version of the list was proposed by members. At this time

SCAMIT already had an established website (www.scamit.org). For more than eight years it was only used to post current newsletters, meeting announcements, and membership forms. This new database was envisioned as an on-line version of the taxa list that would provide scientific users with historical, bibliographical, and ecological data in addition to taxonomic descriptive information for each individual invertebrate species. The database could also provide community assessment tools and calculations for taxa specific indices greatly needed for state mandated sediment quality objectives. The database would then become a central clearinghouse for all SCAMIT's past products such as newsletters, taxonomic keys, voucher sheets, character tables, and digital images. All these useful resources could be linked thru a dynamic species page for each taxa name. This would allow working taxonomists and benthic ecologists instant access to information long kept in notebooks, binders and even brains. The realities of available volunteer time, support money, and lack of computer database skills created many stumbling blocks. Progress has been slowly made over the last nine years with the help of many partnerships. The taxonomic database is still a work in progress but the basic backbone and species pages are currently ready for public display, use and input.

## 28. BIODIVERSITY SURVEY SPECIES NAMES: CAN THEY BE TRUSTED?

**L.H. Harris**. Natural History Museum of Los Angeles County, Polychaete Collections Manager, 900 Exposition Boulevard, Los Angeles, CA 90007.

Accurate specimen identification is the foundation of biodiversity surveys, environmental monitoring, and ecological studies. It is usually assumed that the long lists of names contained within publications are reliable but that's not always the case. Comparison of the polychaete names reported in several recent studies and actual specimens shows that experience matters when it comes to providing trustworthy data. Species lists compiled in university labs by students & non-specialist researchers, monitoring agencies, and consulting companies often contain mistakes. The time required to process the specimens and the level of identification (whether to family, genus, or species) varies according to the quality of the taxonomist as well. Molecular data may give misleading results if not paired with accurate morphological identifications. Good taxonomy results from a combination of factors: 1) education & experience, 2) access to literature, 3) communication between researchers, and 4) access to vouchers & museum specimens. The Southern California Association of Marine Invertebrate Taxonomists (SCAMIT), which promotes all four factors, is an outstanding example of regional cooperation resulting in a high level of competence & standardization in California and beyond.

## 29. THE ROLE OF SAFIT IN THE CALIBRATIVE STANDARDIZATION OF FRESHWATER INVERTEBRATE TAXONOMY IN THE SOUTHWESTERN UNITED STATES

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The implementation of the Clean Water Act by the EPA in 1972 has heavily influenced the way we monitor our waterways throughout the United States. The initial steps toward assessing freshwater stream health were strictly focused on water chemistry and toxicity. In time, it was recognized that to truly assess stream condition, direct measures of instream biological communities were necessary, and thus bioassessment monitoring began. With the inclusion of benthic macroinvertebrate (BMI) communities in bioassessments, it became necessary for many governments, consulting agencies, and citizen monitoring groups to hire freshwater invertebrate taxonomists. To ensure accurate assessments of stream condition it was necessary to standardize the taxonomic naming conventions of BMIs, which in turn, resulted in the formation of the Southwestern Association of Freshwater Invertebrate Taxonomists (SAFIT). The mission of SAFIT is "to promote a better understanding of the taxonomy and systematics of macroinvertebrates in support of assessment of biotic condition in inland aquatic ecosystems of the southwest United States. Fundamental to this mission is the standardization of identification and reporting of taxa." SAFIT accomplishes this task by fostering scientific research, training and professional development of the environmental sciences pertaining to freshwater invertebrates through annual meetings, hosting webinars and workshops on problematic taxa, and has produced a standard taxonomic effort (STE) database to standardize all the taxonomic data collected by various sources throughout the southwestern United States.

### 30. WHAT IS SCAITE?

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SCAITE (Southern California Association of Ichthyological Taxonomists and Ecologists) formed in 2010 and began meeting regularly in 2011. This southern California based SCAMIT-like-fish-group consists of ichthyologists from sanitation districts, academia, museums and aquariums, and governmental agencies. We meet four times a year (typically March/April, June, September, and December) at either Cabrillo Marine Aquarium (CMA) in San Pedro or Southern California Coastal Water Research Project (SCCWRP) in Costa Mesa. Past meetings have focused on specific fish groups, such as rockfishes, syngnathids, and cottids, and typically include a guest speaker, a questions and answer session, and hands-on identification with specimens. This year's meetings will focus on the upcoming Southern California Bight 2013 Regional Monitoring Program. A LISTSERV has been created, has close to 100 scientists, and is constantly growing. Please visit our website at http://scaite.org/ for more information and details about upcoming meetings.

### 31. SIMPLIFYING THE COMPLEX, PART 1 - MOLECULAR APPROACHES TO DISSECTING THE *LEPTOCHELIA* COMPLEX

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Crustaceans of the order Tanaidacea are abundant in soft bottom habitats in the Northeastern Pacific Ocean and measures of species diversity within this group are ecologically significant to ocean monitoring programs. Identification of species within the family Leptocheliidae is problematic due to their small size (2–5 mm) and unresolved species concepts. For example, although *Leptochelia dubia* has been identified worldwide the cosmopolitan distribution of this species is questionable. Specimens identified as *L. dubia* are common in our samples along the California coast; however, limitations of current taxonomy only allow classification to a species complex level that may include several different species. In this study, we use a combination of traditional taxonomic procedures and molecular techniques to explore the systematic relationships of species in the genus *Leptochelia* and related taxa. Specimens of *L. dubia* Cmplx were collected from benthic samples at three sites: San Francisco Bay, San Diego Bay, and offshore of San Diego and Los Angeles. Phylogenetic analyses using the mitochondrial COI gene on the morphologically identified specimens will be presented and compared with GenBank sequences of *Leptochelia* species and other taxa in the family Leptocheliidae from the Atlantic Ocean. In the future, we plan to add the nuclear Histone 3 gene and 28S rDNA to the molecular analyses and include specimens from additional sites along the Northeastern Pacific and other geographic regions.

### 32. SIMPLIFYING THE COMPLEX, PART 2 – MORPHOLOGICAL APPROACHES TO DISSECTING THE *LEPTOCHELIA* COMPLEX

**D.B. Cadien**. Ocean Monitoring & Research Group, County Sanitation Districts of Los Angeles County, Carson, CA. 90745.

Small, white, eyed tanaids (order: Tanaidaceae) of the genus *Leptochelia* have been variously identified over the years in our waters, mostly as *Leptochelia dubia*. They are currently viewed as representatives of

an unresolved complex of taxa, which probably does not even include the nominal *L. dubia*. Recent advances in recognition of separatory criteria for females of this genus developed by others are applied here in an attempt to resolve individual taxa in the *L. dubia* complex locally, determine their number and distribution, and test methods for their separation. The same materials described here morphologically are also being analyzed using molecular methods by Katherine Beauchamp, Eric Pilgrim, and other collaborators. Methods will be described and preliminary results presented. The ability to identify females within this genus, long speciated on characters of adult males, should further adoption of a more gender neutral taxonomy within a group known for complex life cycles and highly skewed sex ratios.

## 33. ASSESSMENT OF DEEP BENTHIC HABITATS OFF SAN DIEGO, CALIFORNIA: PRELIMINARY RESULTS AND THE ROLE OF SCAMIT

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The City of San Diego conducts one of the most extensive benthic monitoring programs in the world, regularly collecting ~240 samples/year from nearly 100 sites at mostly continental shelf depths (< 200 m). Consequently, soft-bottom benthic conditions along the San Diego mainland shelf are fairly well understood. In contrast, less is known about conditions in deeper continental slope waters. The City began to address this issue about 10 years ago as part of its enhanced ocean monitoring objectives by adding sites located between 200–1000 m depths to its regional monitoring efforts. These efforts have been subsequently combined into a long-term Deep Benthic Habitat Assessment Study with the Scripps Institution of Oceanography. A total of 79 quantitative 0.1 $m^2$ grabs sampled to date (2003–2012) captured 7381 individuals, representing about 500 species. Diversity is highly variable at these sites, with species richness ranging between 8–126 taxa/grab. Macrofaunal abundance also varies considerably, ranging between 10–412 animals/grab. Polychaete worms account for about 57% of the animals, molluscs 22%, crustaceans 12%, and echinoderms 7%. Preliminary classification analysis results discriminate between at least nine ecologically-relevant groups occurring at slope depths off San Diego, which appear to separate primarily along depth and sediment type gradients similar to that seen at shallower shelf depths. Details of these deep assemblages will be discussed along with comparisons to sediment quality and other factors. The role of SCAMIT as an important QA component of this study and other local and regional programs throughout the Southern California Bight will also be discussed.

## 34. BENTHIC MACROFAUNAL COMMUNITY CONDITION IN THE SOUTHERN CALIFORNIA BIGHT, 1994–2008

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To evaluate whether the extent and magnitude of altered benthic macrofaunal communities in Southern California vary among habitats and over time, samples were collected using spatially random designs and assessed at 1,111 sites in 1994, 1998, 2003 and 2008, with 382 sites sampled in 2008. Extensive quality assurance and quality control measures were implemented. Benthic community condition was assessed on a four category scale and the area in each category was estimated. Habitats for which assessment tools do not yet exist were not assessed, including slopes and basins (>200m deep), the shallowest areas (< 10 m deep) of the inner shelf, and brackish water embayments with salinity < 27 psu. Overall, benthic macrofauna in Southern California were in good condition during 2008, with 99.7% of the area in reference condition or deviating only marginally. There was no evidence of disturbance on the island shelf or the mainland shelf. In contrast, embayment macrofaunal communities were more frequently disturbed with slightly over 12% of the area supporting clearly disturbed benthos, most often in estuaries (59.0%) and marinas (37.4%). Regional benthic community condition did not change substantially between 1994 and 2008 with less than 4% of the area supporting disturbed benthos and no consistent pattern of change at sites that were sampled during more than one survey. Southern California benthic condition evaluations may be improved by extending the depth and salinity ranges of assessment tools, improving trend detection methods, and improving understanding of mechanisms of impact in estuaries.

## 35. IT SAVES TIME, BUT CAN WE COUNT ON IT? - FIELD TESTS OF THE TRAWL WEIGHT/COUNT METHOD

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For many years local agencies have used a convenient shortcut in evaluating large trawl catches of invertebrates. Using weight/count, assumptions are made about representativeness of a counted subsample, which is separately weighted. The proportion of the total weight of the organism is then used as a multiplier of the exact count to estimate the count of the total catch. The method was a replacement for generic "class" methods used in earlier periods, where effort was truncated by use of 25+, 50+, 200+, etc. These assumptions were recently tested with a variety of different species from several different depths, substrates, and populations to evaluate potential sources of variability in application of the procedure, and to assess the confidence with which the results can be interpreted. This is a step towards providing a defensible methodology for use in SWAMP compatible quality assurance plans for marine trawls.

## 36. CHANGES IN INVERTEBRATE COMMUNITY DIVERSITY AND ABUNDANCE AS A FUNCTION OF OLYMPIA OYSTER (*OSTREA LURIDA*) RESTORATION TECHNIQUES

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The potential role of the Olympia oyster (*Ostrea lurida*) as an ecosystem engineer has not been explored, so little is understood about whether any ecosystem services will be produced by ongoing restoration efforts for the West Coast's only native oyster species. Further, the effectiveness of different techniques for restoring Olympia oyster beds has not been systematically evaluated. The most common technique is augmenting available structured habitat by adding dead shell onto mudflats and allowing remnant oysters to seed the shell with spat. Shell has been added at varying thicknesses, either consolidated in bags or simply placed loose onto the mudflat. We explored the effects of different combinations of Olympia oyster restoration techniques (varying the thickness of constructed shell beds using loose versus bagged oyster shell) on abundance and diversity of epifaunal and infaunal invertebrates. Twenty-five oyster beds were established in Newport Bay, California in June 2010. Five beds were not augmented with any shell and were used as control plots. The other twenty beds were randomly assigned to be constructed using dead oyster shell at thicknesses of 12 cm or 4 cm using shell bagged in jute or loose shell (n=5 replicates per treatment). Preliminary analyses indicate that the bagging of shell had no effect on abundance or diversity of epifauna. However, bed thickness did have an effect; 12 cm-thick beds supported higher community diversity and invertebrate abundance compared to controls while 4 cm-thick beds had intermediate values. Results could inform future restoration efforts for this species and establish *O. lurida* as an ecosystem engineer.

## 37. EXAMINATION OF SOUTHERN CALIFORNIA DROUGHT USING TREE RINGS, AND COMPARISON WITH THE AGGREGATE DROUGHT INDEX (ADI) AND THE STANDARDIZED PRECIPITATION INDEX (SPI)

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Severe droughts have been recorded and have great impacts in Southern California. Tree rings have ability to record drought in a wide variety of climate. In this research, we used tree rings from Bigcone Douglas-fir (*Pseudotsuga macrocarpa*) in the San Bernardino and San Jacinto Mountains to assess drought in the Santa Ana and San Jacinto River basins, respectively. The tree-ring data were detrended and standardized

using the computer software program ARSTAN (Cook, 1985) to build two master chronologies. The chronologies extend back to 1745 in the San Bernardino Mountains and 1375 in the San Jacinto Mountains. The tree-ring chronologies were compared with two drought indices: the Aggregate Drought Index (ADI) (Keyantash and Dracup, 2004), the Standardized Precipitation Index (SPI) (McKee, Doesken, & Kleist, 1993). Both the ADI and the SPI can describe drought conditions for multiple timescales (e.g., 3-, 6-, 12-, 24- month, etc.), and in this research, the two drought indices are compared with tree rings, and each other, over multiple time scales. A comparison of the three drought indicators during the modern era showed significant drought history in Southern California, especially 1947–50, 1959–63, 1987–92, 1998–03, and 2007–09. The ADI had stronger correlations with both tree-ring chronologies than the SPI (at multiple timescales). The ADI correlations were strongest ($r \approx 0.70$) during the end of summer in both basins. Based on the agreement, the tree ring records used to reconstruct ADI values back to 1375.

## 38. DECLINE TO NEAR EXTINCTION OF THE ENDANGERED SCOTTS VALLEY POLYGONUM (*POLYGONUM HICKMANII*) (FAMILY: POLYGONACEAE)

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Scotts Valley polygonum (*Polygonum hickmanii*) (Family: Polygonaceae) is a narrow endemic plant restricted to a specialized habitat (exposed bedrock in annual grassland) in Santa Cruz County, California. The species was named in 1995 and subsequently listed as endangered under the U.S. Endangered Species Act and California Endangered Species Act in 2003 and 2005, respectively. One population with two occurrences exists on three properties in a recently urbanized area in vicinity of the city of Scotts Valley with a geographic range of 0.03 $km^2$. The species persisted as 128 plants in 2012, having declined from 604 plants in 2003 and 1,612 plants in 1998. The primary threats to *P. hickmanii* are habitat alteration due to adjacent land uses and developments, and invasive species and thatch. Cessation of grazing and possibly fire suppression have likely contributed to the increasing presence of invasive species and accumulation of thatch. Intensive management will be necessary for *P. hickmanii* to survive. Unless management is implemented as a matter of urgency, the species will likely disappear within just a few years.

## 39. QUANTIFICATION OF WATER UPTAKE FROM PULSED INPUT VIA DISTURBED AND UNDISTURBED CHANNELS ON A DESERT BAJADA

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Sap-flow gauges were used on creosote bush (*Larrea tridentata*) to provide automated and efficient long-term measurements after simulating rain events (pulses) at three sites on the foot of the Providence Mountains in the Mojave Desert: an upslope channel with natural flow (active channel), a channel below a road with interrupted flow (inactive channel), and an upslope area without a channel (simulated channel). Plants within 3 meters of the active channel had a 20% sap-flow increase showing a maximum peak 16 days after pulse; whereas plants from inactive channel had a 45% sap-flow increase with a maximum peak 8 days after pulse. For plants in the simulated channel, only plants within 1 meter responded to pulse with a 20% sap-flow increase and a maximum peak 15 days after pulse. Plants located further than 3 meters from a channel did not respond to the pulses in any of the three sites. As opposed to expected results, plants located within 3 meters of the inactive channel did respond to the water pulse, and surprisingly showed higher percent increases in sap-flow, however, these values did not persist as in the case observed in the active and the simulated channels. It is not clear why plants near channels that have been cut off from significant flow for greater than 100 years would have a more pronounced pulse response.

## 40. THE IMPACT OF AGE AND MATE QUALITY ON RESOURCE ALLOCATION IN THE HOUSE CRICKET *ACHETA DOMESTICUS*

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Organisms are faced with a tradeoff between allocating resources to somatic maintenance or reproduction. The balance of this trade of may be impacted by the quality of an individual's mate and age at first reproduction. However, few studies have examined how mate quality and age impact reproductive decisions. Reproductive allocation varies with age, mating status and mate quality. Two hypotheses try to explain how mate attractiveness affects reproductive allocation. Reproductive compensation (RC) predicts a female will allocate more resources towards reproduction when her mate is unattractive. Differential allocation (DA) predicts females will allocate more resources when her mate is attractive. We sought to determine which strategy of reproductive allocation is used by house crickets (*Acheta domesticus*), how it varies with age and if females have higher fitness when young and mated to an unattractive male, or older and mated to an attractive male. Older females lay fewer eggs than young females. Regardless of age, female house crickets mated to unattractive males have higher initial rates of egg production compared to females mated to attractive males. Hatching rates don't vary with female age or male attractiveness. However, fertilization rates were highest in young females mated with attractive males and lowest for old females mated with attractive males suggesting attractive males may vary their reproductive investment in response to female age but unattractive males do not. Clearly, house crickets do not strictly adhere to either DA or RC and both male and female strategies vary depending on the context.

## 41. MATE GUARDING AND SPERMATOPHORE REMOVAL IN THE HOUSE CRICKET *ACHETA DOMESTICUS*

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Numerous studies have examined sexual selection prior to mating. However, aspects of sexual selection after mating are not as well understood. In orthopterans, males will continue to compete after mating through various behaviors that presumably increase the number offspring sired. I assessed the post-mating behaviors of the house cricket (*Acheta domesticus*) under varying conditions that should impact male and female behavior. After a focal pair mated, it was put into one of five treatment types. In three of the treatments, an additional male was added that was larger, smaller, or the same size as the focal male. One treatment had no males added and the other had the focal male removed. Aggressive behaviors by the focal male and time until spermatophore removal were measured. I hypothesized that males will mate guard more and that females will remove spermatophores faster in the presence of additional males. There was no difference in the number of stridulations, aggressive calls, mandible flares, or grapples among males in all treatment types indicating that intruder size did not affect aggression levels. However, males spent significantly more time mate guarding females when no additional males were present. Females removed spermatophores significantly faster when no males were added and the focal male was removed. These results indicate that mated males do not require competitors to induce mate guarding and that their presence deters spermatophore removal by females

## 42. UNCOVERING A FOSSORIAL SPECIES: HOME RANGE AND HABITAT PREFERENCE OF THE WESTERN SPADEFOOT (*SPEA HAMMONDII*) IN ORANGE COUNTY PROTECTED AREAS

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The western spadefoot (*Spea hammondii*) is a small, burrowing amphibian that inhabits arid ecosystems in California and Baja California. The species lives underground during the dry season and emerges only after a certain amount of rainfall to make its way to vernal pools for breeding. It is extirpated from most of its range in southern California, with only a few populations remaining in coastal Orange County, western Riverside County and inland San Diego County. Given that little is known of its biology and that both its terrestrial and aquatic habitats are imperiled in California, the spadefoot is recognized as a species of special concern by the U. S. Fish and Wildlife Service and California of Department of Fish and Wildlife, a sensitive species by the Bureau of Land Management and a species of interest by the County of Orange Natural Community Conservation Plan. In response to the need to learn more about the ecology of this cryptic species, we used 11 months of telemetry data for 15 spadefoot to characterize the movement and habitat use for these animals. We found that spadefoot moved a maximum of 262 m away from the breeding pools. Their aestivation sites were between 10 m and 90 m from the breeding sites (mean=46 m). Preliminary analysis of the spadefoot home range suggests that they cover from 24 $m^2$ to 6.5 $km^2$. From field observations, the spadefoot do not seem to show a habitat preference for burrowing sites, but the data have yet to be analyzed.

## 43. VENOM VARIATION AMONG SOUTHERN CALIFORNIA SCORPIONS

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Most groups of venomous animals exhibit substantial variation in venom composition. Variation may exist among taxonomic groups, among geographically delineated populations, among individuals within a population, and sometimes between the sexes and ontogenetically within individuals. Most of our knowledge regarding venom variation derives from extensive literature on snakes. In contrast, only a few studies have examined scorpions. In this study, we sought to characterize venom variation among several genera of Southern California scorpions, including *Hadrurus*, *Smeringurus*, and *Paruroctonus/Vaejovis* (identities to be confirmed). Using high-pressure liquid chromatography (HPLC), we found that each of these genera exhibit distinctive and very complex venom profiles, with numerous peptides and proteins. Mass spectrometry (LC-MS/MS) identification of proteins yielded limited hits, underscoring the tremendous potential of scorpion venoms for bioprospecting. We also found distinctive venoms between the two species of *Hadrurus* and two species of *Smeringurus* examined. We will also present results from our analyses of geographic and intersexual variation in venom. These studies form the basis of more in-depth studies of venom variation that will compare the relative influences of phylogenetic distance, geographic distance, habitat differences, and dietary differences.

## 44.* TEMPORAL AND SPATIAL VARIATION OF THE INTESTINAL INFRACOMMUNITY OF *ALLIGATOR MISSISSIPPIENSIS*

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Ecological stochasticity over evolutionary space and time contributes to the patterns illustrated in host parasitism, reflecting the current state of the environment, and the biodiversity and abundance of intermediate and definite hosts. During the 2009–2011 annual American Alligator (*Alligator mississippiensis*) harvest in Louisiana, the intestinal parasite infracommunity was examined to identify correlations of abiotic and biotic factors influencing parasitism between host size, sex, location and year. A total of 10,421 parasites were collected from 104 infected alligator specimens (96%). A significant difference of parasitism was found between sex ($p=0.02$) and harvest years ($p=0.04$). Sex was found to be the best predictor for parasite aggregation (overdispersion coefficient: 1.6964). Although no significant difference was found among geographic locations, variation in intensity and prevalence among geographic zones may be explained by anthropogenic alteration of the environment, such as agriculture and mining, and annual climactic factors, such as hurricanes.

## 45. A TEMPORAL PERSPECTIVE ON THE DISTRIBUTION OF METACERCARIAL CYSTS OF *CRASSIPHIALA BULBOGLOSSA* (DIGENEA) ON FISHES OF THE HEADWATERS OF THE EMBARRAS RIVER, ILLINOIS

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Fishes of the headwaters region of the Embarras River, Champaign County, Illinois, were surveyed in 1973 (Hinson et al., 1976) for the distribution of metacercarial cysts of the digenetic trematode *Crassiphiala bulboglossa*. The fish hosts were resampled in 1992 and 2011. The preferred fish host species remained similar across this 38 year period. However, the degree to which the hosts were parasitized, as measured by prevalence and mean intensity, varied greatly. The relevance of such measurements of host-parasite interaction may have considerable temporal limitations.

## 46. PARASITE PREVALENCE AND INTENSITY IN RELATION TO HOST MIGRATION: A CASE STUDY OF ATLANTIC COD (*GADUS MORHUA*) PARASITES IN THE NORTHWESTERN ATLANTIC

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Because parasites rely to a large extent on host ecology to perpetuate themselves, it follows that information on the host can be obtained by studying their parasite fauna. While this concept has resulted in numerous studies on the use of parasites to delineate fish stocks and fish migratory patterns there are relatively few studies that examine shifts in parasite recruitment relative to known seasonal movements of its fish host. Data for the present study was collected in 1974 and 1975 in Passamaquoddy Bay, Bay of Fundy, Canada, by examining 517 Atlantic cod (*Gadus morhua*) caught by otter trawl on a monthly basis. Of the 44 parasite species found in cod during the study, ten species were enumerated and classified as to their state of maturity. Results indicate that patterns of parasite prevalence and intensity were not always consistent with parasite recruitment; e.g., in some cases, parasite numbers increased without any evident juvenile parasite recruitment. This suggests that changes in the prevalence and intensity in some parasites is related to host movement and not to parasite recruitment or death. Due to presence of intermediate hosts and other factors, parasites of cod have localized areas/foci of infection and cod moving through these areas become subtly labeled as to their recent past localities.

## 47. THE IDENTIFICATON, PATHOLOGY AND TREATMENT OF *NEOBENEDENIA*, A CAPSALID MONOGENEAN, IN A CLOSED SYSTEM AQUARIUM

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Monogenean infestations are a common occurrence in captive settings. These infestations can be very difficult to contain once on exhibit because of invertebrates and algaes who do not tolerate the treatment options. In this study, the infestation of the capsalid monogenean, *Neobenedenia* is thought to have been introduced through live kelp from the ocean. While a monogenean infestation is considered chronic and rarely a fatal problem, this ecto-parasite can do serious damage to its host – the most concerning of which is to the eyes. The monogeneans will attach to the cornea - causing ulcerations, scarring, edema and infection which can lead to blindness. Monogeneans can also cause infections of the epidermis - which can lead to secondary opportunistic parasite infections, septicemia and death. For control of monogeneans, we regularly identify fish we know to have high infestations and put them a freshwater bath for 4–8 minutes. After treatment, we frequently move fish into a parasite free environment to allow healing and recovery. This is not ideal for wide-spread control, but individually helps fish prone to monogenean related skin and eye problems. Hydro-vacuming the substrate regularly will also aide in removing monogenean eggs before they hatch. Another widely used treatment option is the use of the drug Praziquantel. Praziquantel can be administered as a bath, a prolonged immersion, an intramuscular injection or it can be given orally. We continue to document what species of fish are parasitized by *Neobenedenia* and investigate with different parasite control and management strategies.

## 48. GROSS PATHOLOGY OF SOME METAZOAN PARASITES OF PINNIPEDS IN SOUTHERN CALIFORNIA

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Between 2000 and 2012, 1593 California sea lions (*Zalophus californianus*), 500 Northern elephant seals, (*Mirounga angustirostris*) and 184 harbor seals (*Phoca vitulina*) were found live-stranded on Orange County beaches were admitted to Pacific Marine Mammal Center for evaluation and rehabilitation. All animals were given a fecal parasite examination on intake and additionally, when they died or were euthanized were given a full parasite organ examination. All animals were found infested with one or more metazoan parasites. Photographic depictions of parasite anatomy and the pathology associated with infestation by *Otostrongylus circumlitis, Parafilaroides decorous, Contracaecum osculatum* (Nematoda), *Diphyllobothrium pacificum* (Cestoda), *Corynosoma* sp. (Acanthocephala) and/or *Orthohalarachne diminuata* (Arachnida) are presented. With the exception of *Otostrongylus* sp. and *Parafilaroides* sp., these parasites were not found to be primary causes of morbidity or mortality.

## 49. *GYRODACTYLUS LEPTORHYNCHI* (MONOGENEA) ON BAY PIPEFISH (*SYGNATHUS LEPTORHYNCHUS*) AT THE CABRILLO AQUARIUM

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In October 2011, bay pipefish (*Sygnathus leptorhynchus*) on display at the Cabrillo Aquarium became heavily infected with a previously undescribed species of *Gyrodactylus. Gyrodactylus leptorhynchi* (Cone et al. 2013) is the sixth species of *Gyrodactylus* found on pipefish and can be distinguished morphologically by the shape of the marginal hook sickle. DNA sequence data also distinguishes *G. leptorhynchi* from other previously sequenced *Gyrodactylus* species and within the genus, it is a member of a basal lineage that has radiated among coastal syngnathid, anguillid and gobiid fishes throughout the Atlantic Ocean and some adjacent waters. One to three, *G. leptorhynchi* were present on 63% of pipefish collected at Inner Cabrillo Beach and it was also found on pipefish in British Columbia. In the wild, *G. leptorhynchi* is found predominantly on the dorsal fins and anterior body surfaces. In more heavily infected captive fish, worms can be found in other parts of the body, including the male brood pouch. In captivity, young fish became infected at birth or shortly thereafter. Hyperviviparity and close proximity of pipefish held in captivity without treatment, likely result in an increase in parasite numbers within a short time, even at ambient temperatures. Worms can be removed from pipefish with serial treatment of topical anthelmintic chemicals.

## 51. SEASONAL CHANGE IN PREVALENCE, INTENSITY AND ABUNDANCE OF SYMBIOTIC COPEPODS ON *NEOTRYPAEA* SPP. IN SOUTHERN CALIFORNIA MUDFLATS

**M.D. Murray**, B. Passarelli, and J. Kalman Passarelli. Cabrillo Marine Aquarium, San Pedro, CA, 90731.

Little is known about symbiotic copepods on crustacean hosts, in particular copepods belonging to the family Clausidiidae. In order to better understand the biology of these symbiotic copepods on their hosts, we collected symbiotic copepods on two species of ghost shrimp, *Neotrypaea californiensis* and *Neotrypaea gigas* from two southern California mudflats (Cabrillo Salt Marsh and Santa Ana River mouth). In total, 182 *N. gigas* and 67 *N. californiensis* were collected and 423 and 225 copepods were removed, respectively. So far we have determined the prevalence of copepods at Cabrillo is similar to Santa Ana River for both host species (59.6% and 52.3% for *N. gigas* and 54.8% and 52.8% *N. californiensis*, respectively). The mean intensity of copepods on *N. gigas* at Cabrillo was 5.38 and 8.59 for *N. californiensis.* Mean intensity for *N. gigas* was 2.65 and it was 4.16 for *N. californiensis* at the Santa Ana River mouth. In addition, fluctuations in prevalence and mean intensity of copepods have been observed throughout the season. By assessing the distribution of copepods on *N. californiensis* and *N. gigas,* this study aims to resolve what species of symbiotic copepods occur on southern California ghost shrimp and improve what is known about the life history of symbiotic copepods in the family Clausidiidae.

## 52. PREVALENCE OF BOPYRID PARASITES (ISOPODA: BOPYRIDAE) ON TWO SPECIES OF CRANGONID SHRIMP IN SOUTHERN CALIFORNIA

**J. Kalman Passarelli**[1], B. Passarelli[1], and A.K. Morris[2]. [1]Cabrillo Marine Aquarium, San Pedro, CA 90731; [2]Santa Ana College, Santa Ana, CA 92706.

All known species of adult bopyrid isopods (Family Bopyridae) parasitize decapod crustaceans and occur either on the abdomen or within the branchial chamber of their host. Samples of crangonid bay shrimp

(*Crangon nigromaculata* and *Crangon nigricauda*) were collected from 2009 to 2012 at five locations in southern California (Mandalay Generating Station in Ventura, Inner Cabrillo Beach in San Pedro, Los Angeles/Long Beach Harbor in Los Angeles, Huntington Beach Generating Station in Huntington Beach, and San Onofre Nuclear Generating Station in San Clemente) and were inspected for bopyrid parasites. A total of 2,264 *C. nigromaculata* and 2,172 *C. nigricauda* were collected and locality, carapace length, weight, sex, reproductive status, and parasite location (left or right branchial chamber) were recorded for each shrimp. Of the total shrimp, 293 *C. nigromaculata* and zero *C. nigricauda* were infected with the bopyrid isopod *Argeia pugettensis*. Infection of *A. pugettensis* on *C. nigricauda* has been reported in other localities; however, none were seen infected in this study. Total parasite prevalence on *C. nigromaculata* was 13% and varied by season and locality. Frequency of location in the right or left branchial chamber seems to be random and no shrimp had multiple parasites. No infected female shrimp were brooding, and non-infected brooding females of comparable size were collected in the same sample. Some crustacean host species have been reported to have the ability to reproduce while parasitized by bopyrids. Our results, however, suggest that *Argeia pugettensis* is likely a parasitic castrator of the bay shrimp *Crangon nigromaculata*.

## 53. DETERMINING ACCEPTABLE ERROR THRESHOLD OF BIOMETRIC FINGERPRINT SECURITY

**M. Roesger** and A. Boadi. Homeland Defense & Security Research Team, California State University Dominguez Hills, Department of Computer Science, Carson, CA, 90747.

Biometric security is an emerging and popular solution for many security needs that would otherwise require less secure forms of identification (e.g., passwords, ID cards, PIN numbers). The fingerprint is a convenient solution that is non-reputable as well as unique to each person. When implementing this type of security it is vital that the system be balanced in its ability to not let unauthorized people have access (false positives) but also does not inconvenience legitimate users by rejecting their fingerprints (false negatives). The objective of this research is to establish the threshold of false positives versus false negatives relative to the level of security that is needed as well as the number of users of the system. The first process is using the NFIQ (NIST Fingerprint Image Quality) standard as a variable scale of quality standards. After asserting that the raw image is up to standards, you must set the allowed minutiae percentage error. As the percentage error value increases the number of false positives increases and the number of false negatives decreases, making them inversely proportional. Establishing an acceptable error threshold is highly dependent on the use of the security system. Highly sensitive information should have a very low error percentage making the information more secure, while systems with high amount of users should have a lower percentage error as to not inconvenience the thousands of people who will use this system every day. This research will increase our ease of access as well as our system/information security with biometric data.

## 54. THE RELATIONSHIP BETWEEN TIME PERSPECTIVE AND SPEEDED NEUROPSYCHOLOGICAL TEST PERFORMANCE

**G. Eisman**, L.M. Maes, and T.L. Victor. California State University, Dominguez Hills, Department of Psychology, Carson CA 90747.

Differences in neuropsychological test performance among ethnic groups have been documented, and attempts have been made to deconstruct the "race" concept into the language and cultural variables that can help explain these performance differences. The present study explored the concept of time perspective, a cultural factor that may help explain performance differences, particularly on timed neuropsychological tests. It was predicted that Caucasians will outperform Latino/Hispanic participants on timed tests of neuropsychological functioning, and that these differences will be accounted for, at least partially by time perspective. Participants were neurologically and psychologically healthy undergraduate students divided into two groups based on self-reported ethnicity (Caucasian, $n=11$; Hispanic/Latino, $n=39$). All participants were administered a comprehensive neuropsychological test battery including a timed measure of processing speed (i.e., the Symbol Digit Modality Test oral and written forms; SDMT) and the Zimbardo Time Perspective Inventory. Independent samples t-test revealed significant performance differences by ethnic group with Caucasians outscoring Hispanic/Latino students on the SDMT-oral form.

There were no significant differences found between Caucasians and Hispanics with respect to time perspective, and time perspective was not significantly correlated with SDMT performance nor did it significantly predict SDMT performance in either group. Results are discussed in light of the current literature and study limitations. Future studies should concentrate on using multivariate methods of data analysis with large representative samples, as well as including measures of acculturation, a variable that likely interacts with time perspective to explain group performance differences.

## 55. CITY OF NUMBERS: THE UNITS OVER FIELDS OF PRIME ORDER

**A. Hoffman**. CSUDH Department of Mathematics, Dominguez Hills, Carson, CA 90747.

All numbers can be divided into composite and prime numbers, and every prime number is connected with fields and their corresponding finite units. Since these finite units are used in abstract algebra, number theory, and cryptography, their behavior and nature are of significant interest in mathematics. The goal of this presentation is to give a visual representation of the structure of finite units, and to use these visual models to give us an intuition of the behavior of modular exponentiation. This intuition can help us understand existing theorems in number theory and abstract algebra, and hopefully allow us to come up with new theorems. The presentation will cover the slow approach to constructing diagrams of the units, and discuss some of the immediate consequences that we can conclude from this approach. From there we will use this information to find quadratic roots algorithmically, and use the quadratic algorithm to generate the structure quickly. The presentation will then use diagrams to give visual representations of theorems in number theory and hopefully abstract algebra. Thus the structure of units as visually represented will make a useful tool in teaching. The final part of the presentation will look forward on plausible application and categorical approaches of different types of prime, based on the behavior of their units. We will also look at the structure of units to form a solution for discrete logarithms, one of the most important unanswered questions in cryptography.

## 56. THE CSUDH HADRONIC STRUCTURE LABORATORY

**E. Banuelos-Casillas** and J. Price. California State University, Dominguez Hills, Department of Physics, 1000 E. Victoria Street, Carson, CA 90747.

Modern nuclear physics is not possible without extensive use of computers. Two of the main uses of computers are detector simulation and data analysis, both of which require the highest speeds possible. The amount of data used in a modern physics experiment can exceed 100 Terabytes, and understanding the behavior of the detector requires the simulation of approximately the same amount of data. This is not possible in a reasonable time frame with a single computer, which has led to the development of computer clusters. Both data analysis and event simulation scale linearly with the number of computers sharing the load, so large clusters are very useful for this purpose. A Beowulf cluster uses many identical computers, all connected to each other, performing a task in unison. At the CSUDH Hadronic Structure Laboratory (HadLab), we have built 37-node Beowulf-like computer cluster. All the computers in the HadLab cluster are recycled, mostly from computer labs on campus, to reduce the overall cost of the cluster. HadLab uses two administrative nodes: a "head" node, which controls the overall behavior of the cluster, and a "server" node, which houses a 15-Terabyte disk array, which holds the data used by the cluster; the rest of the computers are used for the calculations done by the cluster. This talk will discuss the motivation, design, and use of the HadLab cluster, and will describe the plans for its future expansion.

## 57. THE PLANNED SEARCH FOR FREE NEUTRON-ANTINEUTRON TRANSFORMATION USING THE NNBARX EXPERIMENT AT FERMILAB AND HOW IT RELATES TO BOUND NEUTRON OSCILLATIONS AT SUPER-KAMIOKANDE AND ELSEWHERE

**J. Venegas**. CSU Dominguez Hills, Department of Physics, Carson, CA, 90747.

In this presentation I will describe the role of CSUDH and present initial planning results on a new experiment at Fermilab called nnbarX that will use *neutrons* from a 1 MW cold spallation source near the Fermilab main accelerator ring which is being upgraded. This project will eventually probe theories of grand unification of the fundamental forces, the stability of matter, and how *Baryons* were created in the early stages of the big bang, at levels of sensitivity to the *baryon* lifetime that will be 100–10000 higher than what is currently available and will rule out or confirm leading theories of grand unification in which *neutrons* and other *fermions* are equally mixed with their antiparticles and can transform to each other in Right-Left symmetric theories such as *SO(10)*. We at CSUDH will be directly collaborating with the University of Tennessee Knoxville, University of Indiana Bloomington, North Carolina State University, Fermilab and Los Alamos National Laboratory on detector R & D for nnbarX and will be also working with a few other institutions in the US and in other countries.

## 58. DOES THE DWARF PLANET PLUTO HAVE AN INTERNAL OCEAN?

K.D. Trego. Center for Oceanic Planetology, La Jolla, CA 92037.

The dwarf planet Pluto is large enough to have an internal ocean result of internal heating. The NASA New Horizons mission to Pluto will image the dwarf planet's surface in 2015 and there may be evidence of an internal ocean on Pluto's surface such as resurfacing events. Pluto is a captured dwarf planet from the Kuiper Belt. The Neptune moon Triton has a similar origin as Pluto being a Kuiper Belt dwarf planet captured in a retrograde orbit around Neptune. Triton may have an internal ocean 20 km below its surface result of internal heating and external tidal forces of Neptune. Some other dwarf planets in the Kuiper Belt are large enough to have internal oceans result of internal heating.

## 59. ICE COVERED OCEANS ON MARS

K.D. Trego. Center for Oceanic Planetology, La Jolla, CA 92037.

It is now proposed that Mars has always had an atmosphere with enough carbon dioxide which would never allow the presence of liquid water on the planet's surface for any significant amount of time. Proposed oceans defined by two different sets of shorelines in the Vastitas Borealis northern hemisphere basin comprise the oceans called Oceanus Borealis. Aquifers exposed by slumping regolith released water to the surface. Water associated with volcanism, particularly in the Tharsis Volcanic Province, was brought to the surface. Fracture patterns associated with planetesimal craters in the Vastitas Borealis also released water to the surface. Cryovolcanism would melt subsurface and surface ice to add water to the surface. The water in the Vastitas Borealis basin would freeze not allowing liquid water oceans to form. The continued flow of liquid water to the surface through planetesimal crater fracture zones under a significant layer of ice cover would allow ice covered oceans to form in the Vastitas Borealis if a significant heat source existed to maintain it . That heat source would most likely be volcanism associated with the Tharsis Volcanic Province. A similar environment on Earth would be ice covered lakes in Antarctica.

## 60. RESTORATION OF CALIFORNIA SAGE SCRUB: RECLAMATION OF GROUND COVER FROM EXOTIC GRASSLAND

C.M. Rodrigue, P. Laris, L. Avelar Portillo, S. Brennan, J. Diminutto, M. Mills, P. Nesbit, A. Santana, C. Tabag, C. Vaughan, and S. Winslow. Department of Geography, California State University, Long Beach, CA 90840-1101.

Coastal sage scrub and interior sage scrub has markedly declined in Southern California in the face of construction, plowing, clearing for grazing, changes in fire régimes, and air pollution. Dwindling to an estimated 10–15% of its previous range, a number of endangered animals species are threatened with loss of habitat. A common type conversion is to exotic-dominated annual grassland, which is often strikingly able to maintain its dominance long past the disturbance that originally led to its replacement of CSS. Concerted efforts to restore CSS have often been disappointing, as grass and associated exotics reclaim restoration sites. That said, there are a number of places where CSS has been able to encroach back onto grasslands on its own. Understanding the reasons for CSS self-restoration is critical for the success of landscape restoration programs. Geography at CSULB has been conducting research in areas of persistently stable boundaries between CSS and grassland and in areas where CSS is expanding into grassland. Our work evaluates hypotheses given in the literature for the loss of CSS and the persistence of grassland: fire frequency, grazing history, plowing history, nitrogen fertilization from air pollution,

edaphic factors, slope and aspect, and geological substrates. Field sites have included the western Santa Monica Mountains and the Palos Verdes Peninsula. Papers in this session report progress on these tests, including the fall 2012 fieldwork done by a biogeography seminar.

## 61. CHARACTERIZING BIOPHYSICAL DIFFERENCES BETWEEN SHIFTING AND FIXED CSS-GRASSLAND BOUNDARIES

**K. Engelberg** and P. Laris. California State University, Long Beach, Department of Geography, Long Beach, CA 90840.

California coastal sage scrub (CSS) has experienced significant decline in the last century, with only ten percent of its original land cover remaining. Exotic annual grassland often takes its place, but only temporarily in many cases. In order to understand why and how CSS rebounds, this study compares CSS-grassland boundaries that have shifted significantly over the last 60 years to those that have remained fixed. Shifting boundaries represent significant CSS regrowth, as shrub species move into previously homogenous grassland. We used field transects to compare topographic, edaphic, and species cover characteristics of shifting and fixed boundaries. Results indicate that shifting boundaries tended to have CSS upslope from grass, be more sandy and less silty, have large ecotones, and contain more species associated with pure CSS, while stable boundaries included more traditionally chaparral species. These findings may help guide land managers in their choice of exotic grassland to be restored to native CSS.

## 62. GEOLOGY, SUBSTRATE AND CSS RECOVERY IN LA JOLLA VALLEY, VENTURA COUNTY, CALIFORNIA

**S. Winslow** and P. Nesbit. California State University, Long Beach, Department of Geography, Long Beach, CA, 90840.

Coastal sage scrub (CSS) is a unique and highly threatened vegetation community in California with an estimated 90 percent of the former biomass lost to development, agriculture, and invasion of exotic plant species. Although many hypotheses exist, the primary conditions and mechanisms that govern the success of CSS recovery are still poorly understood. The purpose of this paper is to explore whether any recognizable associations exist between the geologic substrate and stable CSS/grassland boundaries within the La Jolla Valley. The study area is composed predominantly of older (late Pleistocene-age) alluvial materials which overlie shale and sandstone units of the lower Topanga Formation. Scattered outcrops of intrusive volcanic rock (diabase basalt) also occur around the valley perimeter. Erosion of these geologic units and subsequent redeposition of the eroded material on the valley floor has resulted in the development of a soil profile of variable thickness and composition depending on the parent material. We will analyze the relationship between CSS boundaries over several decades compared with the underlying geologic substrate. We expect to find that CSS is mostly prevalent on geologically youthful and rocky soils while grassland is limited to substrates associated with deeper soils, high clay content, and low permeability. Although both CSS and grasslands are abundantly represented on all geological substrates occurring in La Jolla Valley (Engelberg, 2011), the association between local geologic substrate and dominant species assemblage is considered as one possible controlling factor with respect to CSS recovery.

## 63. IS THERE FUNGUS AMONG US: PRESENCE AND ABSENCE OF MYCORRHIZÆ FUNGUS IN CALIFORNIA SAGE SCRUB

**M. Mills**. California State University, Long Beach, Department of Geography, Long Beach California, 90840.

Restoration and conservation efforts of critically threatened California Sage Scrub (CSS) habitats in Southern California have struggled with the prevalence of non-native grasses and the inability, in some cases, of CSS to reestablish once anthropogenic disturbances have been removed. One hypothesis suggests that CSS is not recovering due to the degraded state of the mutualistic relationship between arbuscular mycorrhizæ and native species. Most non-native grasses in California are not reliant on mycorrhizal mutualism. Their presence significantly affects soil dynamics and may reduce or eliminate mycorrhizal populations. Anthropogenic soil disturbances, such as tilling, also significantly affect mycorrhizæ populations. Furthermore, studies demonstrate species of mycorrhizal fungi recognize specific host plants and will not form infection structures with inappropriate hosts. This study investigates whether there is a difference in presence of mycorrhizæ in exotic grass, native CSS and mechanically disturbed vs. undisturbed sites. Root balls from sites where both natives and non-natives occur, and from both disturbed and undisturbed sites, were collected to compare mycorrhizal presence. The samples were stained with 5% ink diluted in vinegar (5% acetic acid) and examined under a dissecting microscope to determine and census mycorrhizæ fungus presence.

## 64. EFFECTS OF HERBIVORY ON CSS RECOVERY IN LA JOLLA VALLEY, CALIFORNIA

**S.G. Brennan**, C.R. Vaughan, and C.M. Tabag. California State University Long Beach, Department of Geography, Long Beach, CA 90840.

Coastal Sage Scrub (CSS) has recovered immensely in the La Jolla Valley over the last century. Large areas once dominated by nonnative grassland have been repopulated with CSS; however, certain locations in the valley remain persistently covered by grassland. One of these areas, nicknamed the 'Moose' for its shape, is the focus of this research and has maintained a relatively stable boundary between CSS and grassland over the last two decades. Numerous factors can contribute to CSS recovery – edaphic conditions, precipitation, disturbance history, and herbivory. The vertebrate herbivores in the La Jolla Valley include mice, rabbits, and deer that feed on grasses and CSS saplings. The purpose of this research is to analyze the effects of herbivory on CSS expansion in the La Jolla Valley. Using field data that measures changes in CSS sapling height and grass plot height over a two month period, this research will be able to draw insight on the effects, if any, that herbivore foraging has on CSS expansion into the 'Moose' area of the La Jolla Valley. Specifically, our research measures the amount of CSS and grassland vegetation that is consumed by herbivores along the boundary and whether their foraging habits facilitate or hinder CSS recovery. Implications of this research are aimed at informing CSS restoration strategies to account for the impacts of herbivory.

## 65. COASTAL SAGE SCRUB AND THE SUCCESSIONAL INFLUENCE OF BACCHARIS PILULARIS

**S. Brennan** and P. Laris. California State University Long Beach, Department of Geography 1250 Bellflower Blvd, Long Beach, CA 90840.

Large areas of California Sage Scrub (CSS) have been type-converted to exotic annual grasslands. Concerted efforts to actively restore CSS can be expensive and have often been disappointing, as grasses reclaim restoration sites. While much research has focused on active strategies to restore degraded CSS landscapes, less research has focused on more passive strategies. This is surprising given that there are a number of places where CSS has to encroached back into grassland areas once the agent of disturbance has been removed. Understanding the reasons for CSS self-restoration is critical for the success of landscape restoration programs. This study examines cases of CSS recovery in the Santa Monica Mountains National Recreation Area (SMMNRA). We focus on *Baccharis pilularis* (coyote brush), a known seral CSS species with successional qualities that can be advantageous for habitat restoration in Southern California. Combining the spatial location of coyote brush stands with known shifts in CSS boundaries; we were able to assess levels of biodiversity in the wake of shifting boundaries. Preliminary results suggest that biodiversity has increased where coyote brush expands into nonnative grasslands. Implications of this research demonstrate that coyote brush can be used as an effective tool in the passive restoration of CSS.

## 66. THE ADVANCEMENT OF NATIVE SHRUBS INTO NON-NATIVE GRASSLANDS IN LA JOLLA VALLEY CA

**J. Dean**. California State University, Department of Geography, Long Beach, CA 90840-1101.

The current state of the Coastal Sage Scrub (CSS) plant community is poor. Only 10–15 percent of the original habitat remains and is highly degraded due to landscape fragmentation and invasion of annual grasses. As a result, restoration efforts are underway to recover lost habitat. La Jolla Valley in the Santa Monica Mountains represents an area where type conversion from CSS to grasses occurred due to cattle grazing. Grazing ended in the 1970s. Since this time, CSS has advanced into the grasslands in some areas while, in others, grasses have remained dominant. This study examines advancing and stagnant boundaries of CSS, as determined by analysis of historical aerial images taken from 1947 to 2010, applying raster map algebra to calculate the amount of CSS lost and gained. It integrates this imagery with the fire history of Pt. Mugu State Park. Transects were taken perpendicular to these boundaries, collecting species presence and ground coverage. These were then subjected to non-parametric statistical analysis to determine if there is a significant relationship between distance to boundary and species present in the two types of CSS-grassland boundaries and between distance to boundary and maturity of individuals as measured by height. Preliminary analysis suggests that advancing species are not representative of the surrounding CSS habitat, indicating that certain CSS species are better able to colonize grassy areas.

### 67. PASSIVE RESTORATION OF CALIFORNIA SAGE SCRUB?: WHAT HISTORICAL ECOLOGY CAN TELL US

**P. Laris**. Department of Geography, California State University, Long Beach 90840.

Large areas of California Sage Scrub (CSS) have been type-converted to exotic annual grasslands as a result of past disturbance regimes. Even once these disturbances have been removed, many areas of CSS do not recover. Concerted efforts to actively restore CSS can be expensive and results have sometimes been disappointing. While much research has focused on active strategies to restore degraded CSS landscapes, less research has focused on more passive strategies. This is surprising given that there are a number of places where CSS has recolonized grassland areas following release from disturbances such as grazing or disking. Understanding the reasons for CSS self-restoration is critical for the success of landscape restoration programs. In an effort to understand the factors that regulate re-colonization, our research compares and contrasts areas that have recovered without active efforts with those that have not. Drawing on natural experimental results from multiple sites in the Santa Monica Mountains our work examines the role of disturbance intensity and type, topography and soil texture, vegetation boundaries and species type to determine the factors most associated with passive restoration of CSS stands. The findings will be of use to land managers as well as restoration ecologists planning long-term projects.

## POSTER SESSION ABSTRACTS IN PROGRAM ORDER

### 68. ARSENIC IN THE MAINSTREAM: A CONCERN IN FOOD SAFETY

**S. Mantravadi**. California State University Los Angeles, CA 90032.

Arsenic is a naturally occurring heavy metal that is present in air, ground water, and now reported to be present in the food we consume. The presence of arsenic in apple/pear juice, and rice, has implications on the drinking water treatment, crops, the availability of healthy food, and the subsequent ill effects on health from such arsenic exposure. Consumers are concerned of increased levels of Arsenic in the various brands of rice and rice products, such as infant rice cereal, breakfast cereal, rice cakes, and rice beverages. This study will address the significance of the recent discovery of arsenic in rice by the Food and Drug Administration (FDA).

### 69. ACRYLAMIDE: A POTENTIAL INDICATOR OF THE OBESITY EPIDEMIC?

**S. Mantravadi**. California State University Los Angeles, CA 90032.

Acrylamide is known for its use in the coagulation stage of wastewater treatment (Environmental Protection Agency, n.d.). However, it is also used in industrial and agricultural applications. In 1992, close to 100 million tons of Acrylamide was produced in the United States (Mannsville, 1993). Acrylamide is also a chemical intermediate in several cooking procedures, such as frying and boiling coffee. Over the past 30 years, the childhood obesity rate has tripled – now seventeen percent of children are obese (Centers for Disease Control, n.d.). Acrylamide is present in many of the unhealthy foods that children eat – such as French fries and potato chips (National Cancer Institute, n.d.). This paper will address the issue of

increased Acrylamide levels in target food products over the years. Dose response curves will be used to analyze the resulting negative health effects.

## 70. SUSTAINABLE SEAFOOD AVAILABILITY AND AWARENESS DEPENDS UPON THE PREDOMINANT LANGUAGE OF THE ESTABLISHMENT'S CUSTOMERS/PURVEYORS

**G. Ramirez**, J. Arroyo, and S.S. Anderson. Environmental Science and Resource Management Program and Pacific Institute for Restoration Ecology, CSU Channel Islands, Camarillo, CA 93012.

The word "sustainable" has been appropriated and adapted to fit many different audiences, both scientific and non-scientific. We hypothesized that much of the general public would be unfamiliar with this increasingly amorphous word and concept and see little relationship to their food systems. We explored knowledge of seafood sustainability in two different linguistic communities (English- and Spanish-speakers) via point-of-sale surveys of seafood items, seafood-related customer inquiries, and purveyor knowledge at markets and restaurants in Santa Barbara, Ventura, and Los Angeles Counties. Establishments in Anglo-dominant neighborhoods were surveyed in English ($n = 30$) while those in Hispanic-dominant neighborhoods were surveyed in Spanish ($n = 25$) beginning in fall of 2012. Information about seafood and overall awareness of seafood sustainability strongly depended upon an establishment's dominant language. Spanish-speaking establishments proffered less info (species, source, harvest method) about seafood, had employees with little awareness seafood sustainability (*e.g.* 25% of English-speaking fishmongers have heard of MSC, Seafood Watch, *etc.* compared to 0% of Spanish-speakers), and were frequented by customers with little apparent interest in issues related to seafood sustainability (19.4% of English speakers ask about an item's source vs. 1.8% of Spanish speakers in our restaurants). This illuminates a dramatic void in educational efforts to promote healthy and sustainable seafood options. We believe dramatic gains in public awareness/understanding of these issues may be achieved with a greater outreach to and engagement with non-English speaking seafood consumers and sellers across Southern California.

## 71. HOLOCENE OYSTER ASSEMBLAGE OF NEWPORT BAY, CALIFORNIA: UNDERSTANDING THE PAST TO HELP RESTORE THE FUTURE

**K.K. Vreeland** and N. Bonuso. California State University, Fullerton, Department of Geological Sciences, Fullerton, CA, 92834.

Oysters have played a significant role in the ecology throughout Orange County's geologic history, but there has been a vast decline in the diversity and abundance within the region. Current restoration projects aim to reestablish the only native oyster, the Olympia oyster (*Ostrea lurida*) back into its southern California habitat. Fished to near-extinction in the 1930s, then further damaged by sulfite pollution from paper mills, *Ostrea lurida's* species habitat once stretched from Alaska to Baja, Mexico. The modern history of oysters has been well documented by biologists, however the paleontological history of oysters is less well known and many questions remain unanswered such as: Was *Ostrea lurida* always the only native oyster or did multiple oyster species live here? What other organisms thrived as a result of the oysters' reefal hard ground? How did the thickness of oyster beds vary through geological time? Did ocean environments play a role in community structure through time and if so, how? Results reveal highly diverse and abundant oyster communities were present in Newport Bay approximately 10,000 years ago. Future research includes analyzing specimens housed at the John D. Cooper Paleontological Curation Center, which holds a vast collection of Orange County fossils, allowing us to build a database that tracks diversity and depositional environments through space and time. This research will aid ongoing restoration projects throughout southern California by providing a long-term perspective of community change through time.

## 72. HIGH-RESOLUTION EARTHQUAKE FAULT KINEMATICS OF THE SAN PEDRO BASIN FAULTS, CALIFORNIA CONTINENTAL BORDERLAND

**E. Mohammadebrahim** and G.W. Simila. California State University of Northridge, 18111 Nordhoff Street Northridge, CA 91330.

The San Pedro Basin Fault (SPBF) is potentially an earthquake hazardous fault, especially if it is continuous with other faults to the south in the Inner Borderland, such as the San Diego Trough fault (SDTF), or if significant slip transfer occurs across a gap between the faults. About half of the Inner Borderland slip of 6–8 mm/y is taken up by the Palos Verdes fault (PVF); the SPBF appears to be the most likely avenue for the other half. The SPBF terminates to the south in an area of complex faulting and folding between Santa Catalina Island and Lasuen Knoll. This region is a transition zone between the SDTF and Coronado Bank fault (CBF) to the south, and the SPBF and PVF to the north (Legg et al., 2004). Exactly how slip is transferred and partitioned across this zone is not well known, but it is critical to assessing earthquake potential on these regional faults, which are located near a major port and population center (Conrad et al., 2009; 2010). In this project proposes to accurately map the seismicity and associated kinematics (motions) for San Pedro Basin fault and interactions with the Avalon Knoll-San Diego Trough faults in the San Pedro Basin region in the California Continental Borderland. I started my analysis with relocating events using Southern California Seismic Network SCSN data. I relocated 29 events in the tie period of August 2010 to September 2011. Most of the events are low magnitude and are between $1M_w$–$3M_w$. I used Hypoinverse2000 software. For the events located offshore, we had acceptable errors (RMS<0.34) in most of the cases. Our horizontal errors and also the depth values are not accurate in most of the cases which is predictable because I didn't have S waves. The events were located in the area surrounded with interaction of PVF and SPBF and Santa Monica Fault. This result will be revised by adding data from 2010–11 NSF-funded Project Albacore ocean bottom seismographs (OBS).

## 73. POST-STATION FIRE DEBRIS FLOW ANALYSIS IN THE SAN GABRIEL MOUNTAINS

**M.P. Ahlstrom** and R.V. Heermance. California State University Northridge, Department of Geological Sciences, 18111 Nordhoff Street, Northridge, CA 91330.

Debris flows are a source of substantial erosion in mountainous areas; consequently, their occurrence, spatial density, and characteristics provide essential data for understanding erosion rates and volumes. The 2009 Station Fire in the San Gabriel Mountains burned an area of 649.75 km$^2$, and destabilized slopes setting them up for subsequent debris flows. GIS mapping of burn area post-fire debris flows, combined with field mapping, allowed the calculation of flow area and volume calculations and their spatial density. Most debris flows initiated from burned, previously undisturbed, upper channel hill slopes averaging 28° with a spatial density of one flow/two km$^2$. Total flow material deposited is 715,071 m$^3$ and affected 2.5% of the total burn area. The relationship between each debris flow area affected and the volume deposited in each flow reveals a positive linear correlation, suggesting that as the area affected by a debris flow increases, so does the depositional volume of the flow. Assuming a 30 year recurrence of fires and subsequent debris flows, these flows account for $0.12 \pm 0.03$ mm/yr of erosion within the burn area. This erosion rate accounts for 7.5–13.3% of the total erosion rate in the San Gabriel Mountains, according to the erosion rate of 0.9–1.6 mm/yr (Lavé and Burbank, 2004). This new data demonstrates that debris flows are efficient in causing significant erosion compared to typical erosion processes, provides an empirical dataset for future debris flow hazard analysis, and provides a quantitative assessment of post-fire erosion rates in the San Gabriel Mountains.

## 74. MONITORING SURFGRASS AND SARGASSUM DENISTY IN A MARINE PROTECTED AREA OFF SANTA CATALINA ISLAND

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Big Fisherman's Cove off Santa Catalina Island is listed as part of the Blue Cavern State Marine Conservation Area under the California Marine Life Protection Act. It is a designated no take zone and provides habitat for numerous invertebrate and fish species. Surprisingly, little is known about the spatial patterns and variability of algal communities found living in this area – despite its designation as a no-take marine reserve nearly 25 years ago. This study aimed to examine the ecosystem health of the Big Fisherman's Cove area in regards to key foundation and invasive species, as well as to continue to develop a long-term monitoring system for future data collection. Two different species of algae, Pacific surfgrass *Phyllospadix* sp. and the invasive brown seaweed *Sargassum* sp., were regularly monitored underwater using SCUBA. Over a 1.5-year sampling period, we recorded a strong correlation among the density of surfgrass and Sargassum with monthly changes in ocean temperature. Mean density amongst both algal species was highest during the summer months (July–September) when mean water temperatures reached their peak (~70°F). These data will provide a better understanding of the characteristics and stability of algal communities within Big Fisherman's Cove, as well as provide important information about the ecosystem health of the Blue Cavern State Marine Conservation Area at large.

### 75. THE CALIFORNIA NATURALIST PROGRAM

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California Naturalist is a new statewide program developed by the University of California Cooperative Extension to create a committed corps of volunteer naturalists and citizen scientists trained and ready to take an active role in natural resource conservation, education, and restoration. Throughout the country, Master Naturalist programs and citizen science projects have both been shown to increase volunteers' ecological knowledge, understanding of science and/or environment-related behaviors. In California, we provide training for adults to be environmental stewards through an adaptable curriculum that can be as easily applied in the inner city as in the less populated rural counties, by tribes, colleges, natural resource agencies and nature centers. We utilize a core science curriculum called the California Naturalist Handbook, recently published by UC Press, that addresses basic natural history of California as well as classical and modern techniques for recording naturalist observations. We are currently developing advanced training modules in subjects such as estuarine, beach, and near-shore systems, regional modules for specific bioregions, and urban ecology. Additionally the program includes hands-on learning, communication training, and community service to engage adults in interactive learning and provide them with scientific literacy and critical thinking skills. We will report on courses running throughout the State as well as our efforts to couple these courses with citizen science projects and enhance diversity within the program.

### 76. CATALINA ISLAND ECOLOGY, RESTORATION, AND MANAGEMENT

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For two years a summer undergraduate internship program focusing on the natural history and management of Catalina Island has run as a joint effort between the USC Environmental Studies Program, the Catalina Island Conservancy, and the USC Wrigley Institute for Environmental Studies. One of the primary goals of this program is to provide an experiential learning opportunity for students enrolled in the Environmental Studies Program. In Summer 2012, four student interns worked on the maintenance of the Deer Valley trail adjacent to the WIES campus on Catalina Island. Students eradicated invasive plants, set up a long-term monitoring project to examine the spread of invasive fennel, established an interactive plant field guide, and provided overall maintenance of the trail itself. Initial assessments of soil chemistry also were recorded, measuring total carbon, organic carbon, and nitrogen, as well as soil pH texture. Soil chemistry measurements were made along the trail to compare areas highly modified by invasive plants (i.e., fennel monoculture) and areas occupied by native plant communities. In addition to conducting research projects in the laboratory and field, student-learning outcomes included analyzing data, writing research blogs and reports, and providing outreach activities to members of the Catalina community.

### 77. THE NEW FRONTIER OF WATER QUALITY REGULATION: BALLONA CREEK TMDLS

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In 1999 the Environmental Protection Agency entered into a consent decree with the National Resource Defense Council that represented two local non-profits the Santa Monica Bay Keeper, present day Los

Angeles Water Keeper, and the Heal the Bay Organization. This consent decree required that Total Maximum Daily Loads be established for the Los Angeles Region within 13 years. The original problem faced was that section 303d of the Clean Water Act which requires the establishment of TMDLs for impaired water bodies was not being enforced in the Los Angeles Region by the Los Angeles Regional Water Quality Control Board. One of the waterways that was found to be impaired and required the establishment of TMDLs was Ballona Creek. As of spring 2012 four TMDL's had been established for Ballona Creek including: trash, toxic chemicals, metals and bacteria. The main findings of this legislative review were legal standing of TMDLs, the pollution mitigation requirements for the TMDL programs, a timeline of when reduced levels of pollution must be met, and the methodologies that were being implemented by stakeholders to address the pollution.

## 78. CONSERVATION OF RIPARIAN AND UPLAND DIVERSITY IN CALIFORNIA CHAPARRAL

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Chaparral is but one vegetation type comprising the fauna and flora of southern California's high concentration of biological diversity. This globally important Mediterranean biome has a temperate climate with hot dry summers and mild, wet winters. Chaparral is characterized by summer drought-tolerant plants to which fire is a common natural and anthropogenic disturbance. Surveys were made to evaluate ecosystem resilience to disturbance. Species assemblages were assessed across sites to identify chaparral conservation value. Three distinctive datasets of chaparral and associated oak woodland habitat were synthesized from study sites located in southern California's Cajon Pass, San Dimas Experimental Forest, and San Jacinto Mountains. Each site recently burned and shares similar conservation issues such as urban infringement, post-fire erosion, and vegetation control practices. Data collected includes plant and avian community structure and diversity on 199 plots from 1997–2012. We compared diversity metrics among study sites to estimate number of species under the existing habitat categories. Avian species richness ranged from 31 to 142 and plant species richness ranged from 8 to 23. Average avian richness increased and leveled off at 1,000 ha. Plant richness values increased in smaller areas and leveled off at about 50 ha. Initial results indicate larger areas had greater diversity. Burned sites generally had greater species diversity then unburned, but this varied by site characteristics. These estimates show a consistent relationship between diversity metrics and chaparral area. This underscores the importance of habitat size and species associations when protecting valuable resources.

## 79. BENTHIC INFAUNAL INVERTEBRATE COMPARISON BETWEEN RECENT AND ESTABLISHED WETLAND RESTORATIONS

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Restoration efforts for Long Beach's Colorado Lagoon were completed in August 2012 and consisted of dredging to remove contamination, resloping and revegetation. Samples of benthic infaunal invertebrates were taken 6 month after the completion of dredging to create a baseline of the invertebrate community structure in the Lagoon. This criterion can serve as an indicator of habitat restoration progress. Preliminary data indicate that the early invertebrate community at Colorado Lagoon is dominated by insect larvae and lacking deposit feeders, such as oligochaetes. Mimicking restoration trajectory in other regional wetlands, these data indicate a less mature wetland than our reference site, a 10-year-old restoration at Los Cerritos Wetlands located in Seal Beach. Such data and analysis can be used to determine how Colorado Lagoon is developing post-restoration.

## 80. ENVIRONMENTAL AND COMMERCIAL BENEFITS OF CARBON SEQUESTRATION BY *ENCELIA CALIFORNICA* AND *SALVIA LEUCOPHYLLA*

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Because global climate change is a widespread concern, studies that reduce the emissions of $CO_2$ and other greenhouse gases through plant carbon sequestration are of great interest. Plants are major reservoirs of atmospheric carbon and $CO_2$ levels fluctuate with their photosynthetic patterns. Carbon sequestration refers to the storage of $CO_2$ into reservoirs, and describes a method to delay global warming effects and slow the accumulation of greenhouse gases. Specifically, this study quantifies the biomass dry weight of two common drought-deciduous species, *Salvia leucophylla* and *Encelia californica*. These species are part of an ongoing coastal sage scrub $CO_2$ sequestration study also involving *Eriogonum cinereum* and *Rhus integrifolia*. Two methods were used to collect *S. leucophylla* and *E. californica* samples. In Method 1, 12.5–50% of the subject was harvested and dried, and canopy measurements were recorded. Method 2 also required field measurements in addition to subsample samplings from each which was later used to calculate the biomass. (*Encelia californica* was collected using only method 1.) Using regression analysis, the results showed that *S. leucophylla* showed a strong correlation in its biomass and canopy dimension relationships. The correlation between the biomass and the surface area was $y = 58.386x^2 - 217.64x + 698.28$ and the correlation between the biomass and volume was $y = 173.25x^2 + 120.59x + 467.93$. The correlation between biomass and surface area for *E. californica* was $y = 149.86e^{1.5926x}$ and the correlation between biomass and volume was $y = 121e^{0.4317x}$. These equations will be utilized to calculate the amount of $CO_2$ sequestered using only canopy measurements, which will then aid planting efforts to maintain the natural balance of carbon between Earth and the atmosphere.

## 81. THE EFFECTS OF SEA LEVEL RISE ON THE DECOMPOSING COMMUNITIES OF A RESTORED SOUTHERN CALIFORNIA SALT MARSH

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Salt marshes are valuable, interconnected ecosystems that provide many key ecological services. They are sites of major nutrient cycling and a habitat for a diverse set of organisms. Southern California wetlands are shrinking due to anthropogenic factors and future sea level rise will exacerbate these effects. Increased inundation will likely disrupt or hinder key salt marsh functions. The decomposer community is one key functional group that is susceptible to increased inundation. Their role of releasing sequestered carbon and nutrients back into the ecosystem may be impacted. This community is composed of invertebrates, fungi, and bacteria. Each group has an important role in recycling nutrients and breaking down organic substrates. A marsh organ containing native *Spartina foliosa* and sediments has been deployed to simulate sea level rise. It is a wooden structure that holds 3 rows of PVC pipe at different elevations. The PVC pipes contain sediments and *Spartina* with the lowest row receiving maximum inundation. Traditional invertebrate taxonomic classification and molecular microbial community fingerprinting techniques will be used to determine the specific impacts of increased inundation on salt marsh decomposer community structure. Impacts on decomposition function will be assessed via litter bag experiments and sulfate reduction rate assays. I hypothesize that rates of plant litter decomposition and sulfate reduction will decrease and the decomposer communities' diversity and community composition will change, becoming less diverse. The data from this study will assist wetland management and restoration efforts to protect wetlands from impacts of sea level rise.

## 82. IMPACTS OF INVASIVE *TAMARIX* AND ITS HYBRIDS ON INFAUNA AT SAN DIEGUITO LAGOON

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*Tamarix* ssp., introduced from Eurasia and Africa to North America in the 1800s, is one of the most invasive species in the United States. Its impacts are well-known in riparian and desert ecosystems. Yet, little is known about how *Tamarix* affect salt marshes. Our primary objective was to determine the impact of genetically diverse *Tamarix* on the infaunal macroinvertebrate community in a Southern California salt marsh. This study was conducted in San Dieguito Lagoon, a salt marsh located in north San Diego County, CA. Infaunal invertebrate samples were collected in a paired design under *Tamarix* canopies (both pure and hybrid species) and under non-tamarisk canopies. This study found higher infauna diversity under non-tamarisk than under *Tamarix* ssp. and higher infauna diversity under hybrid *Tamarix*

than pure *Tamarix chinensis.* The presence of *Tamarix* spp. altered invertebrate community composition in the marsh microhabitat, increasing the abundance of an isopod *Littorophiloscia richardsonae* (90% of total composition) relative to non-tamarisk canopies (39% of total composition). These discoveries suggest that removal of pure *Tamarix* should be prioritized over removal of hybrid Tamarix in salt marshes for restoration strategies. Further studies still need to be conducted on the driving mechanisms behind the observed differences in the infaunal community.

### 83. MAPPING PLANT RESPONSES TO CHANNEL-WATER INPUT IN A DISTURBED MOJAVE ALLUVIAL FAN

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Water is a precious resource in the harsh climate of the Mojave Desert. Complex networks of alluvial drainage channels (washes) guide rainwater down from desert mountains, providing water to plants throughout desert bajadas. However, roads, railroads, and other anthropogenic features cut across the natural landscape, creating barriers to the even distribution of water to plants from the alluvial channels. In addition, railroad culverts consolidate and channel large amounts of water from upslope, creating large channels down-slope from the railroad. Such changes in water distribution can potentially alter the biotic community structure of the area immediately surrounding these channels, with plants near the channel edges growing larger due to more water availability than plants growing away from the channel margins. The physiological responses of plants at various distances around both anthropogenically impacted and non-impacted washes were examined by measuring the pre-dawn water potential, stomatal conductance, and sap flow of *Larrea tridentata* individuals at three alluvial channels in the Mojave National Preserve. In this study, land survey-grade GPS devices were used to accurately map the positions of the sampled plants as well as the study channel margins. Using the geospatial analysis technique of kriging, the measured physiological responses were used to interpolate water potential, stomatal conductance, and sap flow values of un-sampled plants around the study area channels. This method can be used to predict plant responses across the alluvial fan landscape based on channel distribution and their disturbance.

### 84. DEVELOPING A SEED COLLECTION METHOD FOR LONG TERM STORAGE, AND TESTING VIABILITY OF THE FEDERALLY ENDANGERED PLANT *ERIASTRUM DENSIFOLIUM* SPP. *SANCTORUM*

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The Santa Ana River Woolly Star (*Eriastrum densifolium* spp. *sanctorum*), is a federally-listed endangered plant species native to the Santa Ana River floodplain in Redlands, CA. A major cause for its protection is the lack of occasional flooding from the Santa Ana River due to regional flood control measures. The woolly star has a very specific habitat preference for sand deposits near rivers that experience occasional flooding. This habitat type is very limited and only supports very small populations of woolly stars. The goals of this project were to develop a consistent seed collection protocol and to collect seeds for long term storage and woolly star habitat mitigation. Seeds were collected from four field sites and filtered through a series of sieves (No.14 and No. 25 standard soil sieves) to minimize the debris retained, and maximize seeds recovered within a sample. Seed-to-mass regressions were created by weighing subsamples across increments of ~0.1–0.2 g (up to 0.9 g) and manually counting the number of visibly normal seeds within each sample. These regressions were used to estimate the amount of potentially viable seeds collected for each site. Weekly collections from September 13–November 4, 2012 amassed ~57,000 seeds. Across sites there was some variability among regressions that was not clearly understood, suggesting that more testing may be necessary. Germination of collected seeds ranged from 47% to 79% across all sites with an average of 62%.

### 85. BROOD SEX RATIO AND NEST SUCCESS BASED ON DNA ANALYSIS AND TAIL-FEATHER PATTERN IN COSTA'S HUMMINGBIRD (*CALYPTE COSTAE*) IN THE SONORAN DESERT

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Nest success may be affected by brood sex ratio. Adult Costa's Hummingbird (*Calypte costae*) females are larger than males, but males display sex-specific plumage and behaviors, namely singing and diving, that increase developmental costs and are expensive to maintain. If one sex demanded more resources to fledge than the other the brood sex-ratio might have had an influence on overall nest success. The two chicks might use resources differently (females for body mass, males for developing expensive behaviors); however, the amount of resources required from the parent might be the same. Therefore, I hypothesized that brood sex ratios will not affect nest success because one sex is not necessarily more expensive to rear than the other. Sex of the chicks was determined in two ways: by tail feather pattern and by DNA analysis. I collected chick feathers for DNA analysis to test the hypothesis. The DNA analysis was also used to verify the accuracy of the tail-feather pattern to determine the individual sex of chicks. Brood sex ratios for 26 nests (52 individuals) were successfully determined from feather samples through genetic techniques from DNA. Brood sex ratios were not related to nest success, which supported my hypothesis. This study is the first on Costa's Hummingbird to use genetics to sex individuals and sequence a gene region on the sex chromosomes. This study is also the first to use tail feather patterns to sex individuals for Costa's Hummingbird, and the first to verify this method using genetic analysis.

## 86. COLONY DYNAMICS OF ELEGANT TERN (*THALASSEUS ELEGANS*) IN THE SOUTHERN CALIFORNIA BIGHT IN RELATION TO OCEANOGRAPHIC CONDITIONS AND *DISTURBANCE EVENTS*

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Coastal seabirds are prey generalists known to be influenced by oceanographic conditions related to productivity and affected by various kinds of disturbance. The Elegant Tern, the most abundant seabird in southern California, nests at three locations yet is recognized as a single population in the region. Numbers of nesting pairs provide the first measure of reproductive success, and they fluctuate dramatically for this tern within and among years at the three sites. Recently (2003–2012), nest numbers have ranged from <100–20,000 at the San Diego Salt Works, 300–10,000 at the Bolsa Chica Ecological Reserve, and 0–11,000 at Los Angeles Harbor. What are the forces driving these marked fluctuations? We know that conditions related to temperature and productivity vary within the region, and that disturbance events, which can cause colonies to abandon a site, also vary among the nesting locations. To address our question, we are first assessing oceanographic conditions in the region for 2003–2012 using chlorophyll *a*, sea surface temperature (SST), upwelling intensity, and the Oceanic Niño Index (ONI), a measure of El Niño Southern Oscillation events. Secondly, we are developing an index to quantify the impacts of disturbance, either from human or predator activity. We expect Elegant Terns to be attracted to conditions that increase prey availability, including high chlorophyll, low SST, strong upwelling, and low ONI values. We also expect that disturbance can cause this tern to abandon a site during a given season. Our study should help tease apart the factors driving these striking fluctuations in nest numbers.

## 87. COMPARISON OF DIETS AND DIETARY SAMPLING METHODS FOR NESTING CALIFORNIA LEAST TERNS (*STERNULA ANTILLARUM BROWNI*) AT PURISIMA POINT ON THE CENTRAL CALIFORNIA COAST AND ALAMEDA POINT IN SAN FRANCISCO BAY

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The relationship between diet and reproductive success is important for assessing the status and predicting the future for a recovering endangered species. Accurate dietary data are crucial for assessing this relationship. However, the diet of the California least tern (*Sternula antillarum browni*), a state and federally endangered species, has not been studied extensively. For the dietary assessments that have been completed on this nearshore seabird, multiple techniques have been variously used, making it difficult to compare diets among nesting colonies. To help alleviate these shortcomings, we are comparing CLTE diets over the last decade at two colonies, Purisima Point (37° N, 122° W), Vandenberg Air Force Base, on the central California coast, and Alameda Point (34° N, 120° W) about 300 km distant in San Francisco Bay. We are analyzing diets from the first site using fecal samples and dropped fish for 2001–2012 and fecal samples, regurgitated pellets and dropped fish from the second site for 2000–2012. Preliminary results show that, as expected, birds at Purisima Point feed mostly on subtidal and nearshore fishes while the birds at Alameda Point feed mostly on bay/estuarine and nearshore fishes. We have also found that dropped fish and fecal samples often show different proportions of fish families present in the diet. This study should contribute to a greater understanding of dietary assessment methods for CLTE and of differences in food habits of CLTE nesting at coastal and estuarine sites.

## 88. DIETARY AND STABLE ISOTOPE ANALYSES REVEAL THE ROLE OF A CRYPTIC PREY IN THE ELEGANT TERN (*THALASSEUS ELEGANS*) FOOD WEB IN SOUTHERN CALIFORNIA WATERS

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Species composition of dropped fish collected at Elegant Tern (*Thalasseus elegans*) colonies in southern California shifted from mainly northern anchovy (*Engraulis mordax*) in the 1990s to >60% kelp pipefish (*Syngnathus californiensis*) in 2011. This change was unexpected as ELTE is an open-water forager, and the pipefish is cryptic in kelp. In response, we tested two hypotheses at the Los Angeles Harbor nesting colony in 2012: 1) Kelp pipefish are incorporated into the ELTE diet given the many past deliveries of pipefish; 2) Kelp pipefish feed in a plankton vs. kelp food chain, leaving them vulnerable to predation by the tern. We identified ELTE prey deliveries and determined $\delta^{13}C$ and $\delta^{15}N$ isotope values for ELTE and its prey—northern anchovy, kelp pipefish, market squid (*Loligo opalescens*), and California grunion (*Leuresthes tenuis*). Direct observations revealed that the ELTE chick diet comprised 8% kelp pipefish and 61% northern anchovy even though dropped fish still comprised mostly pipefish. All prey were found to have similar $\delta^{13}C$ and $\delta^{15}N$ signatures, except that California grunion was significantly enriched in $\delta^{15}N$ compared to anchovy and pipefish, indicating it feeds at a higher trophic level. Given that anchovy, grunion and squid feed in the plankton, common $\delta^{13}C$ values suggest that pipefish do also. The similarity of prey isotope values, however, hinders using mixing models to determine relative contributions of prey species to the ELTE diet. Increased prey sampling may resolve this issue as it appears that pipefish and grunion are enriched in $\delta^{13}C$ compared to anchovy and squid.

## 89. DETERMING THE EFFECTS OF ANTHROPOGENICALLY-ALTERED WATER TEMPERATURES ON THE MOVEMENT PATTERNS AND HABITAT SELECTION OF THE EASTERN PACIFIC GREEN SEA TURTLE (*CHELONIA MYDAS*) WITHIN ITS MOST NORTHERN RANGE

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Anthropogenic temperature change along the coastline can affect the distribution and movements of marine species. The endangered green sea turtle (*Chelonia mydas*) is known to utilize coastal habitats as a juvenile and during breeding and foraging periods as an adult. Due to their ectothermic qualities, juvenile green sea turtle (GST) distribution is influenced by water temperature; therefore, anthropogenic influence of coastal thermal conditions may affect GST behavior. Eastern Pacific GSTs have been observed at its most northern limits in southern California particularly within the San Gabriel River and Anaheim Bay Estuary. Due to the warm water effluent from coastal power plants along the river and the shallow ponds within the estuary I hypothesized that the San Gabriel River acts as thermal refugia year round and Anaheim Bay Estuary only during the warmer months, enabling individuals to occupy its most northern range to forage. To date eight GSTs have been tagged and passively monitored using acoustic telemetry. All immature individuals tagged in the river have remained in the river over periods spanning two seasons, while turtles tagged in the estuary have moved into the river once temperatures dropped below 15°C. Water temperatures within the river fluctuate up to 20°C within a month, a temperature swing that should directly affect GST movements. One individual has been tracked for two 24 hr periods within the river, displaying diurnal patterns where at night it would stay in one spot and during the day it would foraging in different parts of the river.

## 90. DETERMINANTS OF BOT FLY INFESTATION IN THIRTEEN-LINED GROUND SQUIRRELS IN COLORADO SHORTGRASS STEPPE

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Larvae of parasitic flies grow inside and feed upon tissues of wildlife species and therefore depend upon healthy hosts. Bot fly (*Cuterebra* sp.) larvae were discovered on thirteen-lined ground squirrels (*Ictidomys tridecemlineatus*) during long-term monitoring studies in northern Colorado. Although bot flies are common parasites of small mammals, there are no records of infestation of this squirrel species and the species of bot fly is unknown. We examined prevalence and load of bot flies in ground squirrels trapped in shrub and grassland habitats in spring and summer between 1999–2011, with the aim of determining host characteristics and environmental factors that influence bot fly infestation. We also investigated possible effects of prescribed fires in grasslands on prevalence. Infested squirrels were rarely found on shrub sites and during spring trapping. Across all summers, average prevalence of infestation in grasslands was 9.8%, although prevalence was especially high in 2008 (25.4%). Infested squirrels had 1–7 bots, with 44% having only 1 larva. Infestation did not vary greatly with host sex, age or weight. Prevalence was much higher (33%) in burned sites the first year after a fire, and remained consistently higher on burned grassland sites than on unburned sites trapped the same years. Our results suggest that fires may alter the environment in ways that increase the susceptibility of squirrels to infestation, or increase fly populations or the ability of flies to find and infest hosts. In the future we hope to identify the bot fly species using molecular genetics analysis.

## 91. POPULATION GENETIC STRUCTURE OF NORTHERN GRASSHOPPER MICE (*ONYCHOMYS LEUCOGASTER*), IN RELATION TO PRAIRIE DOGS AND PLAGUE

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At the Pawnee National Grasslands (PNG) of northern Colorado, high densities of northern grasshopper mice, *Onychomys leucogaster*, are often associated with colonies of black-tailed prairie dogs, *Cynomys ludovicianus*. Prairie dogs suffer massive population die-offs as a result of plague, an introduced disease caused by the bacterium *Yersinia pestis* and spread by fleas. Grasshopper mice share burrows and fleas with prairie dogs, but they are more resistant to plague mortality and suffer less marked population declines. The population genetic structure of prairie dogs is well-understood, but it is not clear if the association between prairie dogs and these wide-ranging mice is reflected in gene flow of mice, or if plague outbreaks on prairie dog colonies influence the population genetic structure of grasshopper mice. To determine the effects of spatial landscape features, such as prairie dog colonies, and episodic mortality events, such as plague outbreaks, on the genetic structure and diversity of grasshopper mouse populations, we extracted DNA from 600 individuals collected on and off colonies between 2004–2011, including sites that suffered plague. We screened samples using 2 types of hyper-variable molecular markers: one mitochondrial gene, *cytochrome oxidase subunit I (COI)*, and 11 nuclear microsatellite loci. Preliminary results from 40 *COI* sequences from 2004 showed some population genetic differentiation between eastern and western subunits of the PNG, indicating a potential isolation-by-distance pattern. Additional analyses of microsatellite data, combined with GIS information on landscape features, will be required to identify pockets of genetic diversity and the effects of plague on population differentiation.

## 92. IMPACTS OF THE INTRODUCED EASTERN FOX SQUIRREL ON THE BEHAVIOR OF THE NATIVE WESTERN GRAY SQUIRREL

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The eastern fox squirrel (*Sciurus niger*), has been introduced to Los Angeles and many other areas within California. Over time, the fox squirrel has expanded its geographic range and has displaced the native western gray squirrel, (*Sciurus griseus*), in many urban/suburban habitats. The western gray squirrel

is considered to be a specialized feeder and highly arboreal while the eastern fox squirrel is a generalist feeder and more adaptable animal. Observations were conducted to compare the behaviors of the gray squirrel among habitats where they exist alone to those where they coexist with the fox squirrel. In addition, the behaviors of the two species were compared in habitats where they coexist. Observations on location, eating, foraging, grooming, and communication were recorded. Each individual animal was observed for a total of 15 minutes and behaviors were recorded at 15-second intervals. Significant differences in behavior were observed in aspects of location, foraging, and eating. Ongoing and future portions of this study include continued behavioral observations, litter counts, natural food preferences, and predator-risk assessments.

## 93. FORAGING BEHAVIOR OF KANGAROO RATS AT SEED TRAYS REVEALED BY GIVING-UP DENSITIES AND REMOTE CAMERAS

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Behavioral ecologists often use indirect approaches to understand foraging decisions of nocturnal, secretive animals such as rodents. Many researchers have measured rates of seed removal by rodents in seed trays to estimate giving-up densities (GUDs), but few studies have documented the number and species of individuals visiting trays, the number of visits, and the amount of time spent foraging and between visits. We studied foraging behavior of the desert kangaroo rat (*Dipodomys deserti*) in seed trays in the Mojave Desert, California, in June 2012. Reconyx PC800 cameras were used to quantify how GUDs were affected by the amount of seed provided (2, 4, 8, or 16 g millet) and by the number of and duration of visits. We successfully recorded 17 foraging trials, during which only 1 individual was observed in a given tray at a time. Except at the lowest initial density (2 g), *D. deserti* removed >70% of seeds and GUDs were relatively constant, i.e. usually <2.5 g, underscoring *D. deserti*'s efficient foraging abilities. The number and frequency of visits were affected by variation in initial seed densities: *D. deserti* made more visits more often to richer patches. Higher seed densities also resulted in lower nightly GUDs and longer first visits to a tray. Although we could not identify individuals, such information could verify that all foraging at tray was done by a single individual. Our results demonstrate that information available from remote cameras can complement traditional approaches to understand the mechanistic basis of foraging of small mammals.

## 94. PATTERNS OF ACTIVITY AND DIVERSITY OF BATS AT THE URBAN-WILDLAND INTERFACE IN SOUTHERN CALIFORNIA

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Habitat loss and fragmentation pose a significant threat to bat populations. Urbanization can decrease roosting sites and foraging habitat for many species in southern California; however, the factors that allow some species to persist in cities and suburban areas, while others decline, are unclear. We used acoustic detectors (Pettersson D240X) to record bat echolocation calls at 4 sites in the eastern San Gabriel Valley that differed in their local site characteristics and the degree of urbanization of the surrounding landscape. Each site was sampled for 10 nights between March and August 2012. Using Sonobat software to identify 6,448 calls, we detected 8 bat species. Activity of the 4 most common species differed among sites: *Tadarida brasiliensis* was recorded at all sites but was the most active species at 2 golf courses, *Myotis yumanensis* was most common species at a large regional park, and *Eptesicus fuscus* and *Lasiurus cinereus* were the most common species at an ecological reserve. Although the reserve had the least bat activity and lowest mean species richness (based on calls), it had the highest species richness after adjusting for the number of calls. Community composition differed significantly between the sites except for the golf courses, which were not different from one another. Our results suggest that bats are abundant in areas of southern California where suitable roosting and foraging habitats are available. Understanding how bats are affected by the loss and fragmentation of natural habitats will aid in regional bat conservation efforts.

## 95. SUBSTRATE ATTRIBUTES DETERMINE GAIT IN A TERRESTRIAL GASTROPOD

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Some terrestrial gastropods are able to move using two gaits: adhesive crawling, where the entire foot is coupled to the substrate by mucus and the snail leaves a continuous mucus trail, and loping, where regions of the foot arch above the substrate and the snail leaves a discontinuous mucus trail. Some previous researchers have suggested that loping is only used as a means of escaping predators rapidly. We found that in the pulmonate *Cornu aspersum*, gait choice is determined in part by attributes of the substrate: snails moved using adhesive crawling on dry acrylic or glass substrates, but loped on dry concrete or wood. Loping snails did not move more rapidly than snails moving by adhesive crawling. Snails loping on concrete secreted a greater volume of pedal mucus per area of substrate contacted than those moving by adhesive crawling on acrylic. Because loping snails contact a smaller area of substrate per distance travelled than do snails using adhesive crawling, loping may help conserve mucus when moving on porous, absorbent substrates like concrete. Additional studies are needed to understand gait choice by terrestrial gastropods in natural habitats and the effects of factors such as body hydration and atmospheric humidity on locomotory behavior.

## 96. IF ONLY WE COULD LIVE APART: COSTS OF COHABITATION AND MULTIPLE MATES IN THE HOUSE CRICKET (*ACHETA DOMESTICUS*)

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Males can maximize reproductive success by fertilizing multiple females; however, for many species, a female can have all of her eggs fertilized during a single mating event. Nonetheless, polyandry (females mating with multiple males) is a common mating strategy that can yield several benefits. For example, females could gain resources from nuptial gifts, increase the genetic quality of offspring by mating with a second male, and replenish sperm. However, there may also be fitness costs associated with multiple mating or cohabitation (e.g., toxic sperm and harassment). In house crickets (*Acheta domesticus*) females do not receive nuptial gifts, but will mate multiply and males produce chemicals that influence female reproduction. To investigate costs and benefits of polyandry, we experimentally manipulated the mating system (polyandry and monogamy) and whether a female was cohabiting with a male using a fully factorial design. We measured female longevity and fecundity. We found no significant effect of multiple mates on female longevity and fecundity. However, there were significant reductions in female lifespan and fecundity when females were cohabiting with males. Male house crickets produce prostaglandins that impact egg-laying in females. To mimic multiple mating, we singly or repeatedly exposed females to Prostaglandin E2 (PGE2). Fecundity increased with increasing dose of PGE2 but lifespan was not impacted. Repeated exposure to PGE2 had no impact on female fecundity or lifespan. Our data indicate that the physical and behavioral interactions between males and females may more costly than repeated exposure of a female to spermatophores of a male.

## 97. DEVELOPMENT OF *MEGASELIA SCALARIS* (DIPTERA: PHORIDAE) AS A MODEL ORGANISM FOR CIRCADIAN RHYTHM EXPERIMENTS

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Urban biodiversity is understudied despite its importance to the majority of humans living on Earth. Species of the fly genus *Drosophila* are a key model organism in the laboratory and are becoming important in field environmental studies. Preliminary data show that flies in the family Phoridae also appear suitable as laboratory organisms. *Megaselia's* diversity and ease of rearing in a laboratory environment would permit evolutionary genetic study of multi-species changes across an urban to non-urban environmental span. To be able to effectively use phorid flies as a model organism, rearing these flies must be improved so that they are as easy to rais as *D. melanogaster*. In this experiment, *Megaselia*

*scalaris* was raised on a ration based on that used for *Drosophila* and rearing temperatures of 22°C and 26°C. At the lower temperature, it took the flies an average of 26.3 days to reach sexual maturity, while at 26°C, the developmental time was reduced to 25.8 days. Preliminary circadian cycle investigations showed similarities to *Drosophila melanogaster* in 12-hour light and dark phases, with higher activity during light phases. Future experiments should test the effects of various rations and broader temperature ranges on developmental rates. The effects of urban light pollution on activity can also be measured to further explore how urban light pollution affects genetic and species diversity. Finally, gene sequencing could compare known circadian genes across phorid species and between *Megaselia* and *Drosophila*.

### 98. IMPACT OF A RESTORED OLYMPIA OYSTER BED ON EELGRASS (*ZOSTERA MARINA*) PRODUCTION AND ECOSYSTEM FUNCTION

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Interest in restoring the Olympia oyster, *Ostrea lurida*, has in part been motivated by recovering potential ecosystem services provided by oysters, including increased habitat complexity and improved water clarity. The potential impact of these ecosystem services on another valuable and coexisting species, eelgrass *Zostera marina*, is unclear. We hypothesize that oyster beds may increase light available to eelgrass, ameliorating a major seagrass growth limitation, through oyster filter feeding behavior and by decreasing the epiphytic load on eelgrass blades, via habitat creation for epiphytic grazers. We are investigating these mechanisms by monitoring an existing eelgrass bed before and after the construction of a restored Olympia oyster bed in Alamitos Bay, Long Beach, CA. We are monitoring changes in eelgrass production (shoot density and biomass), epiphytic load (epiphyte area covered and biomass), epifaunal grazer diversity, and light availability. Two additional eelgrass beds in the bay will serve as reference sites. After 6 months, turion density among all eelgrass beds shows similar seasonal declines, with the greatest decline observed at one of the reference sites. A longer time series and data on other monitored factors may yet reveal significant trends in oyster impact on eelgrass. Understanding the broad impacts of restoration of the Olympia oyster is critical to evaluate the success of ecological restoration. Furthermore, understanding the relationship between *O. lurida* and *Z. marina* is critically important in future restoration design for both species.

### 99. EVALUATING NATURAL HISTORY MUSEUM COLLECTIONS: WHAT CAN THEY TELL US ABOUT ENDANGERED FAIRY SHRIMP BIOGEOGRAPHY?

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For nearly two decades all voucher specimens of the two California federally-listed fairy shrimp species, *Branchinecta sandiegonensis* and *Branchinecta lynchi* (Crustacea: Branchiopoda), have been deposited by California Fish and Wildlife mandate at one of two official depositories: the California Academy of Sciences and the Natural History Museum of Los Angeles County. Until now there has been little or no effort to use these tens of thousands of samples to assess geographical distributions for these two freshwater crustaceans. The main difficulties preventing the use of these collections have been the unstandardized preservation methods and preservatives used, and a lack of digitized collecting data pertaining to the samples. This makes it impossible to efficiently determine where collections were made or what preservatives had been used (formalin, acetone, isopropyl or ethyl alcohol, or other preservative). Without digitized records, searching the massive collections has been prohibitive. Our work has focused on improving this collection's usefulness in three ways. First, we digitized the collection data of approximately 5,000 samples, making the resulting data available on the web, and thereby exposing the collection to researchers. Second, the potential for molecular genetic analysis of the current collection was checked by extracting DNA and performing PCR amplifications for mitochondrial genes on a spot sampling from across the taxa. Third, by working with Fish and Wildlife Services, the collection and preservation protocols for all future collections of these endangered (and other non-endangered) species have been improved and standardized.

## 100. MORPHOLOGICAL CHARACTERIZATION OF SOUTHERN CALIFORNIA PIPEFISH (FAMILY SYNGNATHIDAE)

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Many teleost fish populations, such as the pipefishes (family Syngnathidae) are dependent upon seagrass beds for all of part of their life cycle. Due to similarities in appearance, pipefishes are extremely difficult to identify and differentiate between species. It has been hypothesized that due to climate change and warming water conditions, more southern pipefish species are expanding their range further north into southern California waters. While some work on pipefishes has been conducted, a clear and accurate picture of local pipefish populations is needed. The objectives of this study are to: 1) survey California seagrass beds to gain an understanding of species presence and distribution, and 2) establish morphological characteristics to accurately identify and differentiate between different pipefish species. Our hypothesis is that external morphological characteristics and measurements can be utilized to aid in positive identification of pipefish species. Preliminary data on three pipefish species (bay pipefish, *Syngnathus leptorhynchus*; kelp pipefish, *Syngnathus californiensis*; and snubnose pipefish, *Cosmocampus arctus*) indicates that the head-length to snout-width ratio is significantly different ($p < 0.0001$) between species. Additionally, the bay pipefish has two dark spots at the base of the operculum and the snubnose pipefish has an unusually truncated snout. In order to conclusively characterize pipefish species in southern California, future work will focus on developing molecular fingerprints that can be matched to the unique characteristics of each pipefish species. Accurate and reliable data will be used to create an updated dichotomous key that can be easily utilized by fisheries and field biologists.

## 101. POPULATION CONNECTIVITY OF THE BROWN SMOOTHHOUND SHARK (*MUSTELUS HENLEI*) IN THE NORTHEASTERN PACIFIC AND THE GULF OF CALIFORNIA

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To determine the effects of the prominent biogeographic and phylogeographic barriers of the northeastern Pacific (Point Conception, the Los Angeles Region, and the Peninsula of Baja California) on the population connectivity of the temperate brown smoothhound shark, *Mustelus henlei* (Triakidae), data from the mitochondrial control region (mtCR) and six nuclear microsatellite markers were used to measure gene flow among sample localities from throughout the range of the species (San Francisco Bay, CA, Santa Barbara, CA, Santa Catalina Island, CA, Punta Lobos, Baja California Sur, and the northern Gulf of California). Microsatellite data demonstrated significant contemporary gene flow among all localities with mtCR sequence data detecting significant structure between both San Francisco Bay and Santa Catalina Island and all other localities. Based on these results, female philopatry to the known nursery of San Francisco Bay may have been detected as well as the identification of a putative nursery at Santa Catalina Island. Furthermore, the barriers of the northeastern Pacific seem to have little effect on the contemporary population connectivity of *M. henlei*.

## 102. PRELIMINARY BATCH FECUNDITY ESTIMATE FOR BARRED SAND BASS, A SERIAL SPAWNER WITH INDETERMINATE FECUNDITY IN SOUTHERN CALIFORNIA

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Reliable batch fecundity estimates are essential for calculating total annual fecundity; however, previous batch fecundity studies on barred sand bass (*Paralabrax nebulifer*) contained small sample sizes. We collected barred sand bass throughout the 2011 spawning season (June–August) and into September. Batch fecundity was calculated using the hydrated oocyte method, where the number of hydrated oocytes was counted per 0.10 g of whole-mounted ovarian tissue and multiplied by ovary mass. Active or imminent spawning females were identified by the presence of hydrated oocytes and post-ovulatory follicles (POFs) in histological cross-sections of ovaries from 208 females. Ovaries were categorized by POF age (Day0 =

< 4 hr, Day1 = 4–24 hr, Day2 = > 24 hr), but only females with Day2 POFs ($n$ = 46) were used for obtaining a batch fecundity size relationship. Based on the preliminary model predicted from a subset of females with Day2 POFs ($n$ = 18), hydrated oocyte counts of females with Day0 ($n$ = 6) and/or Day1 ($n$ = 13) POFs underestimated batch fecundity by an average 26 and 20%, respectively. Batch fecundity was linearly related to ovary mass ($y = 1107x + 5147.5$, $R^2 = 0.93$) and the relationship with fish standard length (mm) was best described by the power function, $y = 0.0086x^{2.8028}$, $R^2 = 0.72$. None of the females collected in September met the criteria for estimating batch fecundity. Our results provide a more robust estimate of batch fecundity for barred sand bass and highlight the importance of aging POFs, as results may otherwise underestimate fecundity.

## 103. SEASONAL, GEOGRAPHIC, AND ONTOGENETIC FEEDING ECOLOGY OF EASTERN PACIFIC ANGEL SHARKS

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Angel sharks are primarily benthic dwelling sharks found mainly in temperate and sub-tropical parts of the Atlantic and Pacific Oceans. Their primary method of capturing prey is by ambushing anything small enough to be swallowed by rapidly lunging from a sedentary position on the sea floor. In the eastern North Pacific angel sharks are thought to be generalists predators that exhibit geographic variation in their diet compositions in different environments across their range. In the Southern California Bight blacksmith (*Chromis punctipinnis*) are the most prevalent prey and in the Southern Gulf of California jack mackerel (*Decapterus macrosoma*) are the most prevalent prey item. Curiously, no significant ontogenetic shifts in diet have been previously documented, which would suggest that the sharks might exhibit a local preference for a particular species. In this study the stomach contents of 71 angel sharks from across the Pacific Ocean and the Gulf of California surrounding the Baja California peninsula were examined and used to describe patterns of seasonal, geographic, and ontogenetic feeding habits of these sharks across their range.

## 104. IMPROVED ESTIMATE OF SPAWNING FRACTION FOR BARRED SAND BASS, AN AGGREGATIVE SPAWNER IN SOUTHERN CALIFORNIA

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The previous spawning fraction estimate for barred sand bass (*Paralabrax nebulifer*) was based on a two-week sampling period in July. To determine if spawning fraction varies across the entire spawning season, we quantified ovarian activity using histological cross-sections from 208 barred sand bass collected on the San Pedro Shelf from June–September 2011. The presence of postovulatory follicles (POFs), hydrated oocytes, and atretic follicles was recorded for each ovarian cross-section. We calculated spawning fraction using the POF method to determine the proportion of mature females with POFs < 24 hr old. Spawning fraction varied by month ($X^2$ (3, N=208) = 23.1, $p < 0.001$) and was highest in July and August (mean = 0.13 ± 0.14 95% CI). No difference in spawning fraction was noted between July and August; however, the incidence of recently spawned fish (i.e., females with POFs < 4 hr) was significantly higher in July ($X^2$ (1, N = 166) = 6.75, $p = 0.009$) compared to August. The proportion of nonspawners (i.e., no POFs) varied monthly ($X^2$ (3, N=208) = 89.9, $p < 0.001$) and was significantly higher in June and September (mean = 0.71 ± 0.13 95% CI) compared to July and August (mean = 0.15 ± 0.05 95% CI). The end of the spawning season coincided with a high proportion (0.89) of females exhibiting follicular atresia in September. Our results highlight the importance of sampling throughout the spawning season to avoid over/underestimating the total number of spawning events per female per year.

## 105. VARIANCE IN AGGRESSION LEVEL IN AMONG SPECIES AND BETWEEN SPECIES PAIRINGS OF POLYCHAETOUS ANNELIDS IN THE *NEANTHES ACUMINATA* COMPLEX

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The *Neanthes acuminata* complex consists of four morphologically identical species: *Neanthes acuminata* from the Atlantic coast of the United States, *Neanthes arenaceodentata* from the Pacific coast of the U.S., Hawaii, and Mexico, *Neanthes caudata* from Portugal, and *Neanthes cricognatha* from India, the Philippines, and Hong Kong. Previous studies demonstrated that *N. caudata* showed aggression towards individuals from *N. arenaceodentata* populations. This investigation paired individuals of five cultured populations from the *N. arenaceodentata* group (Venice Beach, Los Angeles Harbor, San Gabriel River, Alamitos Bay, and Newport Beach) to determine aggression levels within this species. *N. caudata* specimens from Portugal were also compared with these five populations. No aggression was observed between males and females within a population (ex. LA Harbor male with LA Harbor female), low levels of aggression were observed in pairs between *N. arenaceodentata* populations (ex. Venice male with Newport female), and high levels of aggression were observed in pairs between species (*N. arenaceodentata* versus *N. caudata* from Portugal). Aggression was defined as one worm killing the other, while nonaggression was defined as the female surviving to lay eggs. Previously, it was found that intersexual aggression is rare within the *N. acuminata* complex. Increased aggression levels may be indicative of premating isolation that has developed between the two species, and is starting to develop between the five populations from Southern California.

## 106. MIXTURE EFECTS OF DES AND HPTE ON CELL VIABILITY AND DIFFERENTIAION OF EMBRYONIC C57BL/6 THYMOCYTES

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Endocrine disrupting chemicals (EDCs) are chemicals that affect a developing organism by mimicking or interfering with hormones that are produced in the body. EDCs can be found in the environment in several forms such as medications and pesticides. Due to the various EDCs present in the environment, people have the potential to come in contact with a mix of EDCs at various concentrations. Despite this information, most experiments looking at EDC effects are done on only individual toxicants. Very Few studies have done experiments on exposure to a mix of EDCs at low dose concentrations. A low dose mixture experiment is more realistic to the exposure experienced on a daily basis. To address the question of the affect of exposure to mixtures we selected two well-known toxicants. Diethylstilbestrol (DES) was a medication prescribed to pregnant women to help prevent miscarriages and other pregnancy related complications. However, the medication was shown to have adversely affected the offspring of those women who took it during their pregnancy. Methoxychlor was a pesticide used in agriculture, and once in the body, it is metabolized to a more toxic form, HPTE (2,2-bis-(p-hydroxyphenyl)-1,1,1-trichloroethane). DES and HPTE have been examined at high concentrations and have shown negative effects on developing thymocytes. Using an in-vitro assay, our research lab attempted to observe the effects of a mix of a range of doses (50 pico-, nano- and micromolar concentrations) of DES and HPTE on maturation and differentiation of embryonic C57BL/6 thymocytes. Interestingly, we have found that when the thymocytes were exposed to a mix of DES and HPTE, the cells decreased in number at micromolar concentrations but there was no significant decrease at the nano- and picomolar concentrations.

## 107. DIFFERENTIAL EXPRESSION OF *SFSWAP* PROTEIN IN THE DEVELOPING MALE AND FEMALE MOUSE CORTEX AND HIPPOCAMPUS

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The cerebral cortex and hippocampus are important for cognitive function and social behavior, many of which show sex differences. Meanwhile, many neurological diseases and mental disorders linked to the dysfunction within the cortex and hippocampus have displayed gender differences in prevalence and symptomatology. Although the molecular mechanisms underlying these differences between the sexes remain unclear, with the growing list of neurological diseases associated with splicing defects, we speculate that alternative splicing might play an important role in sex-specific regulation and disruption of the cortex and hippocampal function. We have recently shown that during early development, mRNA levels of splicing factor suppressor of white apricot (*Sfswap*) in the male mouse cortex and hippocampus were

higher than the females 7 and 21 days after birth. Thus, we hypothesize that the sex difference in *Sfswap* transcript is preserved at the protein level. To test our hypothesis, we measured protein levels of *Sfswap* in the mouse cortex on the day of birth (PN0) and 7 (PN7) and 14 (PN14) days after birth using immunoblotting with the antibody against *Sfswap* protein. We observed that the antibody detected two *Sfswap* protein bands, at 105 kDa and 115 kDa. While our preliminary data did notshow significant sex difference on *Sfswap* protein levels, there seems to be a trend that *Sfswap* expression in the male cortex and hippocampus increases on PN0 and PN14. We are currently increasing the sample size to ensure if the masculine increase in *Sfswap* expression occurs in the mouse cortex and hippocampus during development.

### 108. GENETIC POPULATION STRUCTURE OF THE OLYMPIA OYSTER (*OSTREA LURIDA*) IN SOUTHERN CALIFORNIA

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Although oyster restoration projects are ongoing along the west coast of the USA, restoration managers have no information regarding range-wide genetic structure of the Olympia oyster (*Ostrea lurida*) and therefore cannot include this information when designing restoration projects in order to allocate time, money, and resources appropriately. We aim to provide baseline genetic diversity and structure estimates for the historically impacted native Olympia oyster populations in southern California by using non-coding mtDNA and microsatellite genetic markers. We will test for detectable genetic structure among remnant southern California populations and combine our microsatellite data with unpublished data from central California to Washington in order to examine nearly range-wide genetic structure. We hypothesize that southern California populations will have some genetic structure and that genetic similarity will reflect geographic proximity, the pattern for an isolation by distance model. Genomic DNA was prepared from adult Olympia oysters (n=50 per site) collected at eight sites in southern California from Mugu Lagoon to Tijuana Estuary. We will estimate haplotype or nucleotide diversity, and $F_{ST}$ or related estimates in order to assess within and among site variation. Baseline data from this study will fill a gap in the literature concerning the population genetics of especially southern California estuarine species where restoration of Olympia oysters can serve as a model for the restoration of other native estuarine species.

### 109. GPR30: A POTENTIAL RECEPTOR FOR ENDOCRINE DISRUPTORS

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Many people live their lives unaware that they are unavoidably exposed to harmful chemicals called endocrine disrupting chemicals (EDCs). EDCs are believed to disrupt the function of the endocrine and immune systems by mimicking estrogen. Studies have shown that endocrine disruptors affect our immune system negatively by interfering with thymocyte development and by inducing apoptosis, but the mechanism is yet to be discovered. EDC exposures can cause immune dysfunctions (including autoimmune diseases), learning disabilities, disorders, developmental deformations, and effects on overall growth and development. The goal of this project was to find out if EDCs use the nonclassical receptor G protein coupled receptor 30 (GPR30) to promote cell death in thymocytes. To address our question, we observed the effects of the GPR30 agonist, G1, on the cells at different concentrations, 2nM, 20 nM, 200 nM, and 200 nM, and compared the effects with diethylstilbestrol, (DES a positive control) at a 25μM concentration. G1 has a high affinity for binding to the GPR30 receptor. If the effects of G1 and DES on thymocytes are similar, our findings would support that a common mechanism is being used by G1 and DES. Our results showed that G1 at a 2000nM concentration had similar effects as the 25μM DES concentration, which suggests that the endocrine disruptors may be using the GPR30 receptor. By figuring out the receptor to which these chemicals bind, other research can find a way to block this receptor to inhibit the effects of these EDCs on the immune system.

### 110. NON-CLASSICAL ESTROGEN RECEPTOR GPR30 USAGE BY EMBRYONIC THYMOCYTES OF C57/BL6 MICE WHEN EXPOSED TO HPTE

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Synthetic organic chemicals, commonly referred to as endocrine disrupting chemicals (EDCs), can be found in the air, food, water, and in common household items. EDCs are known to have disrupting effects on hormones and some EDCs, such as HPTE, have the ability to mimic estrogen and can bind to estrogen receptors on T-cells. HPTE is the demethylated metabolite of the insecticide methoxychlor, and has been shown to have high estrogenic activity. Exposure to HPTE has been linked to disorders affecting the developing immune system with the chief mechanism identified thus far being apoptosis of affected cells. While it is well documented that EDCs are harmful and that they can affect the immune system, the receptors they bind to in order to mediate their effects is still unclear. The purpose of this research was to determine whether or not HPTE utilizes the non-classical estrogen receptor, G-Protein Coupled Receptor 30 (GPR30), to mediate its effects on the developing immune system. Embryonic thymocytes (16–18 days of gestation) were cultured and pre-treated with varying concentrations of the GPR30 antagonist G15, which has a high affinity for GPR30. The thymocytes were then exposed to HPTE. Preliminary results suggest that there is a partial rescue from cell death in cells that were pre-treated with G15 prior to exposure to HPTE.

## 111. THE TEMPORAL EXPRESSION OF GENES IMPLICATED IN THE FORMATION OF THE EMBRYONIC SKELETON IN *OPHIOCOMA WENDTII*

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While all adult echinoderms have a skeleton, sea urchins and brittle stars alone express a larval skeleton. The gene regulatory network (GRN) leading from specification of the skeletogenic cell lineage to formation of the mineralized skeletal spicule in sea urchin embryos has been well characterized. The initial genes activated are transcriptional regulators, which begin a cascade of gene regulation culminating in activation of genes encoding the proteins that bind calcium and are integral to the skeleton. Most of the genes implicated in this GRN are also involved in adult skeleton formation in sea urchins as well. We would like to know the extent of conservation of this skeletal GRN between sea urchins and brittle stars. Previous studies have identified homologues of several of the transcription factors that are part of the sea urchin skeletal GRN in the brittle star *Ophiocoma wendtii*. These include Alx1, Dri, Ets1/2, Erg and Gapb. Proteomic approaches have identified transcripts that encode proteins that are occluded in the *Ophiocoma wendtii* skeleton. These include LUPK, 00358, 00266, PO24 and 01464. The purpose of this work is to study the temporal expression of these genes during the development of O.*wendtii* embryos and to compare that to what has been characterized in sea urchins.

## 112. THE EFFECT OF DIETHYLSTYLBESTEROL ON THE Vβ AND Vα REPERTOIRE OF DEVELOPING THYMOCYTES

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The T cell receptor (TCR), an integral membrane protein of thymocytes and T cells, is composed of two different chains (α and β), each containing a constant (C) and variable (V) region. The V β and V α subsets on the TCR play a crucial role in immune homeostasis and specificity and protect the body against self-antigens. Absence or dysfunctions of these subsets can be advantageous to pathogens that are introduced into the body and may result in autoimmune diseases. It has been hypothesized that endocrine disrupting chemicals (EDC's) may have an effect on the distribution of T cell receptors in thymocytes that develop in their presence. The primary focus of our research is to elucidate the effects of EDCs on T-cell development. This study attempts to reveal whether EDCs alter expression of specific V β or V α subsets, which would suggest that a correlation between EDC exposure and autoimmune disease may exist. To address our question embryonic thymocytes were exposed to DES, a known endocrine disrupting chemical, at 50 and 0 μM concentrations. Following a two-step *in vitro* differentiation assay, fetal mouse thymocytes were stained with V β and Vα antibodies. Preliminary results suggest that exposure to DES causes a decrease in the V β and Vα positive populations. However, it does so in a non-specific manner.

## 113. THE EFFECTS OF DIETHYLSTILBESTROL ON MATURATION AND DIFFERENTIATION OF SEX SPECIFIC EMBRYONIC C57BL/6 THYMOCYTES IN ORGAN CULTURE

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The endocrine system consists of a network of hormone producing glands. Hormones are released in low doses and serve as chemical messengers that regulate many of the body's functions, including the immune system. Endocrine disrupting chemicals (EDCs) are substances, which interfere with endocrine system of the body. These chemicals display hormone like properties or interfere with hormone activity which may disrupt the development of the immune system. Furthermore, it has been demonstrated in studies of neonatal and adult systems that sex is also a variable in the effects of EDCs. Diethylstilbestrol (DES), a synthetic estrogen that serves as a model for other EDCs, was once prescribed during pregnancy to prevent complications. It was later discovered to cause endocrine disruption and reproductive health risks. Along with reproductive effects, there is evidence that developmental exposure to DES can alter the functioning of the immune system. Previous studies in our lab indicate that DES impacts developing thymocytes. It is unclear, however whether DES affects thymocyte development differently in male and female embryos. Therefore, the aim of this study was to determine whether there are sex differences in DES effects on developing embryonic T cells. PCR- amplification of a gene on the Y chromosome was used in sex identification. An *ex vivo* assay was used to examine the development of embryonic thymocytes from C57BL/6 mice embryos at 16 to 18 days of gestation. Our results indicate that DES decreases thymocyte viability to similar levels in both females and males in a dose dependent manner.

## SATURDAY ABSTRACTS IN PROGRAM ORDER

### 114. THINGS I BET YOU DON'T KNOW ABOUT GRAVEL/COBBLE BEACHES LIKE SAN ONOFRE AND TRESTLES!

**D.C. Lees**. Littoral Ecological & Environmental Services, Leucadia, CA 92024.

While evaluating effects of beach washing on hardshell clam assemblages living in coarse-grained sediments oiled by the *Exxon Valdez* oil spill in Prince William Sound, we found that these sediments are actually a different class of sediment than the usual sediments observed on beaches. Relationships between particle size and sedimentary properties (*e.g.*, quantities of silt/clay or organics) and biological properties (*e.g.*, abundance, species richness, or biomass) are markedly different in heterogeneous coarse-grained (gravel) sediments than in finer homogeneous sediments (*e.g.*, sand, silt, or mud). It appears heterogeneous sediments have not been previously recognized geologically or biologically in published literature. An important feature of heterogeneous sediments is that the coarse rocks concentrated at the sediment surface can organize to form an "armor" or fabric. Organization, which can be measured photogrammetrically, increases the sediment's resistance to hydrodynamic or biological disruption, increasing stability. Organization appears to be a critical factor in the development of rich infaunal assemblages that can develop in this sediment type. Characterizing animals include hardshell clams, burrowing mussels, and burrowing shrimp and worms. Wet bivalve tissue weights exceeding 7 kg have been observed subtidally in Alaska. Disturbance of organized heterogeneous sediments is accompanied by dramatic long-term delays in recovery of the rich assemblages. Recovery following disturbance may require several decades. Such delays have been observed in Prince William Sound and at Trestles and San Onofre. In this paper, I demonstrate the physical, chemical, and biological relationships characterizing the contrasting sediment classes and provide examples of the infauna and these sediments.

### 115. LOCAL EXTIRPATIONS AND REGIONAL DECLINES OF ENDEMIC UPPER BEACH FAUNA IN SOUTHERN CALIFORNIA

**D.M. Hubbard**, J.E. Dugan, N.K. Schooler, and S.M. Viola. Marine Science Institute, University of California, Santa Barbara, CA 93106.

The upper intertidal zones of sandy beach ecosystems are increasingly threatened by impacts of human activities, erosion, and climate change. Upper beach zones typically support invertebrates with restricted distributions and dispersal. We hypothesized that disproportionate loss or degradation of these zones in the last century has resulted in declines of upper shore macroinvertebrates in southern California. From a suite of potentially vulnerable endemic upper beach fauna with direct development, low dispersal and late reproduction, we investigated historical changes in distribution and abundance of two intertidal isopod species (*Tylos punctatus* and *Alloniscus perconvexus*). Populations of these isopods have been extirpated at 57% and 64%,

respectively, of historically occupied sites. Numerous local extirpations have caused regional declines and greatly reduced connectivity among populations. Two littoral cells (Santa Barbara, Zuma) currently support 74% of the remaining populations. Abundance has declined and the northern range limit of the southern species, *T. punctatus*, has retreated 31 km south since 1971. These isopods persist primarily on relatively remote, ungroomed, unarmored beaches with restricted vehicle access and minimal management. These predominantly narrow, bluff-backed beaches also support species-rich upper beach assemblages, suggesting these isopods are useful indicators. The high extirpation rates of isopod populations over the last century provide a compelling example of the vulnerability of upper beach invertebrates to coastal urbanization. Sea level rise will exert further pressures on upper beach zones and fauna globally. In the absence of rapid implementation of effective conservation strategies, our results suggest many upper intertidal invertebrate species are at risk.

## 116. BURROWING IN BEACH FILL: IMPLICATIONS FOR RECOVERY OF SANDY BEACH ECOSYSTEMS

**S.M. Viola**, D.M. Hubbard, J.E. Dugan, and N.K. Schooler. Marine Science Institute, University of California, Santa Barbara, CA 93106.

Beach nourishment is often considered an environmentally sound approach to maintaining eroding shorelines, however, the ecological consequences of this practice are poorly understood. Beach fill activities cause intense mortality of beach macroinvertebrates, potentially altering these intertidal communities for months to years. Ecological recovery following fill activities depends on successful recolonization of the entire intertidal community from offsite sources. The use of incompatible fill sediments can impede recolonization of intertidal invertebrates. We hypothesized that both intertidal zone and burrowing mode could influence responses of beach invertebrates to altered sediment texture, and ultimately the potential for colonization and recovery of beaches disturbed by fill projects. We tested these predictions when a dredge disposal project at Goleta Beach, California introduced mismatched fine sediments to all zones of the beach in 2011. Experimental trials in fill material and native beach sand found the fine fill significantly inhibited burrowing of characteristic species from all intertidal zones, including sand crabs, clams, isopods, talitrid amphipods, and worms. For several species, burrowing was completely inhibited in the fill, excluding the animals. We also found burrowing of lower intertidal species was sensitive to sediment mixtures with $<10\%$ fines. Burrowing inhibition by mismatched fill sediments exposes beach species to stresses, which could depress recruitment and survival at all intertidal levels. Our results suggest use of incompatible fill sediments creates unsuitable habitat that could significantly delay intertidal community recovery. By reducing the availability of intertidal invertebrate prey, impacts of filling could affect shorebirds and fish and extend beyond the beach itself.

## 118. AVIAN PREDATION ON MIDNIGHT SPAWNING RUNS OF THE CALIFORNIA GRUNION (*LEURESTHES TENUIS*)

**K.L. Martin** and J.G. Raim. Pepperdine University, Department of Biology, Malibu, CA, 90263.

The California Grunion (*Leuresthes tenuis*) synchronizes its spectacular midnight spawning runs with the high semilunar tides of full and new moons. The narrow window of time when tides are right requires potential parents to aggregate *en masse* in appropriate areas at specific times. Tidal cycles are readily predictable and most marine animals are acutely aware of tidal rhythms. Forming aggregations at predictable times in particular places may lead to an increased likelihood of predation for beach spawning fishes. Because *L. tenuis* fully emerge onto sandy beaches while spawning, they are potentially exposed to terrestrial as well as marine predators. It has been suggested that *L. tenuis* spawn only at night as a way to reduce predation on the runs. However, at Malibu Lagoon State Beach, we have observed numerous birds that normally feed diurnally, actively preying upon nocturnal spawning runs of *L. tenuis*. These birds do not regularly feed at high tides or at night, appearing on shore solely on nights when spawning runs are likely to occur, even before the fish begin to run. We hypothesize that the birds have an environmental cue that allows them to predict the timing of the runs to some extent. A nearby beach that hosts equally large spawning runs of *L. tenuis* does not have the same avian predators. We conclude that avian predators predict spawning runs of *L. tenuis* by the tidal heights, are present after full and new moons, and in overcast skies, and are site-specific.

### 119. COMMUNITY-BASED SCIENCE AND OUTREACH IN THE CONSERVATION OF SNOWY PLOVERS AND LEAST TERNS IN LOS ANGELES COUNTY, CALIFORNIA

S.M. Vigallon and T.P. Ryan. Los Angeles Audubon, Los Angeles, CA, 90093.

From 2007 through 2012, Los Angeles Audubon collaborated with project biologists, management agencies, recreation facilities, and other local Audubon chapters to address conservation concerns about the western snowy plover (*Charadrius nivosus nivosus*) and the California least tern (*Sternula antillarum browni*) on Los Angeles County beaches. We coordinated volunteers to monitor and restore habitat, and we conducted community outreach activities. The goals of these projects were (1) to greatly increase the data-gathering capacity of projects staffed by only a few biologists; (2) to engage the public in community-based science in the highly urbanized setting of Los Angeles as a way to promote conservation of these coastal species; (3) to engage inner-city public school students in multidisciplinary projects that would provide us with visual media to further promote conservation. Through these projects we have been able engage a broad spectrum of the beach-going public, including inner-city public school children, college students, employees from a major corporation, experienced birders, and local beach communities. Volunteers have contributed thousands of hours to monitoring and habitat restoration; and they have proven highly effective in gathering information on target species' population size, location, and behavior, and threats to target species. Hundreds of public school students have participated in conservation-themed field trips and on-campus activities, producing signage, online galleries, and two public service announcement videos that we have subsequently used to promote conservation of plovers and terns.

### 120. CHALLENGES FACED BY THE ENDANGERED CALIFORNIA LEAST TERN AND THREATENED SNOWY PLOVER ON THE URBAN BEACHES OF LOS ANGELES COUNTY, CALIFORNIA

T.P. Ryan[1] and S. Vigallon[2]. [1]Ryan Ecological Consulting, Monrovia, CA 91016; [2]Los Angeles Audubon, Los Angeles, CA 90093.

It is known from historic egg collections that both the California least tern (*Sternula antillarum browni*) and the western snowy slover (*Charadrius alexandrinus nivosus*) nested on the sandy beach and coastal dune habitats along the Coast of Los Angeles County. Coastal development in the early 1900's extirpated the snowy plover as a nesting species, although they now persist in non-breeding flocks. The least tern still nests at two protected and managed colonies near their historic nesting areas. We present results of monitoring efforts that show recent high productivity by the least tern at both colonies. However, both colonies are facing declines, likely due to unknown food resources issues and adaptation by predators to management techniques. Between 10–15% of the population of the western snowy plover uses the urban beaches as winter roosting and foraging areas. We describe efforts underway to protect these important winter roosts. We present monitoring data that indicates recent management efforts are leading to increases in wintering individuals, but no nesting. We discuss lessons learned from management efforts and make recommendations for further protections for both species.

### 121. BRINGING BACK THE BEACH: THE DOCKWEILER PLOVER FENCE

D.S. Cooper. Cooper Ecological Monitoring, Inc., 255 Satinwood Ave., Oak Park, CA 91377.

In late 2008, I was hired to monitor the western snowy plover (*Charadrius alexandrinus nivosus*), a Federally-Threatened shorebird, at Dockweiler Beach in Los Angeles County, to prevent their disturbance during pipeline construction and a sand-cleaning operation. While the birds appeared unaffected by this project, they were being constantly disturbed by trucks of various unrelated public agencies, as well as by joggers. This led to my working with Los Angeles County officials and others to place orange cones around the main roosting area in 2009, and to help expedite the construction of fencing around the main roost of the plovers, which was finally completed in early January 2010, despite considerable resistance. Since then, the fence has been rebuilt, and informational signage has been posted, and several dozen plovers continue to use the roost through the winter. Pre-breeding behavior has been noted, and future nesting is possible, as has occurred elsewhere in the region. As importantly, the fence has allowed for the establishment of a native foredune/coastal strand plant community, which now includes at least one additional sensitive species, the red sand verbena (*Abronia maritima*), a CNPS Rank 4 plant.

## 122. FIRST REPORT OF SHEETS OF SOFT FIBRILLAR BONE TISSUES FROM A *TRICERATOPS* HORN FOSSIL AND REACTION TO THE DISCOVERY

**M.H. Armitage**. Biology Department, California State University Northridge, 587 Ventu Park Road #304, Thousand Oaks, CA 91320.

During excavation of a fossil site at the Hell Creek Formation, Glendive, Montana in May 2012, the largest *Triceratops horridus* supraorbital horn ever recovered from Glendive was jacketed and transported to CA for microscopic analysis. The horn was discovered to be highly vascular, filled with moist matrix and featured both permineralized and unfossilized material. Subsequent to decalcification with EDTA, soft and hard remains were thin sectioned and examined by light and electron microscopy. Permineralized vascular vessels which remained after decalcification exhibited internal spherical structures consistent with size and shape of blood cells. Soft tissues collected from deep within the horn yielded heavy populations of layers of osteocytes. Osteocytes featured delicate filopodia and internal structures consistent with nuclei and other organelles. Soft sheets of fibrillar bone examined under Scanning Electron microscopy were characterized by groupings of tightly aligned osteocytes, widely connected via filipodia with widths approaching 500nm. Results of this study conform to previous soft tissue studies in ancient materials and strongly suggest that this is endogenous dinosaur tissue. Reaction to this discovery has been mixed.

## 123. THE EVOLUTION OF MARINE TURTLES, WITH AN EMPHASIS ON FOSSIL SPECIMENS FROM THE EASTERN PACIFIC

**J.F. Parham**. John D. Cooper Archaeological and Paleontological Center, Department of Geological Sciences, California State University, Fullerton, CA 92834.

The seven extant species of marine turtles represent the last representatives of a lineage with a long and poorly known history. Although the fossil record of marine turtles extends into the Jurassic (~150 mya), until recently it was not clear whether these earliest sea turtles are part of the same clade or represent an independent evolution of a marine ecology. This uncertainty, combined with a lack of detailed study of some key specimens, has confounded our understanding of the evolutionary history of marine turtles. Recent advances in reconstructing evolutionary relationships of all turtles (marine and non-marine), combined with the discovery of new fossil specimens, are providing a new picture of sea turtle evolution. In particular, specimens from the Miocene (10–15 mya) of the eastern Pacific (California and Peru) reveal unexpected patterns of biogeography and morphological evolution that set the stage for the origins and diversification of the extant species.

## 124. AN EDENTULOUS DESMOSTYLUS (ORDER: DESMOSTYLIA) FROM THE LATE MIOCENE OF ORANGE COUNTY, CALIFORNIA

**G.F. Santos**[1], B.L. Beatty[2], and J.F. Parham[1]. [1]John D. Cooper Archaeological and Paleontological Center, California State University Fullerton, Department of Geology, Fullerton, CA, 92834; [2]New York College of Osteopathic Medicine, Northern Boulevard, Old Westbury, NY 11568-8000.

Desmostylians are an extinct group of large, herbivorous marine mammals that inhabited the northern Pacific Rim from the late Oligocene to the late Miocene (~30–7 mya). They are known for their unique bounded columnar molars for which the group is named. Well preserved material of paleoparadoxid and desmostylid desmostylians are known from Orange County, but most material remains undescribed. A new specimen of a nearly complete mandible of the genus Desmostylus from the Puente Formation was discovered during the construction of the Eastern Transportation Corridor toll road in 1996. Unlike all other known desmostylians, this specimen is edentulous except for a pair of large, downward-turned tusks. These features may represent characteristics of a new species, or may have developed as a result of advanced age and wear in the individual. Though much of the ontogeny of the Desmostylia is still poorly understood, the comparisons of this specimen to more complete material of Desmostylus from other collections could clarify ontogenetic sequences of desmostylians.

### 125. THE FOSSIL RECORD OF ELEPHANT SEALS (*MIROUNGA*) IN SOUTHERN CALIFORNIA

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Modern elephant seals consist of two species in the genus *Mirounga*. The northern elephant seal (*Mirounga angustirostris*) was intensively hunted during the nineteenth century. Once thought extinct, current populations of northern elephant seals have very successfully rebounded from a single surviving population of very few individuals to over 150,000 today. Despite a strong historical record of northern elephant seals, very few fossil elephant seals have been reported. A new specimen of *Mirounga* sp., a fragment of maxilla consisting of a canine tooth, has been identified from the Palos Verdes Sands Formation in Newport Beach, California, very close to Los Angeles County Museum of Natural History (LACM) locality 1066, which has produced a skull and postcranial material of *Mirounga*. The presence of several individuals of elephant seal, including juveniles, in late Pleistocene deposits of Orange County, could potentially even indicate a breeding population, since elephant seals spend most of their lives at sea. This is in contrast with historical and archaeological records, which do not record *Mirounga* breeding sites in coastal southern California. Previous studies have noted the apparent rarity of northern elephants seals in California in archaeological sites in contrast with their abundance today, and have suggested that Native American predation may have displaced elephant seals in the Holocene. Establishing a baseline of the relative abundance of *Mirounga* prior to human inhabitation in southern California illuminates the adaptability of the northern elephant seal, and may help answer questions about the population density of elephant seals in southern California prior to European hunting.

### 126. FOSSIL SITES WITHIN THE LA HABRA FORMATION OF RALPH B. CLARK PARK, ORANGE COUNTY, CA

B.E.M. Watkins[1], L.C. Babilonia[2], and J.F. Parham[1]. [1]John D. Cooper Archaeological and Paleontological Center, Department of Geological Sciences, California State University, Fullerton, CA 92834; [2]Clark Paleontology Museum, Buena Park, CA 90621.

The fossils found in Ralph B. Clark Park (housed at the Clark Park Paleontology Museum) provide an exceptional record of prehistoric life in Southern California. The park is in northern Orange County, on the border of Buena Park and Fullerton. The park includes the southwestern portion of the La Habra Formation, which consists of interbedded mudstones, sandstones, siltstones, pebbly sandstones, and conglomerates that are poorly consolidated. The limited exposure of the La Habra Formation inside the park rests unconformably over the Coyote Hills Formation, and underlays Holocene alluvial deposits. The fauna and unpublished radiocarbon dates suggest the La Habra Formation is in the late Rancholabrean North American Land Mammal Age (240,000-10,000 kya, Late Pleistocene). There are several well-documented sites in the park. Hudson's Hope (LC-40) is the most productive site, with over 60 species including plants, invertebrates, mammals, birds, reptiles, amphibians, and fish. Analysis of the sediments and the fauna suggest the paleoenvironment includes floodplains, open grasslands, woodlands, and braided streams. The relative stratigraphic positions of the fossil sites within the La Habra Formation are unknown. A detailed comparative sedimentary analysis of all fossil sites, a stratigraphic column, geochemical analysis, and a detailed study of the fauna, will give us a better understanding of the age and paleoenvironment of the La Habra Formation.

### 127. PAST ECOLOGICAL IMPLICATIONS FROM MICROVERTEBRATE REMAINS FROM CAVE OF THE CHIMNEYS (CA-SMI-603), SAN MIGUEL ISLAND, CALIFORNIA

J.A. Allen, E.L. Whistler, and R.L. Vellanoweth. Department of Anthropology, California State University, Los Angeles, 5151 State University Dr., Los Angeles, CA 90032.

Cave of the Chimneys (CA-SMI-603) is a rockshelter located on the northeast coast of San Miguel Island. The site is deeply stratified and contains at least seven distinct strata dated to between about 8000 and 1000 Cal BP (1∑). Preservation of faunal remains is excellent. Previous archaeological studies have found abundant evidence of human subsistence remains, bone and shell tools, and early Holocene cordage and beads. Temporal chronology and density of subsistence remains support short-term occupation or intermittent human use of the rockshelter giving rise to the question of how microvertebrates accumulated within the deposits. While microvertebrate remains only make up approximately less than 1% of this assemblage (by weight), high MNI (Minimum Number of Individuals) of rodents and reptiles have been identified throughout the strata. Preliminary analysis has yielded species infrequently seen in the archaeological record of San Miguel Island including gopher snake (*Pituophis catenifer*), ornate shrew (*Sorex ornatus*), and the extinct giant island deer mouse (*Peromyscus nesodytes*). Through detailed femoral measurements we see the possible targeting of juvenile rodents for prey by raptors. Measurements were also taken of mandibular tooth row length to address the possibility of an increase or decrease in rodent size through time. This study seeks to contribute to our understanding of past terrestrial environments, shifting ecological baseline, and predator/prey species relationships.

## 128. SHELLS, BONES, AND STONES: MIDDLE HOLOCENE MATERIALITY ON SAN NICOLAS ISLAND

**R.F. Murphy**, R. Vellanoweth, and M. Evans. Department of Anthropology, California State University, Los Angeles.

In 1959 UCLA archaeologists Sam-Joe Townsend and Fred Reinman excavated 20 burials eroding out of a cemetery on a dune site, CA-SNI-40, on San Nicolas Island. The burials were radiocarbon dated to the middle Holocene. Grave goods associated with the burials include thousands of *Olivella*sp. shell beads, woven water bottles, projectile points, abalone shells, bone tools, pendants, ground stone artifacts, and other constituents. Our resent excavations of the midden at CA-SNI-40, began in 2010. Material linkages identified between the cemetery and the midden grant insights into the daily life and mortuary practices of middle Holocene Channel Islanders.

## 129. THE ECOLOGICAL AND DEMOGRAPHIC UNDERPINNINGS OF DIVERGENT PREHISTORIC SETTLEMENT TRAJECTORIES ON SAN CLEMENTE AND SAN NICOLAS ISLANDS

**B.F. Byrd** and A.R. Whitaker. Far Western Anthropological Research Group.

San Nicolas and San Clemente islands are relatively remote compared to the northern Channel Islands. Despite their geographical proximity to one another, the history and organization of prehistoric settlement on the two islands are dramatically different in terms of site size, site distribution by topographic region, and the intensity of occupation through time. Comparison of these two robust and well-documented occupation records is possible because of large-scale cultural resource management efforts undertaken by the US Navy to identify and evaluate the significance of archaeological sites. San Nicolas Island is marked by larger sites during all periods and has a fairly even distribution of radiocarbon-dated site components beginning around 6,000 years ago in the Middle Holocene and continuing through the Late Holocene. In contrast, San Clemente has a sparse Early Holocene record (beginning by at least 9,000 years ago) that persists, with a few additions, through the Middle Holocene. During the Late Holocene, however, there is a dramatic increase in dated sites associated with a profusion of small, generalized sites in nearly all topographic and environmental zones. These striking temporal and spatial differences in settlement patterns between the two islands appear to be driven by divergent human adaptive responses to a complex set of ecological and demographic factors. These baseline variables include differences in land mass, topographic and resource diversity, annual rainfall, geological inundation and erosional processes, and the regional orientation of cultural interaction. This talk explores these trends and provides an initial assessment of the underlying causal factors.

## 130. ARCHAEOLOGICAL PERSPECTIVES ON ISSUES OF MARINE ECOLOGY ALONG CALIFORNIA'S CENTRAL COAST

**T.L. Jones**. Department of Social Sciences, California Polytechnic State University, San Luis Obispo.

The degree to which managers of contemporary California marine environments should or will listen to archaeological interpretations of paleo-ecology is debatable. In many cases, archaeological studies are not sufficiently grounded in empirical evidence to be considered credible by natural scientists, yet alone to provide a basis for management policy. Adding to this challenge along the central coast are archaeological studies that suggest that certain aspects of the marine environment are very different today from what they were in the past, including ocean chemistry, and species richness and diversity. I illustrate this point with discussion of estuarine fisheries, marine mammal populations, and the sea otter-abalone ecological dynamic.

## 131. EXPLORING DIFFERENCE IN SIZE OF INTERTIDAL SHELLFISH SPECIES: ANALYZING TWO DISTINCT STRATIGRAPHIC LEVELS FROM CA-SNI-40, SAN NICOLAS ISLAND, CALIFORNIA

**J. Morales**, Q.G. Lapeña, and R.L. Vellanoweth. Department of Anthropology, California State University, Los Angeles, CA, 5151 State University Dr. Los Angeles California.

Excavations at a middle Holocene dune site (CA-SNI-40) on the west end of San Nicolas Island revealed two distinct occupation phases. These periods of occupation are characterized by a high density of black abalone (*Haliotis cracherodii*) in the earlier period and an increase in the number of red abalone (*Haliotis rufescens*) in the later. Radiocarbon dates suggest that people initially inhabited the site from 4300-4100 cal. B.P., abandoned it for approximately two centuries, and reoccupied the site around 3900-3700 cal. B.P. Detailed measurements of fragile whole shells were recorded during excavations at CA-SNI-40. This paper will discuss statistical differences between the size of intertidal shellfish species within the two distinct depositional episodes at the site. Granted that human predation can significantly affect local faunal resources, a detailed analysis of this taxon may reveal an anthropogenic effect on the marine resources at San Nicolas Island.

## 132. SOURCING ARCHAEOLOGICAL BITUMEN FROM THE CALIFORNIA CHANNEL ISLANDS TO SUBMARINE SEEPS

**K.M. Brown**, N.W. Poister, J. Connan, and R.L. Vellanoweth. Department of Anthropology, California State University, Los Angeles, CA, 5151 State University Dr. Los Angeles California.

Asphaltum, often referred to as bitumen, is a naturally occurring form of petroleum used for thousands of years by native Californians for a variety of practical, decorative, and symbolic purposes. Ethnohistoric accounts state that asphaltum from terrestrial seeps was shaped by hand into cakes and traded throughout coastal Southern California and was the only type of asphaltum employed in the manufacture of plank-canoes. While there are no terrestrial seeps on the California Channel Islands, drift asphaltum exuded from submarine seeps can frequently be found washed up on the shore. It remains unclear to what extent prehistoric island populations relied on this drift asphaltum and whether or not they acquired terrestrial asphaltum through trade. This study combines Gas Chromatography/Mass Spectrometry (GC/MS) and liquid chromatography coupled with carbon isotopic analysis in an effort to identify the sources of six archaeological bituminous mixtures from San Nicolas and San Miguel Islands. We compare the archaeological asphaltum to four modern samples collected from marine tarballs and a mainland terrestrial seep. Further, we compare our data to a chemometric database, published by the USGS, in an effort to track our archaeological samples to extant sources. Our results show that prehistoric peoples on the Channel Islands utilized drift asphaltum from submarine seeps in a variety of technological applications throughout the Holocene.

## 133. LATE HOLOCENE HUMAN IMPACTS ON MARINE AND TERRESTRIAL FAUNA IN SOUTHERN COASTAL CALIFORNIA: TWO ARCHAEOLOGICAL PROJECTS ON SAN NICOLAS ISLAND AND THE PALOS VERDES PENINSULA

**S.R. James**. Department of Anthropology, California State University at Fullerton, P.O. Box 6846, Fullerton, CA 92834-6846.

The Channel Islands off the southern California coast provide a unique opportunity to study prehistoric adaptations in an insular environment, a region sometimes referred to as the North American Galapagos. Although the broad cultural historical outlines of the region have been examined for over a hundred years,

new archaeological data are providing significant information regarding the peopling of the Americas, origins of social complexity, and intensive marine resource utilization. During the past decade, field classes from California State University at Fullerton under the direction of the author have conducted investigations at archaeological sites at the Palos Verdes Peninsula and on San Nicolas Island, including test excavations at one of the deepest sites on the island (CA-SNI-44). Zooarchaeological data from these projects are presented with regard to overexploitation and resource depression of marine mammals, fish, and shellfish populations. The role of domestic dog as a top predator introduced in prehistory on San Nicolas Island and other Channel Islands is also examined. Biologists, conservationists, and other researchers need to consider prehistoric impacts in managing and preserving coastal ecosystems for the future.

## 134. MARINE MAMMAL EXPLOITATION AT SITE CA-SNI-44 ON SAN NICOLAS ISLAND DURING THE LATE HOLOCENE: ZOOARCHAEOLOGICAL RESULTS AND INTERSITE COMPARISONS

**S.R. James** and K. Gonzales. Department of Anthropology, California State University at Fullerton, P.O. Box 6846, Fullerton, CA 92834-6846.

Test excavations at CA-SNI-44 on the Central Plateau of San Nicolas Island in the southern Channel Islands, Ventura County, California, were conducted by field classes from the Department of Anthropology, California State University at Fullerton (CSUF). SNI-44 is one of the deepest shell middens (2.75 meters) thus far excavated on the Central Plateau. A relatively large marine mammal archaeofaunal assemblage was recovered during the excavations. Identified species include sea otter (*Enhydra lutris*), California sea lion (*Zalophus californianus*), harbor seal (*Phoca vitulina*), and Guadalupe fur seal (*Arctocephalus townsendi*), as well as undetermined species of whales and dolphins (Cetacean). Sea otter dominates the assemblage in all test units with smaller percentages of the other identified taxa. Aside from presenting the zooarchaeological results of the analysis, intersite comparisons are examined with regard to marine mammals identified from other prehistoric sites on the island. The absence of northern elephant seal (*Mirounga angustirostris*) in the archaeofaunal assemblage from SNI-44 and other late Holocene sites is significant, especially given the abundance of this species today on the island. The results have implications for the modern management of these and other marine mammals in the Channel Islands.

## 135. ZOOARCHAEOLOGICAL RESEARCH ON SAN NICOLAS ISLAND: FISH EXPLOITATION AT SITE CA-SNI-44 DURING THE LATE HOLOCENE

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Field classes from the Department of Anthropology, California State University at Fullerton (CSUF) conducted archaeological test excavations at CA-SNI-44, which is located on the Central Plateau of San Nicolas Island in the southern Channel Islands, Ventura County, California. SNI-44 is one of the deepest sites (2.75 meters) thus far excavated on the Central Plateau and provides evidence for short-term seasonal occupations at the site throughout the late Holocene. Although situated about 2 km from the coast, the inhabitants transported large quantities of marine subsistence remains to the site where they were consumed and discarded. Zooarchaeological analyses indicate that California sheephead (*Semicossyphus pulcher*) and rockfishes (*Sebastes* spp.) account for over 85 percent of the identified fishes based on bone counts (NISP). Small amounts of surfperches (Embiotocidae), silversides (Atherinidae), herrings (Clupeidae), white sea bass (*Atractoscion nobilis*), giant kelpfish (*Heterostichus rostratus*), señorita (*Oxyjulis californica*), and lingcod (*Ophiodon elongatus*) are also represented. The prehistoric Nicoleños caught most of these species from nearshore kelp beds and rocky reefs. Analytical results are presented and comparisons with fishes reported from other prehistoric sites on the island are discussed in order to provide patterns of late Holocene fish exploitation.

## 136. SETTLEMENT PATTERNS ALONG ALISO CREEK IN ORANGE COUNTY: A REGIONAL PERSPECTIVE

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This study will utilize Geographic Information Systems (GIS) to analyze the spatial patterning of 202 archaeological sites along the Aliso Creek Watershed in Orange County, California. The goal of this project is to identify regional patterns in prehistoric coastal southern California during three cultural periods: Millingstone (6000 to 1000 B.C.), Intermediate (1000 B.C. to A.D. 500), and Late Prehistoric (A.D. 500 to 1804). Data collected for this study include recorded sites along the Aliso Creek Watershed derived from Cultural Resource Management (CRM) archaeology, utilizing the unpublished "gray literature" to make contributions to the prehistory of coastal southern California. A secondary goal of this study is to identify patterns in prehistoric settlements as they relate to paleoenvironmental change, specifically drought during the Intermediate and Late Prehistoric periods.

### 137. PILOT STUDY OF GC-MS METHYL MERCURY DETERMINATION IN FISH FROM SANTA FE DAM LAKE

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In 2009, the San Gabriel River Regional Monitoring Program found elevated levels of mercury in some fish species from the Santa Fe Dam Lake, posing a potential public health risk to individuals consuming these fish. The USEPA method 245.7 was utilized assuming that nearly all mercury found was in the methyl mercury form. The agency again evaluated the mercury contamination at this location with an additional study into finding what percentage of the total mercury measured is methyl mercury. The additional study required my developing a gas chromatography/mass spectrometry method for analyzing organic mercury compounds extracted from fish tissue. This pretreatment method involved tissue digestion, organic solvent extraction, and then derivatization for GC/MS detection. The method was reasonably efficient with methyl mercury recoveries ranging from 55% to 95%, providing a potential alternative that is a convenient and accurate analysis of environmental mercury impacts to the public.

### 138. THE GENETIC DIVERSITY AND POPULATION STRUCTURE OF BARRED SAND BASS (*PARALABRAX NEBULIFER*)

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Barred sand bass (commonly, sand bass), *Paralabrax nebulifer*, is part of the largest recreational fishery in Southern California as well as a large artisanal fishery in Mexico. This species ranges from Santa Cruz, California to the southern tip of Baja California, Mexico, but is common only south of Pt. Conception. Sand bass form large spawning aggregation in the summer months of June–August which makes them highly susceptible to overfishing. In the last decade, populations of sand bass in southern California have experienced a severe decline in numbers and subsequently the recreational fishery has been seriously impacted. The population structure and genetic diversity of barred sand bass populations was previously unknown. This study looks at both using the d-loop region of the mitochondrial DNA for populations in California and Mexico. Populations in southern California lack genetic structure, have high levels of genetic diversity and are indicative of panmixia across the region.

### 139. REPRODUCTIVE BIOLOGY OF A SEVERELY DEPRESSED SPORTFISH THE BARRED SAND BASS, (*PARALABRAX NEBULIFER)* FROM SOUTHERN CALIFORNIA

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Years of intense fishing pressure has caused the fishery of the barred sand bass, (*Paralabrax nebulifer*) of Southern California to decline precipitously in the first decade of the 21$^{st}$ century. The large aggregations that this species forms during their spawning season have left them vulnerable to fishermen who remove them by the tens of thousands each summer. Specifically this proposed study into the reproductive biology of barred sand bass aims to document the monthly gonado-somatic index (GSI) for both male and female for a full year and determine fecundity for a wide range of female size classes. These parameters can indicate when spawning is occurring and at what possible magnitude. A total of 699 barred sand bass where collected in 2011 from three sites (San Diego, Santa Monica Bay, Long Beach/Huntington) across Southern California. GSI begins to increase in May, peaks in July, and continues into September. Fecundity increases with size, indicating fecundity is a function of size. Understanding the reproductive cycles and the duration of energy allocation towards reproduction is important for the proper management of this fishery. Historically, barred sand bass have played a prominent role in the recreational fishing industry. Now 53 years since implementation, fishing regulations will undergo change as of March 1,2013. It will be several years before we can accurately assess any possible change but protecting and properly managing this fishery is a necessity in order to prevent any further decrease in the stocks and the ultimate collapse of the fishery.

## 140. IMPACT OF ORGANIC POLLUTANTS ON THE GROWTH AND FECUNDITY OF *PARALABRAX NEBULIFER* (BARRED SAND BASS) FROM SOUTHERN CALIFORNIA

**B.D. Sanchez** and M.A. Steele. California State University, Northridge, Department of Biology, Northridge, CA, 91330.

Pollution is widespread in marine environments, where pollutants can accumulate in sediments and in the tissues of marine organisms. Many pollutants have carcinogenic and mutagenic properties. Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and heavy metals can cause physiological stress in fishes by limiting the abilities to acquire resources for growth, reproduction, and survival. Benthic associated species are more impacted by pollutants by their direct and indirect contact with the substrate, especially in areas of high pollutant concentrations, like harbors. This study evaluated the impacts of pollutants on growth and fecundity of a recreationally important coastal marine fish in Southern California. This study was conducted at four sites: two highly polluted sites within harbors and two less polluted sites located outside of harbors. Tissue concentrations of pollutants, growth, physiological condition, and reproductive potential were compared among the sites. There was a significant difference of pollutant type and concentration among sites, with fish in harbors having the highest tissue concentrations. Measures of growth, physiological condition, and reproductive potential did not differ among sites, implying that the concentrations of pollutants in the harbors studied were not high enough to affect these variables. Organic pollutants are still present in the marine environment of Southern California, but this research indicates that the concentrations are too low to significantly impact the growth and reproductive potential of the barred sand bass population.

## 141. BIOGEOGRAPHY, CRYPTIC DIVERSITY AND EVOLUTION WITHIN THE SEA SLUG GENUS *PLEUROBRANCHUS* (NOTASPIDEA: PLEUROBRANCHIDAE)

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Opisthobranchs, otherwise known as sea slugs, are a highly diverse group of organisms that play important roles as primary or secondary consumers in marine ecosystems. Opisthobranchs also have biomedical importance both as sources of potential drugs and models for neurological research and are commonly found in a vast array of marine ecosystems. My thesis focuses on the Opisthobranch genus *Pleurobranchus*, characterized by an internal shell and a gill exclusively on the right side of the body. Species in this genus are commonly found worldwide, but there is a substantial amount of confusion regarding the ranges and identification of individual species. Difficulties in phylogenetic reconstruction and identification of pleurobranchids using morphological traits has resulted in complex classification schemes, with several species having disjunct ranges across physical and biogeographic barriers (including the tropical Indo-Pacific, the eastern Pacific and the Atlantic). In addition, a sizeable number of species have been described that supposedly belong to this genus, though morphologically and biogeographically they have strong similarities. Molecular phylogenies will be constructed using the mitochondrial genes Cytochrome Oxidase 1 (CO1) and 16S and the nuclear gene H3 and morphological data for each species will be included to address these issues. Preliminary data indicate discrepancies in the current identification of many species in *Pleurobranchus*, and morphological work still needs to be conducted in order to match the previously described species with our molecular phylogeny.

## 142. COMPARING EFFECTS OF PH AND DISSOLVED OXYGEN STRESSORS ON THE DEVELOPMENT OF THE SQUID, *DORYTEUTHIS OPALESCENS*

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The market squid (*Doryteuthis opalescens*) is not only California's largest fishery but also ecologically important to the California Current Ecosystem. Throughout embryogenesis, squid egg capsules are attached to the seafloor where they can be exposed simultaneously to near-hypoxic and $pCO_2$ induced low pH environments. To identify the relative impact of each, squid embryos in this study were chronically exposed to each stressor separately for 27 days: pH=7.56, $pCO_2$=1,350.8 μatm and dissolved oxygen (DO)=83.6 μatm. Squid chorions and embyros were analyzed using photo-microscopy, ImageJ$^{TM}$ Software (Ver.1.46r), and ANOVA. Results indicate slower growth and yolk consumption under DO stress compared to pH stress. These results suggest that metabolic suppression is more strongly induced in response to the DO stressor. If current patterns of intensified upwelling persist, environmental DO stress will play an increasingly important effect on embryo development in nature. Field work is needed to corroborate these results and physiological research is needed to identify the mechanisms that induce these responses.

## 143. MOVEMENTS AND CONNECTIVITY OF ESTUARINE PREDATORY FISHES BETWEEN TWO DISCRETE RESTORED ESTUARIES

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Restoration has become a popular tactic to increase estuary habitat coverage; however, large gaps between these habitats may pose a problem to their accessibility, connectivity and effectiveness. Using acoustic telemetry, we assessed connectivity potential, habitat preference, and homing behavior of five coastal predator fishes between two restored estuaries. Juvenile California halibut, *Paralichthys californicus* (n=30), spotted bay bass, *Paralabrax maculatofasciatus* (n=9), gray smoothhounds, *Mustelus californicus* (n=30), shovelnose guitarfish, *Rhinobatus productus* (n=6), and leopard sharks, *Triakis semifasciata* (n=5) were caught at Bolsa Chica Full Tidal Basin and Huntington Beach Wetlands, fitted with acoustic transmitters and translocated between study sites (approximately a 10 km distance). All species except *P. maculatofasciatus* have individuals that moved between study sites. For fish that homed back to their estuary of capture, the residence time in the translocation site significantly differed by species; however, the time spent moving between study sites, or homing time, did not. Fishes spent an average of 14±35 days homing; however, 66% made the journey in 3 days or less. *Rhinobatos productus*, *T. semifasciata*, *M. californicus*, and *P. californicus* movements are evidence of connectivity between estuaries at this distance and detections of these individuals from receivers in other areas suggest possible connectivity across even larger distances. The translocation residency exhibited by *P. maculatofasciatus* possibly indicates that individuals may remain in the estuary where they first recruit.

## 144. THE EFFECTS OF SIMULATED SIZE-SELECTIVE HARVESTING ON A SEX- CHANGING TEMPERATE REEF FISH, *RHINOGOBIOPS NICHOLSII*

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Environmental pressures and anthropogenic impacts can influence the life history and population ecology of a species. Fishing pressure, both recreational and commercial, is a prominent anthropogenic influence along our coast. Correlative links have been established between harvesting tactics and changes in the life history and population ecology of sex-changing fishes; however, the causal links have not been demonstrated. We used a field experiment to investigate the impacts of size-selective harvesting on the reproduction and growth of a sex-changing fish that is not normally harvested. Artificial reefs were constructed and populated with a standard density and size distribution of blackeye gobies (*Rhinogobiops*

*nicholsii*) which were then manipulated, simulating fishery-style harvesting. Reproductive output and growth were measured over a period of weeks. Size-selective harvesting had no significant effect on the reproductive output or growth of the blackeye goby. This result, however, appeared to be due to unexpectedly high immigration and settlement, which caused population densities and size structures to be similar among treatments. From these results we infer that relatively low intensity size-selective harvesting may not impact reproductive output or growth of protogynous species.

### 145. ASSOCIATING GENETICALLY DIVERSE TAMARISK INVADERS WITH THEIR IMPACTS IN A SALT MARSH ECOSYSTEM

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Invasive tamarisk has many impacts in freshwater systems including increasing soil salinity, decreasing water content, and causing a shift in food web structure. Tamarisk species originally introduced to the U.S. have hybridized and have been documented invading salt marsh systems in San Diego County, California. The main goals of this study were to determine the abiotic and biotic impacts of tamarisk within a salt marsh and among genetic types of tamarisk. Amplified Fragment Length Polymorphism was used to determine genetic identity of each individual salt-marsh invading tamarisk. Abiotic impacts depended on microhabitat, as did tamarisk tree morphology, and infauna community composition. Tamarisk altered abiotic factors in the upland and upstream microhabitats. The tamarisk invasion had the most pervasive biotic impact on the infauna in the marsh microhabitat. 17.8% of trees were hybrids of *Tamarix ramosissima* x *T. chinensis*. The remainder were pure *T. chinensis*. Tamarisk genetic identity did not influence abiotic factors, although invertebrate diversity was lower beneath pure *T. chinensis* than the hybrid. The introduction of hybrid tamarisk was not an *in-situ* hybridization because there were no pure *T. ramosissima* present at the site, rather they were most likely introduced from another site during rain and flood events.

### 146. WHO'S ON FIRST?: COMPARISONS OF ABOVE- AND BELOWGROUND PHENOLOGICAL VARIATION AMONG NATIVE AND INVASIVE ANNUALS

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Phenological variation among coexisting species is an often overlooked and yet critically important factor in community assemblage and invasibility. Those species first to establish exert priority effects – alteration of biotic and abiotic conditions through preemption – influencing the potential for additional species to establish and persist. In annual plant communities seasonal priority effects can result from differences in phenology. Within habitat comparisons have shown that invasive species tend to have earlier growth activity relative to natives. However, the majority of these studies neglect the potential for belowground dynamics to contribute to aboveground observations. In the present study we sought to quantify above- and belowground phenological variation among native and invasive annuals and asked whether these patterns were indicative of priority effects underlying the competitive superiority of invasive species. Phenological state, density and relative growth rates were quantified, and data used to construct life tables for species encountered. Belowground growth dynamics were quantified via an automated mini-rhizotron imaging system. Results obtained thus far are generally consistent with the priority effects hypothesis. As predicted, invasive species displayed greater germination rates earlier in the season while native species germinated later, over a longer period of time. In contrast to expectations however, natives displayed faster relative growth rates and greater survivorship relative to invasives. No differences in root growth rate were detected. The observation of phenological differences above- but not belowground is intriguing. However, observations remain ongoing and this discrepancy may be merely an artifact of limited data.

### 147. NATURAL VARIATION AMONG *DROSOPHILA MELANOGASTER* POPULATIONS IN RESPONSE TO *BEAUVERIA BASSIANA* EXPOSURE

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Pesticides are commonly used as a means of controlling insect populations; however, this widespread use has resulted in the continual progression of resistance in various insect species. Consequently, new methods of pest control are being studied to counteract these developing resistances. Previous research of insect exposure to the fungal pathogen *Beauveria bassiana* suggests that a separate immunological pathway might be used to mediate an insect's resistance to this fungus than to various pesticides. This raises the possibility of using *B. bassiana* as an alternative means of pest control. Additionally, there seems to be a difference in survival rates between populations derived from temperate and tropical climates. Nevertheless, none of these previous studies involved any genetic analysis, when a thorough understanding of the underlying molecular mechanisms involved in pathogenic resistance is necessary. In order to better understand the genetic underpinnings of an insect's fungal resistance, we used *Drosophila melanogaster* as our model organism. We exposed flies from both temperate and tropical populations to the fungus *B. bassiana*, and assayed their mortality rates for 28 days. Whole genome sequences are available for the fly genotypes chosen for this experiment, allowing us to link differences in resistance to their underlying genomic sequences. In agreement with previous studies, our preliminary results show a difference in resistance among temperate and tropical populations, suggesting that there is natural variation for the genes involved. We are currently analyzing the results from our experiments in order to detect possible genomic sequences involved in this differential resistance among populations.

## 148. HOW DOES THE EVOLUTIONARY LOSS OF A SEXUAL SIGNAL AFFECT THE AGE STRUCTURE OF FIELD CRICKET POPULATIONS SUBJECT TO AN ACOUSTICALLY ORIENTING PARASITOID FLY?

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There is considerable interest in the consequences of evolutionary events, especially those that on a contemporary timescale. Such an event occurred in some populations of the Pacific field cricket (*Teleogryllus oceanicus*). Males in certain Hawaiian populations have experienced the evolutionary loss of the wing structures necessary to produce sound, with the loss occurring within 20 generations. As such, these populations now contain two distinct male morphologies: normal-winged males, which are capable of producing mate-attracting songs, and *flatwing* males, which are obligately silent and unable to attract mates via song production. However, flatwing males are protected from lethal parasitism from an acoustically orienting parasitoid fly, *Ormia ochracea*, which may have helped flatwings not only become established but also maintained within a population. We explore how the evolutionary loss of a sexual signal - song - alters the age structure of populations of this species subject to parasitism from *O. ochracea* by aging wild-caught individuals in the field.

## 149. *CIS*-2,5-DIAMINOBICYCLO[2.2.2]OCTANE, A NEW SCAFFLOD FOR ASYMMETRIC CATALYSIS OF THE HENRY REACTION: APPLICATION TO THE SYNTHESIS OF β-ADRENERGIC RECEPTOR BLOCKING AGENTS

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A new chiral tetrahydrosalen ligand (+)-**2** has been designed and synthesized from *cis*-2,5-diaminobicyclo[2.2.2]octane (−)-**1**. The complex generated in situ by the interaction of the ligand with $(CuOTf)_2.C_6H_5CH_3$ is an efficient catalyst for the asymmetric Henry reaction, producing nitroaldol products in high yield and good stereoselectivity. The Henry reaction catalyzed by this tetrahydrosalen-Cu(I) complex led to syntheses of β-adrenergic blocking agents (*S*)-toliprolol, (*S*)-moprolol and (*S*)-propanolol.

## 150. INFECTION WITH THE *PROBOLOCORYPHE UCA* TREMATODE ASSOCIATED WITH INCREASED COURTSHIP EFFORT BUT NOT CLAW BRIGHTNESS IN THE CALIFORNIA FIDDLER CRAB (*UCA CRENULATA*)

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The manipulation hypothesis states that parasites are selected to alter host behavior to enhance their transmission and fitness. Altered hosts exhibit increased conspicuous or risky behaviors, often resulting in higher rates of host predation and parasite transmission. While many sexual signals are both conspicuous and risky, little is known about their potential for parasitic manipulation. We hypothesized that parasites increase host sexual signaling to enhance their transmission to predatory final hosts. To quantify parasitic effects on sexual signaling, we measured courtship displays and claw brightness in fiddler crabs (*Uca crenulata*) naturally infected with the *Probolocoryphe uca* trematode. We observed that males harboring more *P. uca* parasites displayed more frequently, but exhibited no differences in claw brightness.

### 151. THE RATE AND SPECTRUM OF SPONTANEOUS MUTATIONS IN EXPERIMENTAL POPULATIONS OF THE NEMATODE *CAENORHABDITIS REMANEI*

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To what degree natural selection has shaped the rate of spontaneous mutations among different taxa remains an important unresolved question in evolutionary biology. While mutation rates are known to vary among and within taxa, the relative importance of natural selection versus non-adaptive processes has yet to be determined. Theory predicts that the strength of natural selection to reduce the deleterious mutation rate should be stronger in asexual and selfing taxa than in outcrossing sexual taxa, leading to an adaptive decrease in mutation rate in the former. Whether this general trend exists in nature is currently unknown. Nematodes in the genus *Caenorhabditis* provide an ideal system to test questions of how mutation rates vary among closely related species with different reproductive strategies. Within the genus the ancestral reproductive state is outcrossing (gonochorism), however self-fertilization (hermaphroditism) has evolved independently several times. Here we present estimates of the rate and spectrum of spontaneous mutations based on whole genome re-sequencing of a set of long-term mutation accumulation lines of the outcrossing species *Caenorhabditis remanei*.

### 152. "MALES FIRST OR SECOND?" EXAMINING POSSIBLE MATE COERCION IN THE FIDDLER CRAB *UCA MJOEBERGI*

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Male fiddler crabs such as *Uca mjoebergi* attract mate-searching females by waving an enlarged claw. Upon reaching the male's burrow, the female must decide whether to enter the displaying male's burrow, or move on to another suitor. Typically, the male will 'lead' the female to the burrow entrance and enter the burrow first. However, it has been documented that males will occasionally lead a female to their burrow and then step aside, to allow the female to enter the burrow first. Our observations suggest that females are less likely to enter the burrow when the male doesn't enter first. Males may trap females that enter first, potentially increasing their mating success under some circumstances.

### 153. DIVERGENT SPECIES YET RARE LINEAGES: NICHE MODELING OF 20 ENDANGERED CALIFORNIA TAXA AND THEIR CLOSEST RELATIVES – IMPLICATIONS FOR CONSERVATION

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Species listed as endangered face extinction within their niche. Close relatives of these taxa should occupy similar niches, and thus, share similar risks of extinction. However, few comparative analyses of niche conservatism exist for endangered and threatened taxa across a wide array of taxonomic groups. Using ecological niche modeling (ENM), we evaluated niche overlap in 20 listed species in California and their sisters, together representing plant, snail, amphibian, reptile, bird and mammal lineages. Each pair was modeled in Maxent using extensive museum collections data and 15 topographic and bioclimatic variables.

We employed Schoener's D and background randomization tests in ENM Tools to examine whether niches were more different from one another than expected based on the environmental background available to them. Almost all (31 of 32) pairwise comparisons had niche overlap scores of < 0.5 and niches more dissimilar than similar. Background randomization tests were mixed but with more (14) divergent than convergent (10) pairwise niche comparisons. Most (18 of 26) of the sister taxa are recognized as endangered, threatened or sensitive. Even though the target and sister taxa mostly showed niche divergence, they still constituted rare lineages in most cases. Thus, for conservation purposes our results indicate that close relatives should be evaluated for rarity as part of a management strategy for any endangered species.

## 154. NON-TARGET EFFECTS OF INSECTICIDAL CONTROL OF AN AGRICULTURAL INSECT PEST

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The glassy-winged sharpshooter (*Homalodisca vitripennis* Germar) is an exotic agricultural insect pest in southern California. It has had devastating impacts in the wine grape-growing region of Temecula, California where it vectors a bacterial pathogen, *Xylella fastidiosa*. The bacterium blocks movement of plant sap within the xylem, resulting in eventual death of the grapevine. Systemic insecticides (e.g. imidacloprid) have been widely used in the control of *H. vitripennis*, with some success. Vineyards throughout the Temecula Valley vary in their approach to control and management of this pest, with some organic vineyards applying no pesticides of any kind and others applying imidacloprid yearly or only intermittently. Analysis of sticky trap surveys indicates that vineyards applying imidacloprid intermittently (less than once per year) have similarly low densities of *H. vitripennis* present in contrast to high densities of untreated sites. Concomitantly, disease surveys indicate similar low disease prevalence in all intermittent or yearly treated sites. However, foliage tap samples revealed that intermittently and yearly treated vineyards also have similar low species richness and densities of predaceous and parasitoid insects in contrast to the greater predator and parasitoid diversity of untreated vineyards. The results of these combined studies demonstrate that effective control of *H. vitripennis* can be achieved with minimal use of insecticides, and that increased use may actually counteract other methods of control (e.g. predation, parasitism).

## 155. PILOT STUDY OF *CAMPYLORHYNCHUS BRUNNEICAPILLUS COUESI* (CACTUS WREN) ON THE PALOS VERDES PENINSULA, CA

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The coastal cactus wren (*Campylorhynchus brunneicapillus couesi*) is an obligate, endemic species that lives in coastal sage scrub, a unique plant community that expands from Ventura to Baja California. Isolated populations of coastal cactus wrens are extremely threatened due to habitat fragmentation and degradation. This pilot study was conducted on several populations living on two preserves on the Palos Verdes Peninsula (managed by Palos Verdes Peninsula Land Conservancy), Alta Vicente and Three Sisters. The habitat characteristics and behaviors of the cactus wrens were studied. Cactus wrens spent more time in the top portion of all substrates than the middle and lower portions. Male cactus wrens preferred the cactus *Opuntia littorilis* and spent the most time performing self-hygiene behaviors relative to other behaviors. In the middle and lower portion of all substrates, males preferred to spend time on the invasive tree tobacco *Nicotiana glauca* and performed self-hygiene and flight behaviors. Female Cactus Wrens preferred *O. littorilis* at all heights, but did not perform any one type of behavior more than another. Cactus Wrens only utilized two species of plants for nesting, *O. littorilis* and *Cylindropuntia prolifera*. Future conservation efforts should seek to preserve *O. littorilis* and *C. prolifera*, as they are desirable for their height. Removing *N. glauca* from the preserves could interrupt a dynamic structure of the habitat that Cactus Wrens utilize.

## 156. HABITAT COMPOSITION AND EXTINCTION RISKS AT SITES OF LONG-TERM COEXISTENCE BETWEEN WESTERN GRAY SQUIRRELS AND EASTERN FOX SQUIRRELS

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The native western gray squirrel (*Sciurus griseus*) has been extirpated in some of its former range due to habitat fragmentation and the introduction of the invasive eastern fox squirrel (*S. niger*). Particularly in the greater Los Angeles metropolitan area, *S. griseus* populations have declined in urban habitats where *S. niger* has been introduced. A previous study created a Habitat Suitability Model (HSM) to predict the presence or absence of *S. griseus* and *S. niger* within these habitats. My study tested this model by predicting the presence or absence of *S. griseus* and *S. niger* at 11 additional sites. Predictions agree with on-site observations in seven of the 11 sites tested. To further test the presence/absence model I continued a long-term census at a botanical garden in Claremont, California with the prediction of squirrels coexisting. In addition, my study analyzed fine-scale details of habitat structure by creating an abundance-based HSM for long-term coexistence sites. The model shows that species of tree, particularly low percentage of oak trees and high percentage of conifers, have a positive relationship with the relative abundance of *S. griseus*. Each of the six long-term coexistence sites used in the analysis were also analyzed for *S. griseus* extinction risk to determine relative timelines and suitable habitat size for *S. griseus* existence with *S. niger*. The findings were used to make recommendations to habitat managers in southern California, using a landfill and regional park as examples, in the hopes of informing management decisions to maintain populations of *S. griseus*.

## 157. EFFECTS OF EXERCISE ON BRAIN STIMULATION

G. Gavilanes. St. Lucy's Priory High School, Mentor: S. Mejia, University of La Verne.

Aerobic activity is a powerful stimulus for improving mental health and for generating structural changes in the brain. The presence of novel experiences or learning is an especially important component in how these changes are manifest. This experiment relates the distinct time courses of structural brain changes with both aerobic activity. In the experiment, 29 students exercised for an hour before taking various tests that measured cognitive function. Scores were compared with those of students that had not exercised before taking the tests. Most of the students who took the test after the exercise received a higher score than those who did not partake in exercise before the test. Demographic and clinical characteristics of the students were taken into account and are discussed. In addition, rats were tested to further analyze the study. Rats were given voluntary access to individual running wheels attached to their cages and these rats exercised as babies and continued to do so until their mature growth. Another group of male and female rats did not exercise. Behavioral testing (object recognition tests) were administered to both groups of rats. Exercise increased spatial learning and memory in the object recognition tasks in that the exercised rats displayed a decreased latency in locating the hidden platform than the non-exercised rats. The non-exercised rats spent more time exploring the novel objects than the exercised rats in one of the tests. The exercised rats spent significantly less time exploring the most recently encountered object in the task in comparison to the non-exercised controls, therefore showing improved temporal recognition memory. Results of cognitive function tests in both humans and rats indicate that exercise enhances both spatial and recognition memory and therefore exercise can improve learning retention.

## 158. INVESTIGATING THE LEVELS OF MERCURY CONTAMINATION IN FARMED VS. WILD CAUGHT SALMON

J. Adan and D. Gonzalez-Jurado. Manual Arts High School College Preparatory Magnet Los Angeles, CA 90015.

Highly toxic organic forms of the element mercury concentrate in the tissues of many fish. When consumed by humans in the form of methylmercury the element causes a multitude of adverse health effects and is difficult for the body to eliminate. Salmon is generally regarded as a species that accumulates relatively lower mercury levels. In my study I used the analytical chemistry method of gas chromotography to determine the levels of mercury contamination present in samples of both farmed and wild caught salmon from several sources around the world. My results showed that while on average there were not significant differences in mercury contamination between wild caught and farmed salmon, there was great variation in mercury levels within the different types of both wild and farmed salmon samples in my study.

## 159. PRODUCING ELECTRIC POWER FROM THE WIND; A STUDY OF WINDMILL BLADE FLOW MECHANICS

E.O. Frost. Chaminade College Preparatory, Mentor: C. Farhat, Aero Astro Engineering.

Electric power generated from the wind can help our society become less dependent upon the production of foreign oil. Windmills of old were made with blades that had a cross-section of a rectangle. These were inexpensive blades sweeping out small circles by today's standards. Windmill rotor blades today have airfoil cross-sections which reduce drag and increase the performance (Hansen, 2000). However, does a flat bottomed airfoil produce more power or the symmetrical airfoil? My hypothesis is that the symmetrical airfoils will outperform the others and the control blades. To test my hypothesis, I created a wind tunnel and wind mill to measure the different blades' power output. The blades were readily available from Flying Foam, Colorado Springs, Colorado, in both 2 and 5 inches from front to back. The length of the blade was 12 inches. The windmill was made out of PVC pipe (Tymos, 2009). To smooth the airflow, I used an array of pre-cut pipes resembling the same used in a 2009 US DOE report (US DOE, 2009). In each series of experiments, I waited for the wind tunnel and air smoother to reach a steady state flow of air. The airflow speed was 11.2 feet per second and 5.8 feet per second. I set the Static Angle of the blades on the rotor and then put the windmill into the airflow. I waited for the rotors to reach steady state and then recorded power data and measured the rotational speed of the rotor with a strobe light. I averaged the observations and graphed the output results. I calculated the net Dynamic Angle of attack for points along the leading edge of the rotors and graphed the ratio of the coefficients for each calculated net Dynamic Angle. My hypothesis was correct as the symmetrical airfoils out performed the flat-bottomed airfoils both when compared with each other and the control blades. At the 11.2 ft/sec wind speed, the 2″ symmetrical blade produced 28% more power than the 2″ flat-bottomed blade at a 5 degree static angle; 56% more power at a 10 degree static angle. The 2″ symmetrical blade also produced twice the power of the 5″ symmetrical blade. At the 5.8 ft/sec wind speed, the 2″ symmetrical blade produced 11% more power than the 2″ flat-bottomed blade at 5 degree static angle; 84% more power than the flat-bottomed blade at a 10 degree static angle. The 2″ symmetrical blade power output increased 12.5% at the 10 degree static angle over the 5 degree static angle. The 2″ blade produced 23% more power than the 5″ symmetrical blade at the 5.8 ft/sec wind speed.

## 160. THE EFFECTS OF SEASONAL TEMPERATURES ON SELENIUM CONCENTRATION

C.H. Nguyen and N.T. Trivedi. Huntington Beach H.S.; I. Swift, Supervising Wetlands Biologist for the Irvine Ranch Water District.

The San Joaquin Marsh in Irvine, California has been experiencing a modest – and possibly toxic – buildup of selenium. Selenium is similar to sulfur in its chemical properties, and given an excess of selenium, organisms replace it into their biochemistry. The resultant selenium-containing amino acids produce faulty proteins and enzymes. The bioaccumulation of selenium can result in the deformed embryos of local fowl (such as the mallard and great blue heron), which are secondary consumers in the wetlands' delicate food chain. While this has yet to be the case in the San Joaquin Marsh, the amount of selenium necessary to be a danger has yet to be found. Without knowing this, the IRWD wishes to resolve the issue by removing selenium altogether. In the hopes of understanding selenium's reaction to various temperatures for the purpose of phytoremediation, the selenium in the San Joaquin Marsh's water was measured with an inductively coupled plasma mass spectrometer, and then compared against average seasonal air temperatures in the area. An inverse relationship was found between the two parameters.

## 161. THE EFFECT OF VARYING DC-DC CONVERTER CONFIGURATION ON SUPERCAPACITOR OUTPUT EFFICIENCY

R. Nguyen. Palos Verdes Peninsula H.S. Mentor: B. Nguyen, Sigma Test Labs.

My experiment's objective is to improve the ability to extract useful power from supercapacitors by using two different DC-DC converter configurations and determining their power efficiency. First, I decided to use a step up and a step down converter to compare because of their significantly different topology and operation. Two sets of test hardware were constructed, one for each type of converter. Each set of hardware consisted of a set of supercapacitors, a DC-DC power converter(one step up and one step down), and an LED load that was used in both test set ups. For the step up converter, the initial supercapacitor output voltage of 2.50 volts was "up- converted" to 3.27 volts. The step down converter was run with an initial supercapacitor output voltage of 9.80 volts and "down- converted" to 3.27 volts. In both cases, the converter output was connected across the LED load, and the converter was run for 80 minutes with measurements being taken every minute. For each test run, the voltage and current were measured at the output of the supercapacitor and at the input of the load, which allows the efficiency of the converter to be calculated. The data shows that the power efficiency of the step up converter is initially greater than that of the step down converter by 10–14%. However, towards the end of each run, the step down converter efficiency surpasses that of the step up converter. This observation can potentially be exploited to improve energy efficiency.

### 162. ASSESING THE EFFECTS OF MARINE PROTECTED AREAS UPON THE RECREATIONAL LANDINGS OF TARGET SPECIES

R.L. Sanders. Culver City High School; Mentor: D. Gonzalez-Jurado, UCLA.

In the last decade the Marine Life Protection act has established a network of Marine Protected Areas (MPA's) off the Pacific Coast of California. The support of both the commercial and recreational fishing community both enabled the passing of this legislation and continues to ensure the success of the MPAs themselves. The fishing community supposedly benefits from the establishment of MPA's because of the phenomena called the "spillover effect", that occurs when the fish stocks within an MPA are replenished and subsequently spill over into the non-protected areas. While numerous previous studies worldwide have overwhelmingly shown evidence of the general existence of the spillover effect, baseline data confirming the extent to which this effect occurs for recreationally targeted species has not been gathered. Sometimes protective conditions within a MPA favor an increase in predator populations. If this occurs, the spillover of predators may lead to the trophic cascade of prey populations decreasing in surrounding fishing grounds outside of MPA's. In this study, we sampled across the Southern California Bight Region using methods commonly employed by recreational fishermen and recorded average size of several targeted species relative to distance from the nearest MPA. This data will provide tangible evidence of the most MPA's most relevant impacts to the recreational fishing community.

### 163. DETERMINING AND PROFILING THE PREVALENCE OF ANTIBIOTICS- RESISTANT BACTERIA (ARBS) IN THE WATERS OF THE BALLONA WATERSHED

A. Lee and D. Pham. Palos Verdes Peninsula H.S.; Mentor: J. Dorsey, Loyola Marymount University.

Antibiotics have been the foremost means of fighting disease caused by infectious pathogens. However, the overuse of antibiotics has led to the rise of antibiotics-resistant microbes in the environment, posing a public health threat. Recently, a prevalence of bacterial strains with insensitivities to a wide variety of commonly prescribed antibiotics (such as tetracycline and ampicillin) has been found in the Ballona Wetlands. With many different inputs from the urban environment into the wetlands, the bacteria present are put under selective pressure. Though wetlands are supposed to function as means of pollution filtration in the environment, the Ballona Wetlands have experienced severe reduction due to urban pollution and have been less effective in naturally controlling the general bacterial count; thus contributing to the rise of antibiotics-resistance genes (ARGs) which are classified environmental pollutant, and consequently, antibiotics-insensitive bacteria. This investigation addressed the Ballona Wetland's effectiveness in reducing these bacterial counts. Ebb/flood tide, and sediment samples were collected from the Ballona Wetlands. Bacteria was extracted from the samples and plated. A standard replication method was then used to replicate colony growth and the tryptic soy agar plates were then infused with antibiotics. Photos of replica plates were taken and were analyzed and colonies were identified. Then, the bacteria were tested to determine the presence of ABIs using the Kirby-Bauer method. Cumulative frequencies of ABIs of flood, ebb, and sediment samples were compared using the Kolmogorov–Smirnov test. If the wetlands were functioning properly, bacterial counts would be reduced during ebb tide (low tide, higher UV exposure that would eliminate more bacteria.) and that there would be a significant difference between the ebb and flow tide samples, however it was determined that in most cases the ebb and flood tide's ABI frequencies were nearly identical. It was also expected that the cumulative frequency of ABIs found in sediment would have a very different trend compared to those of the ebb or flow tide samples, yet the trends were very similar. The existence of bacteria resistant to a wide spectrum of antibiotics in the Ballona Wetlands has been confirmed. Additionally, with the exception of one sample collection, the patterns (as in the frequencies in numbers of bacterial isolates/colonies resistant to antibiotics found) of frequencies of ABIs occurring have been consistent. As this research is ongoing, the next steps will involve DNA sequencing of the bacteria through PCR assay to profile and assess the species of prevalent bacteria in order to verify the existence of human pathogens.

### 164. REDUCING CARBON FOOTPRINT THROUGH INTEGRATION OF LED STREETLIGHTS

**A. Wei**. Walnut H.S.; Mentor, Dr. Sonner.

Cities throughout the world are still using incandescent and compact fluorescent bulbs for their street lights, unaware of how detrimental they are to the environment and economy. The hypothesis was that although the wattage and lumen output is less amongst the light-emitting diode, or LEDs, it provides a wider spectrum of colors, allowing for less wattage usage and lumen output, but will still provide a similar result relating to the general brightness and color output, if not better, than those of Compact Florescent Lights (CFLs) and incandescent bulbs. My goal and mission is to educate the public and city on the implementation of LEDs into city street lights. This phasing in of LEDs will reduce energy consumption, reduce the chance of mercury poisoning among civilians and surrounding landscapes, reduce the amount of mercury that is released into the air through the burning of coal, and increase the environmental benefits. Subjective testing was done using a 23W CFL, a 60W incandescent, a 9W LED, and a 20W LED, comparing the general brightness and color output of the bulbs when shown to a general audience. The audience were not told the wattages of the bulbs prior to the experiment to avoid skewing the data. A positive relationship was found between the usage of less wattage and general brightness and color output.

### 165. OBSERVATION OF THREATENED CALIFORNIA GNATCATCHER (*POLIOPTILA CALIFORNICA CALIFORNICA*) IN DIFFERENT LOCATIONS OF CALIFORNIA SAGEBRUSH

**S. Yong**. Palos Verdes Peninsula H.S.; Mentor and Institution: A. Dalkey, PVPLC.

My project was set up to find if the abundance of *Polioptila californica californica* (California gnatcatcher) would increase along with the growth of *Artemisia californica* (California sagebrush). The purpose of doing this project is to see if the California gnatcatcher, which was once endangered, and now threatened, is able to recover from that title with the help of newly installed California sagebrush. Therefore, I hypothesize that with the growth of newly installed California sagebrush; there will be an increase of California gnatcatchers as well. To increase their chances of survival, I exploited PVPLC's newly installed canopies and measured the canopy's height, and two diameters. To do this, I went on surveys with volunteers of PVPLC to Three Sisters Reserve and collected data from the site which had the habitat of the California gnatcatcher. Also, I have collected data at two sites within Vicente Bluffs as well as Alta Vicente. In addition, to go further into my research, I have utilized the 2008–2013 dataset from the PVPLC- PV/SB Audubon collaborative survey in order to compare my data that I have collected in 2012–2013. Due to the non-normal distributed data, I used the Kruskal-Wallis test to statistically compare the variance of the maturity of Three Sisters Reserve, Vicente Bluffs, and Alta Vicente sites. After completing the test, it was reported that the median values among the three sites were greater than would be expected by chance, therefore there is a statistical significant difference of ($P = < 0.001$). To investigate the numerical data of the California gnatcatcher, I have calculated the observational rate for each site. From the calculations, I found that from 2012–2013; Three Sister's Reserve had an observational rate of 1.93%. From the 2012–2013 Vicente Bluffs data, I have found that the observational rate is 1.50%. Lastly, the observational rate for Alta Vicente was 2.2%. Overall, from comparing the three observational rates, the number of California gnatcatchers is greatest in Alta V.

## 166. RADIOFREQUENCY IMPEDANCE MATCHING: AN ANALYSIS INTO MATCHING NETWORKS OF SERIES CIRCUITS WITH BOTH KNOWN AND UNKNOWN LOADS USING THE COMBINED L-SECTIONS APPROACH

W.T. Ton[1] and O.O. Bernal[2]. [1]Department of Science, Biomedical Research Program, Alhambra High School, 101 South Second Street, Alhambra, CA 91801; [2]Department of Physics and Astronomy, Nuclear Magnetic Resonance Laboratory, California State University, Los Angeles, 5151 State University Drive, Los Angeles, CA 90032-8530.

The lack of impedance matching between source and load in a transmitter or receiver system leads to poor efficiency of power transfer and continuous signal reflections. This study presents an optimal design of capacitors, resistors, and air-core inductors along with a set of formulae that guides in the construction of a matching network for cases of known and unknown load impedance at 10 Megahertz. This design can match a known load and an unknown load to their source at radiofrequencies; in this case, the frequency is 10 Megahertz for both known and unknown loads. The network designs presented are based on two combined "L-Type" sections, simplified for noise reduction. This approach has been validated with construction of two networks encased inside anti-electromagnetic interference metal containers of rectangular base size two inches by one inch. The networks were tested with an Agilent Technologies network analyzer and found to comply with the required characteristics at the frequency of 10 Megahertz. Factors such as the number of turns or surface area of the insulated wire used were also analyzed to determine their effect on the two impedance matching networks presented. The design and analysis of these results shed light on the combined "L-Type" section approach as a successful impedance matching network. Factors that impede its success and some transmission line design problems are discussed.

## 167. THE EFFECTS OF MAN-MADE STRUCTURES ON WIND PATTERNS

S.M. Tan and W. Jing. Gabrielino High School; Mentor D. Araya, California Institute of Technology.

The rising number of cities creates urban heat islands which cause uneven distributions of heat between urban and rural areas. One method in which heat is directed away from cities is through wind. Data was collected from 11 locations at the Gabrielino High School campus and was compared with model results obtained from a small-scale model, which demonstrated that urban structures create localized areas with higher wind speed. The taller the building, the stronger the updraft of wind is created over the structure. A difference of 3 meters in height between area B and both areas A and C induced an average increase of 1.5 km/hr in wind speed of the higher area B. When warmer areas are surrounded by cooler denser air, there are surges in velocity. The temperature of the football field causes the wind to increase in velocity by an average of 1.65 km/hr over 119 meters. Therefore, as the temperature difference widens, wind velocity increases as well. General wind direction reflects the effects of local orography on wind flow. On the field, wind normally heads north or northeast due to the placement and elevation of surrounding houses. Another experiment was conducted using Particle Image Velocimetry (PIV) capturing the movement of neutrally buoyant particles moving across steps constructs made to represent the steps of the bleachers. The parallels between the data from PIV and the bleachers are currently being analyzed in hopes of quantifying changes in wind speed. New buildings and cities can also be designed to generate wind flow that maximizes the release of heat and usage of natural energy.

## 169. THE EFFECTS OF DIETHYLSTILBESTROL ON MATURATION AND DIFFERENTIATION OF EMBRYONIC C57BL/6 THYMOCYTES IN THE RECOVERY CULTURE

A. Patel. Damien High School. Mentors: C. Zambrano and C. Broussard, Department of Biology, University of La Verne 1950 Third Street, La Verne, California 91750.

Endocrine disrupting chemicals (EDCs) are compounds that mimic or block the normal action of the endocrine system. Some EDCs have been shown to kill thymocytes and alter the development of T cells, potentially harming the immune system. The immune system is a vital organ system, responsible for

protecting the body from foreign objects, pathogens and diseases such as cancer. If the immune system is compromised, the body can be put in harm's way. The current experiment focused on the endocrine disruptor diethylstilbestrol (DES), a synthetic estrogen given to 5–10 million pregnant women with the purpose of reducing pregnancy complications such as miscarriages and premature births. However, consumption of DES during pregnancy resulted in harmful effects in the mothers and their descendants. We have seen in previous experiments that DES decreases the number of embryonic mouse thymocytes, and alters development. We wanted to determine whether there is a difference in endocrine disruptor effects on embryonic thymocytes if they are exposed while being signaled to differentiate versus after being signaled. We hypothesized that the endocrine disruptor effects would be more harmful if the cells were exposed at the same time they were being signaled to differentiate. This experiment utilized an in vitro assay that signaled embryonic thymocytes to differentiate in the presence or absence of nano- and micromolar doses of DES. The data obtained from this experiment showed that the number of living cells was much lower when DES was added during signaling than when it was added after signaling.

## 170. LONGEVITY OF SIRTUIN 1 ON LEUKEMIA CELLS

C. Diep. San Gabriel H.S.; Mentor: W.Y. Chen and M.l Roth, City of Hope.

Sirtuin 1 (sirt1) is a mammalian protein deacetylase that modifies cellular protein functions by removing an acetyl group from its substrate. Sirt1 is implicated in cancer cell survival and chemo-resistance. Expression in commassie stains and western blots demonstrate that with certain mutations, sirt1 has lowered in intensity. Sirt1 is traditionally difficult to express in full length human sirtI, but mammalian expression of ku70 using lentivirus vector and ecoli expression has determined that it is possible. This study indicates that sirt1 under the petduet-1 vector can be inhibited or targeted to advance modern medicine or improve clinical treatment of leukemia.

## 171. A COMPARITIVE INVESTIGATION INTO THE DIETARY PATTERNS OF AMERICAN VERSUS JAPANESE-DESCENDED STOMACH CANCER PATIENTS LIVING IN THE UNITED STATES

J. Kim. Beverly Hills High School, 241 Moreno Drive, Beverly Hills, California 90212.

In the absence of curative treatments, the best strategies to manage cancer as a disease focuses on preventative measures and identifying the genetic and environmental causes. In 2009, stomach cancer was the fourth most common type of cancer occurring in humans worldwide. Among the different pre-defined ethnicities of cancer patients, people of Japanese descent annually have one of the three highest stomach cancer rates in the world alternating with nearby Korea and Mongolia. All three of these countries occur from the same part of the world and culturally the human inhabitants share a recent common ancestry with similar dietary habits. Since the initial genesis of stomach cancer is suspected of having strong links to dietary habits These statistics call for data to help elucidate what patterns in cancer diagnosis exist to identify manageable external environmental variables that can be modified (diet, smoking, alcohol consumption, physical activity) and eliminated to prevent cancer development. Here we use a double blind survey of the dietary habits of 150 stomach cancer patients of Japanese American and Japanese ethnicity compared to a control group of stomach cancer patients not of Japanese or East Asian descent to reveal common patterns in diet associated with cancer diagnosis. The results from each group in the survey are compared for statistical significance using Standard's $t$-test.

## 172. ASSOCIATION OF CORONARY ARTERY CALCIFICATION WITH THORACIC BONE DENSITY

L. Liao. Palos Verdes High School; Mentor: S. Mao, Los Angeles Biomedical Research Institute.

Osteoporosis and atherosclerosis are major public health problems that often coexist in both genders worldwide. In the past, dual-energy X-ray absorptiometry (DXA) and computer tomography (CT) scanning have been utilized for measuring bone mineral density (BMD) and coronary artery calcification (CAC), respectively. However, quantitative computer tomography (QCT) provides more accurate BMD measurements based on cardiac CT images, and can thus eliminate additional patient imaging radiation resulting from the use of both DXA and CT scanning. If there is a valid association between CAC and BMD, then cardiac CT will provide an opportunity to evaluate bone health while assessing atherosclerotic risk. This study included 2866 participants who underwent cardiac CT from 2005 to 2008 at the Saint John Cardiovascular Research Center at the Los Angeles Biomedical Research Institute. Participants were free of clinical cardiovascular disease at baseline. Thoracic BMD was measured by QCT 5000. Multivariable regression models were used to relate CAC and BMD. The mean thoracic BMD was significantly greater in men compared to women ($160.2 \pm 41.8 mg/cm^3$ vs. $159.6 \pm 48.0 mg/cm^3$). Greater CAC scores were significantly associated with lower thoracic BMD after age, gender, BMI, and race/ethnicity adjustment. CAC and BMD are inversely correlated. Cardiac CT provides an opportunity to evaluate bone health while assessing atherosclerotic risk without additional patient imaging radiation.

## 173. MICRORNA-29 NEGATIVELY REGULATES EXPRESSION OF ONCOGENE TET2

**J. Li**. Glen A. Wilson High School; Mentor: M. Boldin, City of Hope Department of Molecular and Cellular Biology.

MicroRNAs are small, noncoding RNAs that post-transcriptionally regulate gene expression by binding directly to complementary sequences located within the 3′ UTRs of target mRNAs, thereby inhibiting their translation. Ten-eleven-translocation 2 (TET2), a gene frequently mutated in myeloid disorders, plays a key role in DNA methylation, a critical process in gene expression and cell differentiation. Mutations in TET2 are known to lead to aberrant changes in DNA methylation patterns that are strongly associated with leukemic transformation and hematopoietic malignancies. In this study, we identified 4 potential binding sites for miR-29 in the 3′UTR of TET2. To confirm the hypothesis that miR-29 directly regulates TET2 expression, the 3′UTR of TET2 containing these sites was cloned downstream of the firefly luciferase gene in the pMIR-REPORT reporter vector. The reporter plasmid was co-transfected with either a miR-29 mimic or a mimic control, and luciferase levels were measured after 48 hours. The luciferase analysis revealed that the reporter's activity was significantly suppressed by the miR-29 mimic, resulting in over a three-fold decrease compared to the control. Thus, our data indicate that miR-29 directly targets TET2, and therefore it may play a role in regulating the development of hematopoietic malignancies.

## 175. EFFECTS OF PRESERVATIVE SOLUTION PH UPON STRUCTURAL DEGRADATION RATES OF PRESERVED NEUROLOGICAL ANIMAL TISSUES

**J. Molina**, A. Rosas, and M. Barba. Orthopedic Medical Magnet High School, 300 W 23rd St, Los Angeles, CA 90015.

Scientists and clinicians often preserve brains and other animal nervous tissues to allow for the structure and function of the tissue to be investigated and studied for extended periods after being removed from an organism. At present with the proliferation of genetics, more studies require brains preserved in its intact and natural state. Preserved brains damaged or modified at even the sub-cellular levels usefulness become limited. Historically brains and other animal nervous tissues have been preserved with formaldehyde liquid solutions subsequently stored in alcohol mixtures. Fixing tissues in general using such methods is widely regarded to protect the tissue from decomposition. However, regarding specialized tissues such as brains, the extent to which the preservative solutions themselves may chemically alter the physical structure of the brains stored in them is less documented. In this study we investigated the effect the pH of the alcohol preservative solutions had upon the rates of degradation of sections of lab rat brain tissues. We used spectrophotometer readings to quantify the degree of degradation occurring in brain tissues over time period of a month.

## 176. THE EFFECTS OF HERBICIDES ATRAZINE AND GLYPHOSATE IN INDUCING ADIPOGENESIS IN CULTURED 3T3-L1 PREADIPOCYTES

**B. Nguyen**[1] and B. Blumberg[2]. [1]Marina High School, 15871 Springdale St, Huntington Beach, CA 92649; [2]Blumberg Lab, Department of Developmental and Cell Biology, University of California Irvine School of Biological Sciences, 4351 Nat Sci 2 (courier address), Irvine, CA 92697-2300.

Exposure to two commonly used herbicides, atrazine and glyphosate, has been linked to adverse health consequences both humans and animals. Atrazine is used on the majority of U.S.-grown corn crops and is a common water contaminant in the United States. Atrazine exposure has been linked to reproductive problems in wildlife and at least one recent report suggests that rats exposed to atrazine become obese and insulin resistant. Glyphosate (a.k.a. Roundup) is a very commonly used herbicide in agriculture and resistance has been engineered into soybeans, alfalfa, corn, sugar beets, canola, and cotton. About 34% of the US population is obese (BMI $\geq$30), and previous results in the Blumberg laboratory demonstrated that other agrochemicals can cause fat cell differentiation in culture and increased fat in animals. Therefore, I hypothesized that herbicide exposure might also induce adipogenesis in a cell culture model. I tested this hypothesis by treating 3T3-L1 preadipocytes with multiple doses of each chemical and evaluating the efficacy of the chemical treatment to induce differentiation into fat cells and to up-regulate fat-specific gene expression.

### 177. CONTROL OF HOMOLOGOUS RECOMBINATION BY *HSRAD52*

K. Tang. Glen A. Wilson High School; Mentor: A. Bailis, City of Hope Department of Molecular and Cell Biology.

Loss of genome stability stimulates tumorigenesis. Homologous recombination (HR) promotes genome stability by repairing breaks in DNA. *RAD52* is an HR gene that works with the breast cancer susceptibility genes *BRCA1* and *BRCA2* to maintain genome stability. Mutations that alter its function in HR are likely to stimulate tumor formation. The *RAD52* gene is highly conserved in eukaryotes, such that the human gene (*HsRAD52*) can function in budding yeast, a single-celled eukaryote that is easy to grow, and manipulate at the genetic and molecular levels. Studies in yeast have shown that *RAD52* functions in distinct mechanisms of HR that preferentially conserve, or alter chromosome structure, and that these functions are attributable to different ends of the protein. I propose to use budding yeast to study how the structure of the human *RAD52* protein determines its function in HR, by deleting its C-terminal domain and examining its effect on conservative and non-conservative HR. I will also examine the effects of mutations in *HsRAD52* obtained from cancer patients in order to assess their potential role in disease. With this approach I hope to clarify how *RAD52* controls HR and how this control is involved in tumor suppression.

### 178. EXPRESSION AND IDENTIFICATION OF N-ACETYLGLUCOSAMINE-6- SULFATASE (GNS): A POTENTIAL ERT DRUG FOR SANFILIPPO SYNDROME D

R. Dokko. Palos Verdes Peninsula H.S.; Mentor: P. Dickson, Los Angeles Biomedical Institute.

Mucopolysaccharidosis IIID (MPS IIID or Sanfilippo syndrome D) is a genetic lysosomal storage disorder caused by an absent lysosomal enzyme, N-acetyl-glucosamine-6-sulfatase (GNS), which breaks down long sugar chains called glycosaminoglycans (GAGs). The accumulation of these GAGs in the body may cause severe cognitive impairment and skeletal deformity. There is currently no cure for MPS IIID, but an enzyme replacement therapy (ERT) treatment may be one of the potential treatments that may attenuate symptoms for MPS IIID patients. In order to obtain enough enzyme for the ERT, the human *GNS* gene was transfected into Chinese hamster ovary (CHO) cell lines, and the protein was purified from the culture medium. A sulfatase activity assay was used to isolate the highest expressing clones out of 58 original clones, after which, the GNS activity assay was run to confirm the expression of these clones. After the highest expressers were isolated, they were re-cultured and their activities were monitored over two weeks. Then two cell lines of MPS IIID fibroblasts were incubated with the rhGNS CHO cell culture medium and tested for GNS uptake. Nine clones showed the highest sulfatase activity, and when monitored over two weeks, their activities all increased. After the screening with the GNS assay, however, these clones showed minimal GNS activity, suggesting that another CHO cell line needs to be transfected with the human *GNS* gene to acquire greater expression of the enzyme. Because optimization of the GNS assay and confirmation of a functioning GNS protein were achieved, in the future, the GNS produced by the transfected CHO cells may be used in ERT to treat patients with Sanfilippo Syndrome D.

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# Evaluating Monoculture Versus Polyculture Planting Regimes in a Newly-Restored Southern California Salt Marsh

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*Abstract.*—Salt marsh plants are a key source of primary productivity, ameliorate harsh abiotic conditions, and provide habitat structure to many organisms. As a consequence, rapid re-establishment of plant cover following restoration can speed the recovery of degraded ecosystems. Despite demonstrated positive relationships between plant biodiversity and ecosystem functions, many salt marsh restoration plans still incorporate single-species plantings under the belief that this approach will lead to faster increases in plant cover (a typical management goal). In this study, we evaluated post-restoration recovery of a non-vegetated high marsh berm in Brookhurst Marsh, Huntington Beach, CA, with two active planting strategies: monoculture plots of the competitive dominant *Sarcocornia pacifica* (pickleweed) versus polyculture plots of pickleweed and eight other common salt marsh plant species. Although monocultures did increase in total percent plant cover faster than polycultures, both treatments had reached 80–100% cover after one year, easily exceeding the permit-mandated goal of 20–40% cover in that time. The effects of increasing plant cover on abiotic parameters (e.g., % light reaching the ground, soil temperature, and soil salinity) were comparable between the two treatments and provided physical conditions sufficient to support similar macroinvertebrate communities. In contrast, plant species richness and canopy complexity were significantly higher in polyculture versus monoculture plots by the end of the experiment. Mean plant height was lower in polyculture plots, but maximum plant height (which can influence habitat use by perching birds) did not differ by treatment. Our data suggest that polyculture plots performed as well as, or better than, *S. pacifica* alone with respect to multiple indicators of ecosystem function. Active planting of high-diversity plots should therefore be seriously considered as a restoration tool to achieve common management goals in southern California salt marshes.

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Coastal wetlands provide a variety of key ecosystem functions that include food web support, nutrient cycling, sediment stabilization, and nursery habitat for many ecological and economically important species (Mitsch and Gosselink 1993; Minello et al. 2003). Nevertheless, during the past century loss of coastal wetlands and their associated services has been extensive; in California, less than 10% of historical distributions remain intact (Dahl 1990; MacDonald et al. 1990). To offset such habitat loss, wetland managers and conservation groups have increasingly turned to restoration and mitigation as potential solutions (Zedler 2000). In southern California, nearly every major embayment has one or more wetland restoration programs completed, in progress, or planned (Zedler 1996; SCWRP 2001). The success of such activities will depend upon how well we

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understand the ecological processes that control salt marsh community organization and function (Montalvo et al. 1997; Pennings and Bertness 2001) and the degree to which we incorporate such knowledge into restoration planning.

Current theory and empirical evidence suggest that post-restoration salt marsh succession is highly contingent on the overall amount of plant cover within a given system (Palmer et al. 1997; Levin and Talley 2002). As percent cover and density of vegetation increase, shading by the plant canopy ameliorates harsh abiotic conditions such as high soil temperatures, salinities, and degree of compaction, all factors that influence the development of local invertebrate communities (Bertness et al. 1992; Nomann and Pennings 1998; Bortolus et al. 2002; Whitcraft and Levin 2007). Fish and other free-swimming organisms are more likely to recolonize vegetated rather than non-vegetated areas (Williams and Desmond 2001) as plants provide food and a refuge from predation (Vince et al. 1976; Rozas and Odum 1988; Irlandi and Crawford 1996). Birds also benefit from increased plant cover in marshes; for example, in southern California the state-listed endangered Belding's Savannah Sparrow (*Passerculus sandwichensis beldingi*) uses several marsh plant species for nesting habitat (Powell, 1993). For these reasons, establishing high plant cover is perceived to be an important restoration target for coastal wetland projects (Streever et al. 2000; O'Brien and Zedler 2006).

To achieve this management goal, restoration plans can incorporate either passive or active re-vegetation strategies. Passive restoration assumes that natural recruitment of plants will occur after suitable habitat is created or restored. Although this method requires minimal investment of resources, it can take a long time for plants to become established if local source populations are absent or propagules exhibit low dispersal capabilities (Bakker et al. 1997). In contrast, active restoration (the method chosen for this study) involves the planting of native vegetation in specific areas at specific relative densities, with the expectation that the resulting plant community will be similar to some desired endpoint (Parsons and Zedler 1997; Sullivan 2001).

Implementing an active restoration strategy requires that planners identify in advance which plant species to include in the project. A common approach is to use only a few (or even a single) species, typically introduced in monoculture plots (Gilbert and Anderson 1998). Often the most common and easily established species are chosen, in the belief that this approach will lead to faster increases in plant cover (Sullivan 2001). The downside of using local dominants in an active restoration is that less competitive species may never become established, resulting in a permanent state of reduced species diversity relative to natural marshes. There is ample evidence that plant species richness, relative abundances, and identity can have significant effects on ecosystem function in coastal wetlands (Callaway et al. 2003; Armitage et al. 2006; Diggory and Parker 2011; Doherty et al. 2011). High species richness potentially increases the resilience of the plant community and decreases the likelihood that a single extreme environmental event will wipe out all plant populations at once, as certain species have differential success in response to varying environmental stresses (e.g., high salinity, drought, long-term inundation) (Zedler and Nordby 1986). Species-rich canopies may also reach taller heights and exhibit more discrete layers than monocultures, even when both exhibit comparable percent cover (Keer and Zedler 2002). Determining the most effective and efficient active restoration methods is necessary if we are to successfully evaluate alternative restoration proposals and policies (Streever et al. 2000; Callaway et al. 2003; Zedler 2005).

The Huntington Beach Wetlands complex is an approximately 200-acre remnant of a 2900-acre wetland area that once existed at the mouth of the Santa Ana River in

Huntington Beach, California. This area consists of restored salt marsh and coastal dune habitat and is bisected by roadways into several distinct sections, including Brookhurst Marsh where this study takes place. The marsh is hydraulically linked to the Pacific Ocean by a flood control channel running along its northeastern border. Historically, the natural tidal creeks in the marsh were diked and filled for the purpose of oil and gas exploration, isolating the area from surface tidal exchange for over 70 years (Dage and Reardon 2004). Full tidal flow was restored to the 67-acre marsh in 2009. In this study, we evaluate post-restoration recovery of plant cover and associated indicators of ecosystem function on a high marsh berm in Brookhurst Marsh with two active planting strategies: monoculture plots of the competitive dominant *Sarcocornia pacifica* (pickleweed) versus polyculture plots of *S. pacifica* and eight other common salt marsh plant species. We were particularly interested in whether the different treatments could reach a permit-mandated goal of 20–40% plant cover within one year of planting. The specific aim was to provide suitable nesting habitat (dense, complex canopies) for the state-listed endangered Belding's Savannah Sparrow. We also hypothesized that treatment-specific differences in plant community structure and plant traits would lead to changes in abiotic conditions, invertebrate species richness and abundances, and plant community structure over time.

## Materials and Methods

### *Experimental Design and Planting*

All work was done on an unvegetated high marsh berm in Brookhurst Marsh, Huntington Beach, CA (33° 39′ N, 117° 59′ W). Full tidal influence was restored to the marsh in June 2009; initial sampling and planting was done in September 2009. To test the effects of monoculture versus polyculture plantings on post-restoration recovery of ecosystem functions, we established a series of plots with either 1 or 9 plant species. *Sarcocornia pacifica* was chosen as the focal species in our monoculture plots because the site restoration plan included it as the primary species to be used in re-vegetating the other berms in the marsh. In addition to *S. pacifica*, polyculture plots included eight additional plant species common in southern California: *Arthrocnemum subterminale* (glasswort), *Batis maritima* (saltwort), *Cressa truxillensis* (alkali weed), *Distichlis spicata* (saltgrass), *Frankenia salina* (alkali heath), *Isocoma menziesii* (goldenbush), *Jaumea carnosa* (salty susan), and *Monanthochloe littoralis* (shoregrass). These species were chosen based on their ability to survive and grow in this habitat and their general use by multiple organisms within the marsh (Powell 1993; Sullivan 2001).

Paired plots ($n$ = 10 per treatment group) were spaced 2 m apart in a randomized block design at a single tidal elevation (~1.5m above Mean High Water). Each 2 × 2 m plot was tilled and planted with eighty-one seedlings (~7.5 cm tall) supplied by the Tree of Life Nursery, San Juan Capistrano, CA, and the Huntington Beach Wetlands Conservancy Nursery, Huntington Beach, CA. Seedlings were planted in a 9 × 9 grid with 20-cm spacing between plants (Callaway et al. 2003) and 15 g of slow-release fertilizer (Osmocote©; 19-6-12) in each hole (Broome 1990). Whereas monoculture plots (designated S) each had 81 *S. pacifica* seedlings initially, polyculture plots (S+) were comprised of 9 *S. pacifica*, 9 *A. subterminale*, 12 *B. maritima*, 9 *C. truxillensis*, 3 *D. spicata*, 9 *F. salina*, 9 *I. menziesii*, 12 *J. carnosa*, and 9 *M. littoralis* seedlings. Composition of the polyculture plots was determined by the relative abundances of the different species in nearby natural systems (authors' personal observations) and the availability of seedlings. The location of individuals within each plot was randomized. Plots were watered with fresh water twice daily for one year via an automated sprinkler system, after which the irrigation was shut off.

*Sampling*

Starting in September 2009, changes in total plant cover were monitored monthly until March 2011 (18 months after planting), with the exception of April-June 2010 when the marsh was closed due to bird nesting activity. Plant cover was estimated for the entire plot using the Daubenmire method with classifications of 0–20%, 20–40%, 40–60%, 60–80%, and 80–100% cover (Daubenmire 1959). Abiotic conditions in experimental plots were sampled in September 2009, February 2010, May 2010, October 2010, and March 2011. On each sampling date at a randomly selected point in each plot, incoming solar radiation ($W/m^2$) was recorded with a LI-COR 250A light meter and pyranometer; three readings above and below the plant canopy yielded a mean percent light reaching the ground. Soil temperature in the top 2 cm was measured with a digital thermometer and probe and porewater salinity was measured with the paste method on a single sediment core (Richards 1954).

Plant community composition and attributes were measured at the end of the experiment. Plant cover by species (% species cover) was estimated using the same method as total plant cover and species richness as the number of plant species per plot. Canopy complexity was estimated as the mean number of discrete canopy layers intersecting a vertical meter stick placed at the center of each plot and four additional points located halfway between the center and each corner (after Sullivan 2001). Mean plant height was calculated from individuals measured at the same five points, and maximum plant height was measured on the single tallest individual in each plot.

Macroinvertebrate groups were sampled in several different ways in September 2009, February 2010, October 2010, and March 2011. Mobile ground-dwelling fauna were sampled with a pitfall trap (50-mL centrifuge tube containing 8% formalin) buried near the center of each plot and collected after 24 h. Benthic infauna were sampled with a sediment core (18.1 $cm^2$, 2 cm deep) collected at a random point within each plot. Samples were preserved in 8% formalin and washed through a 300-μm sieve. Canopy insect communities were sampled only in October 2010 and March 2011 using a leaf blower modified to vacuum air. The plant canopy in each plot was vacuumed for 30 seconds; samples were frozen until processing. In all cases, organisms were identified to the lowest possible taxonomic group and total abundance, species richness, and relative species abundances recorded. The combination of these three different sampling methods provides a relatively robust measurement of overall macroinvertebrate community composition (Topping and Sunderland, 1992).

*Data Analysis*

Treatment-specific differences in percent cover over time were evaluated with a Wilcoxon signed-rank test, with sampling date and treatment as nominal predictors and percent cover as the ordinal response variable. Mean percent cover at the end of the experiment (based on mid-class values) was compared with a general linear model that included block as a random nuisance factor and treatment as a fixed main effect. Plant attributes (species richness, canopy complexity, and mean and maximum height) were tested with the same model. Abiotic factors (light, temperature, and salinity) and macroinvertebrate abundances and species richness (pitfalls, infauna, and canopy insects) were tested with a general linear model that included block as a random nuisance factor, sampling date and treatment as fixed main effects, and their interaction. Visual inspection of model residuals was done for every analysis. Where variances showed significant heterogeneity or departures from normality were detected, data were transformed with a $\ln(x + 1)$ function (Sokal and Rohlf 2011). Tukey's HSD post hoc tests were used to identify differences among appropriate means when the main test was statistically significant at the $\alpha = 0.05$ level. All univariate statistical analyses were done with Minitab 16 software (Minitab, Inc., State College, PA).

Hypotheses about multivariate differences in macroinvertebrate community structure as a function of sampling date and treatment were tested with rank-based two-way analysis of similarity (ANOSIM; 9999 random permutations). Abundance data were transformed with a $\sqrt{\sqrt{x}}$ function prior to analysis to increase the relative contribution of rarer species to Bray-Curtis similarity coefficients (Clarke 1993). Non-metric multidimensional scaling (MDS) ordinations were used to visualize variation in macroinvertebrate assemblages (Field et al. 1982). All multivariate statistical analyses were done with PRIMER v6 software (PRIMER-E, Ltd., Plymouth, UK).

## Results

Total plant cover increased through time, with monocultures initially increasing faster than polycultures (Wilcoxon signed-rank test; $N = 11$, $W = 66$, $P = 0.004$); however, by the end of the experiment both treatment groups had reached 80–100% cover, and there was no significant difference between them (Table 1A; Fig. 1). The increase in plant cover in experimental plots was associated with significant decreases in % light reaching the ground, soil temperature, and soil salinity (Table 1F-H; Fig. 2). There was no evidence that effects of plant cover on abiotic conditions differed between treatments (all $P > 0.05$).

By the end of the experiment, the species composition of plots that were initially monocultures of *S. pacifica* was essentially unchanged, with plant cover comprised almost exclusively of pickleweed (Fig. 3). In contrast, although the % contribution of *S. pacifica* to plot totals typically increased from the initial value, polyculture plots were otherwise characterized by a relatively even mix of many plant species (Fig. 3). There was substantial variation among polyculture plots with respect to final species composition, such that spatial variation in plant community structure was greater than it might appear from just looking at pooled data. Treatment-specific differences in plant community structure resulted in significant differences in plant attributes as well. Plant species richness and canopy complexity were significantly higher in polyculture versus monoculture plots by the end of the experiment and mean plant height was lower; maximum plant height did not differ by treatment (Table 1B-E; Fig. 4).

The observed increase in plant cover over time and associated changes in abiotic conditions were accompanied by significant increases in the abundances and richness of mobile ground-dwelling fauna, benthic infauna, and canopy insects (Table 1I-N; Fig. 5). There was no evidence of treatment effects or interactions between treatment and sampling date (all $P > 0.05$). Similarly, multivariate analyses of macroinvertebrate community structure demonstrated significant differences among sampling dates (ANOSIM; pitfalls: $R = 0.44$, $P = 0.001$; infauna: $R = 0.07$, $P = 0.004$; canopy insects: $R = 0.70$, $P = 0.001$), but no difference between monoculture versus polyculture plots (pitfalls: $R = -0.02$, $P = 0.681$; infauna: $R = -0.04$, $P = 0.990$; canopy insects: $R = -0.01$, $P = 0.563$). These conclusions are supported by MDS plots that show overlapping macroinvertebrate assemblages between treatments but clear differences among assemblages across sampling dates (Fig. 6).

Table 1. Tests of multiple response variables (A–N) in experimental monoculture versus 9-species polyculture plots over time (see text for details of experimental design). Bolded *P* values are significant at the 0.05 level.

| Plant attributes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (A) % cover | | | (B) Plant richness | | | (C) Canopy complexity | | |
| | df | MS | *F* | *P* | MS | *F* | *P* | MS | *F* | *P* |
| **Block** | 9 | 97.8 | 0.79 | 0.637 | 1.3 | 2.03 | 0.152 | 0.3 | 2.11 | 0.141 |
| **Treatment** | 1 | 80.0 | 0.64 | 0.443 | 115.2 | 178.76 | **<0.001** | 2.4 | 16.07 | **0.003** |
| **Residual** | 9 | 124.4 | | | 0.6 | | | 0.1 | | |
| | | (D) Mean height | | | (E) Maximum height | | | | | |
| | df | MS | *F* | *P* | MS | *F* | *P* | | | |
| **Block** | 9 | 105.5 | 1.61 | 0.257 | 214.4 | 0.81 | 0.625 | | | |
| **Treatment** | 1 | 612.5 | 9.33 | **0.016** | 0.5 | 0.00 | 0.966 | | | |
| **Residual** | 9 | 65.6 | | | 265.9 | | | | | |
| Abiotic factors | | | | | | | | | | |
| | | (F) % light | | | (G) Soil temperature | | | (H) Soil salinity | | |
| | df | MS | *F* | *P* | MS | *F* | *P* | MS | *F* | *P* |
| **Block** | 9 | 662.9 | 2.17 | 0.032 | 23.9 | 3.17 | 0.003 | 774.9 | 2.14 | 0.036 |
| **Date** | 4 | 17242.2 | 56.56 | **<0.001** | 1461.9 | 193.99 | **<0.001** | 11198.3 | 30.89 | **<0.001** |
| **Treatment** | 1 | 83.4 | 0.27 | 0.602 | 27.0 | 3.59 | 0.062 | 52.2 | 0.14 | 0.705 |
| **Date x Trt** | 4 | 629.0 | 2.06 | 0.093 | 7.1 | 0.94 | 0.445 | 132.9 | 0.37 | 0.832 |
| **Residual** | 81 | 304.9 | | | 7.5 | | | 362.5 | | |
| Macroinvertebrates | | | | | | | | | | |
| | | (I) Pitfalls abundance | | | (J) Infauna abundance | | | (K) Insect abundance | | |
| | df | MS | *F* | *P* | MS | *F* | *P* | MS | *F* | *P* |
| **Block** | 9 | 2.3 | 2.64 | 0.012 | 0.9 | 1.01 | 0.444 | 0.6 | 1.91 | 0.096 |
| **Date** | 3 | 26.8 | 31.14 | **<0.001** | 5.0 | 5.74 | **0.002** | 25.4 | 86.17 | **<0.001** |
| **Treatment** | 1 | 3.4 | 3.93 | 0.052 | 0.2 | 0.18 | 0.675 | 1.1 | 3.84 | 0.061 |
| **Date x Trt** | 3 | 0.9 | 1.09 | 0.360 | 0.1 | 0.15 | 0.929 | 0.0 | 0.01 | 0.930 |
| **Residual** | 63 | 0.9 | | | 0.9 | | | 0.3 | | |
| | | (L) Pitfalls richness | | | (M) Infauna richness | | | (N) Insect richness | | |
| | df | MS | *F* | *P* | MS | *F* | *P* | MS | *F* | *P* |
| **Block** | 9 | 1.8 | 1.50 | 0.169 | 1.3 | 0.90 | 0.528 | 29.5 | 3.36 | 0.007 |
| **Date** | 3 | 26.3 | 21.87 | **<0.001** | 7.4 | 5.15 | **0.003** | 1478.3 | 168.05 | **<0.001** |
| **Treatment** | 1 | 0.5 | 0.37 | 0.543 | 0.3 | 0.22 | 0.644 | 3.3 | 0.37 | 0.548 |
| **Date x Trt** | 3 | 0.2 | 0.15 | 0.928 | 0.1 | 0.08 | 0.972 | 0.0 | 0.00 | 0.985 |
| **Residual** | 63 | 1.20 | | | 1.45 | | | 8.80 | | |

*Notes:* df = degrees of freedom, MS = mean square, *F* = *F* ratio, *P* = *P* value.

## Discussion

Our data suggest that polyculture plots performed as well as, or better than, *S. pacifica* alone with respect to multiple indicators of ecosystem structure and function. Although monocultures did increase in total percent plant cover faster than polycultures, both treatments had reached 80–100% cover after one year, easily exceeding the permit-mandated target of 20–40% cover in that time. As the polycultures eventually achieved

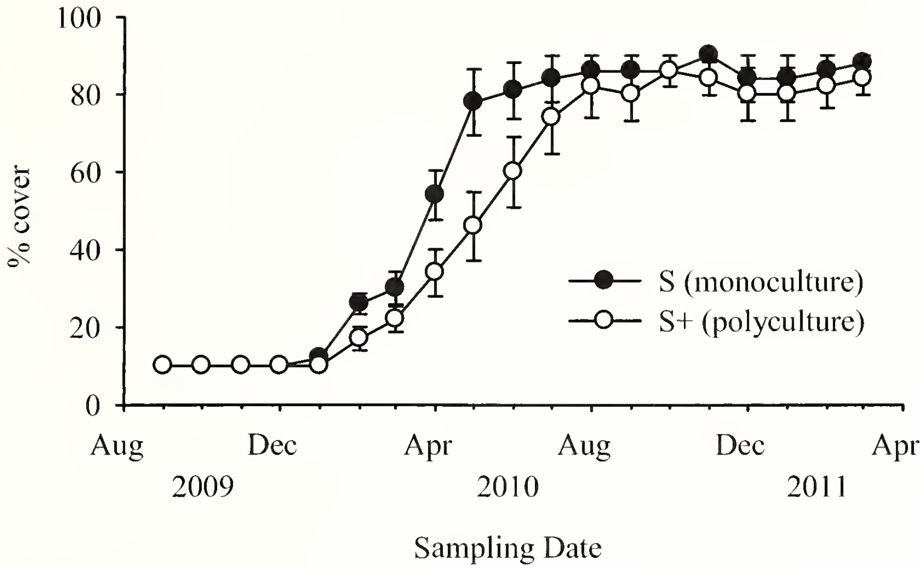


Fig. 1. Mean ± SE percent plant cover over time in experimental plots as a function of original plant species diversity (S, monoculture (*black circles*); S+, 9-species polyculture (*white circles*)).

equivalent percent cover to monoculture plantings of the local competitive dominant, our data address landowner concerns that high plant species diversity and high percent cover are incompatible management goals.

The effects of increasing plant cover on abiotic parameters (e.g., % light reaching the ground, soil temperature, and soil salinity) were comparable between the two treatments, resulting in the rapid amelioration of harsh environmental conditions present on the berm prior to planting. This pattern is consistent with restoration trajectories observed in other vegetated marsh ecosystems (Nomann and Pennings 1998; Bortolus et al. 2002; Whitcraft and Levin 2007). Habitat amelioration such as shading and decreased soil evaporation due to the presence of neighbors has been shown to have positive effects in polycultures relative to monocultures, where mortality is often higher due to increased intra-specific competition among individuals (Callaway 1995; Hacker and Bertness 1996; Callaway and Pugnaire 2007). Nevertheless, we found few mortality differences between treatments. This discrepancy is likely because we used only a single high-performing species in monoculture. Presumably, if we had instead assessed many different species, each in monoculture, the average performance of plants in monocultures would be lower than the average in polycultures (Callaway et al. 2003; Stachowicz et al. 2007).

Although previous research has evaluated relationships between plant species diversity and attributes such as percent cover, height, and canopy complexity (Keer and Zedler 2002; Doherty et al. 2011), our study also addressed the concurrent development of macroinvertebrate communities which few studies have experimentally investigated. Within 12–18 months post-restoration, monoculture and polyculture plots provided physical conditions and food resources sufficient to support similar assemblages of macroinvertebrates. At the end of the experiment in March 2011 (six months after regular watering was stopped), the plants in many of the plots were noticeably drier than on previous sampling dates (e.g., *S. pacifica* exhibited redder tips or had turned brown in some plots). This change may explain observed decreases in some components of the

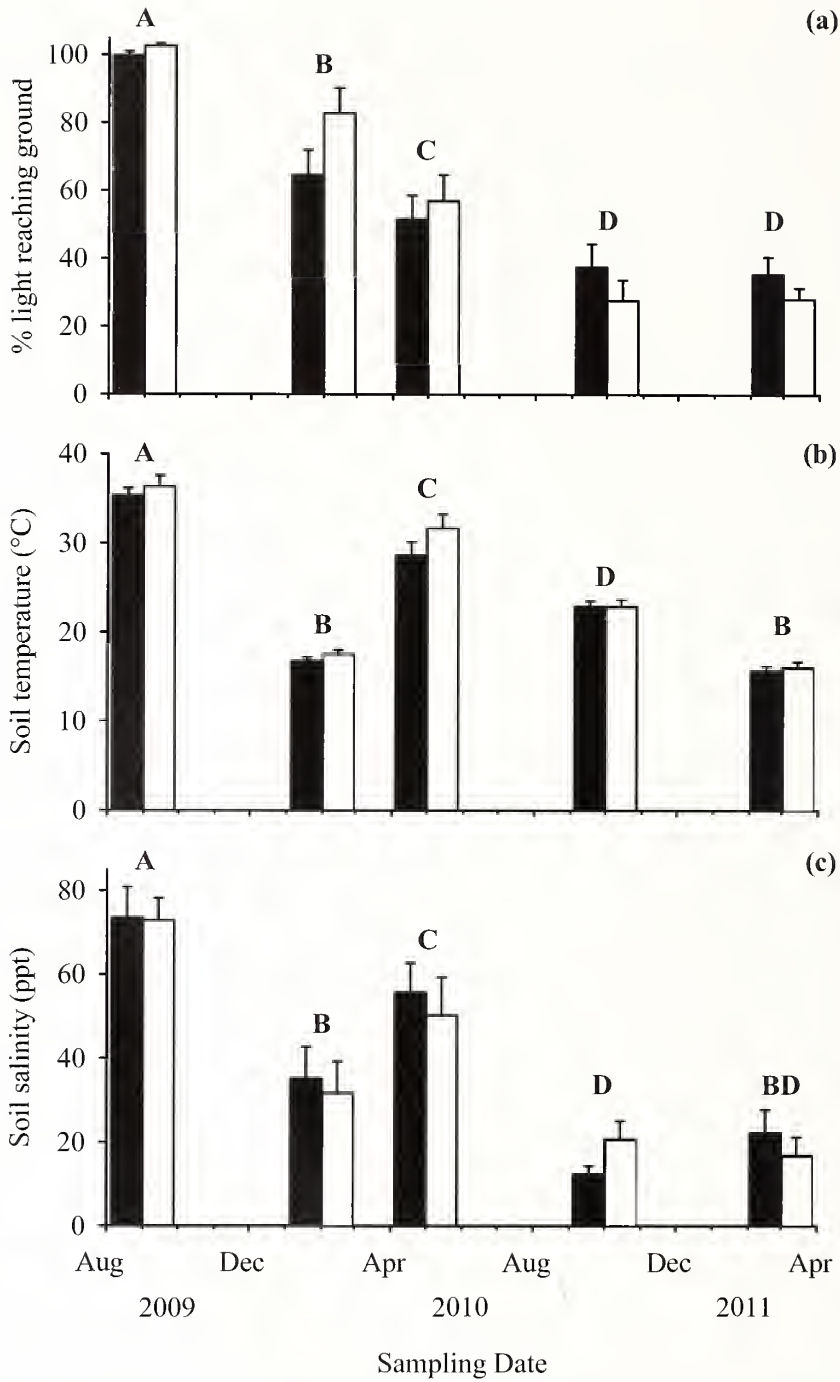


Fig. 2. Mean ± SE abiotic conditions over time in experimental plots as a function of original plant species diversity (S, monoculture (*black bars*); S+, 9-species polyculture (*white bars*)): % light reaching the ground (a), soil temperature (b), and soil salinity (c). Plots were sampled in September 2009, February 2010, May 2010, October 2010, and March 2011. Different letters indicate statistically significant differences among sampling dates at the $\alpha = 0.05$ level with Tukey's HSD test. There were no significant differences among treatments (all $P > 0.05$).

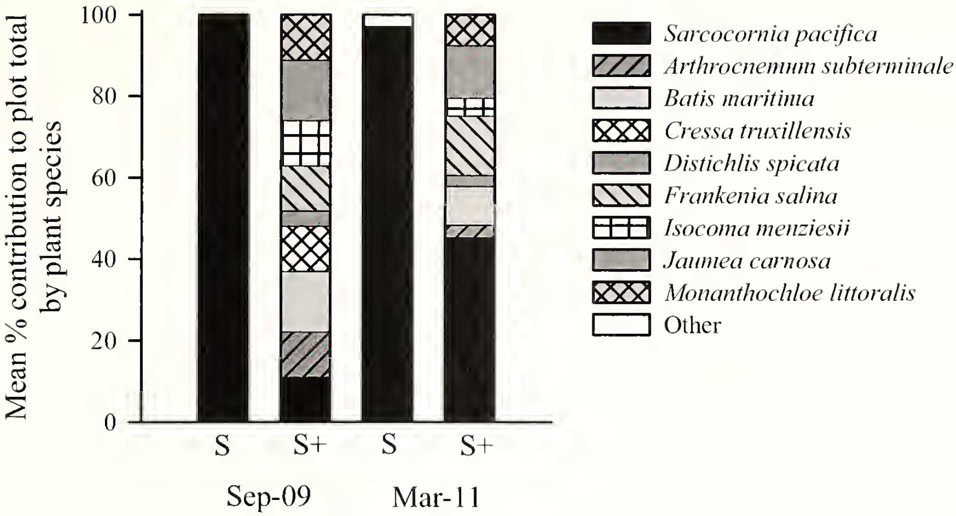


Fig. 3. Mean percent contribution to plot total by plant species in September 2009 (number of individuals) and March 2011 (percent cover) as a function of original plant species diversity (S, monoculture; S+, 9-species polyculture). The 'Other' category refers to plant species not originally planted and includes plant of both native and non-native status.

macroinvertebrate communities relative to October 2010. This research can facilitate understanding of the sequential consequences of changing salt marsh plant cover for higher trophic levels, including rapid development of trophic support for fish and birds and contribution of primary production from the marsh to secondary production in deeper water (Minello et al. 2003).

There were no substantive changes in species composition within treatment plots over the course of the experiment. Plots that were initially monocultures of *S. pacifica* had plant cover comprised almost exclusively of pickleweed 18 months later. Other studies have shown that dense stands of perennial dominants can suppress recruitment of less competitive species, hindering development of a diverse salt marsh plant assemblage (Bertness et al. 1992; Zedler and West 2008). In contrast, mean plant species richness in this study remained high in polyculture plots. Persistent differences in plant species diversity resulted in characteristic differences in canopy complexity and mean (but not maximum) plant height in monocultures versus polycultures. Keer and Zedler (2002) reported similar patterns in both an observational field study and manipulative experiments in the field and greenhouse. The physical arrangement of vegetation is an important determinant of the degree to which plants provide important functions to other species. For example, canopy complexity is correlated with bird species diversity (MacArthur and MacArthur 1961; Karr and Roth 1971), predator foraging efficiency (Crowder and Cooper 1982), and local retention of plant propagules (Peterson and Bell 2012). Plant canopy height can determine the suitability of restored habitat for use by nesting birds (Zedler 1993).

Current theory suggests that communities with many species that perform a given function in a similar way but have different sensitivities to abiotic conditions will exhibit greater temporal stability of ecosystem properties (Hooper et al. 2005). In addition to influencing resistance to environmental perturbations, species diversity has been linked to a variety of ecosystem properties that include primary productivity (Hacker and Bertness 1994; Tilman et al. 1997), nutrient accumulation rates (Sullivan et al. 2007), community

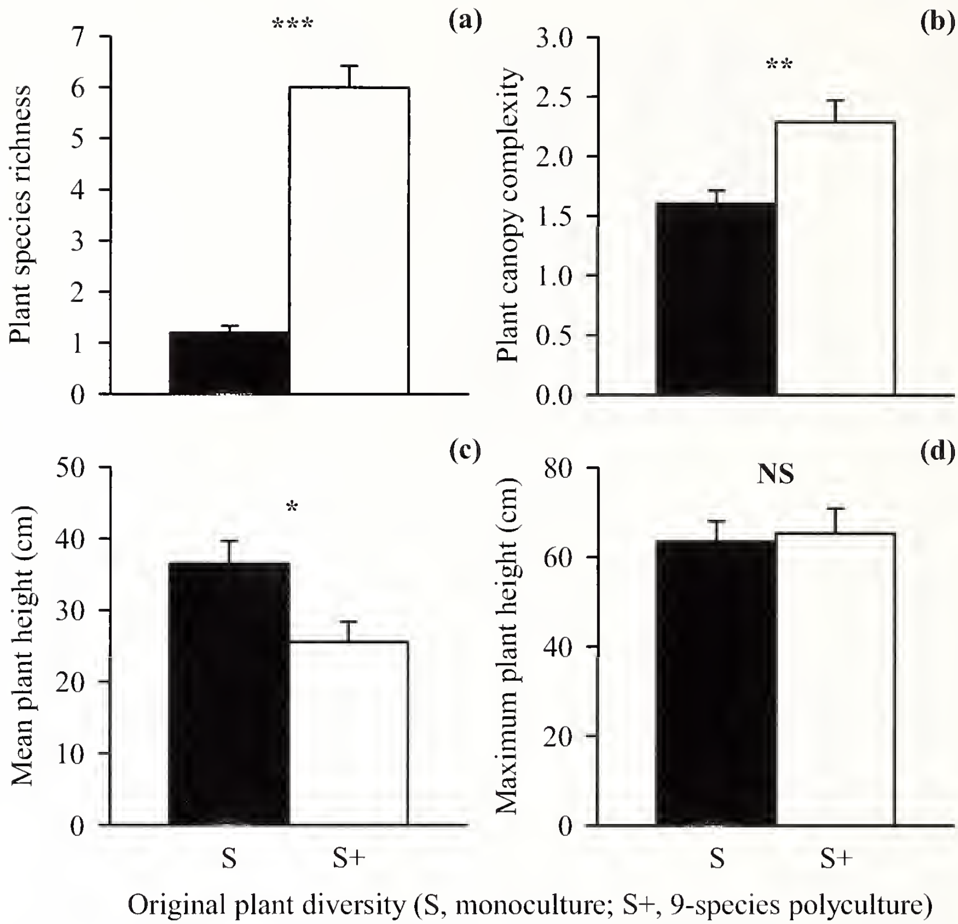


Fig. 4. Mean ± SE plant traits in experimental plots in March 2011 as a function of original plant species diversity (S, monoculture (*black bars*); S+, 9-species polyculture (*white bars*)): species richness (a), canopy complexity (b), mean plant height (c), and maximum plant height (d). Statistically significant differences among treatment groups are indicated as: *** ($P < 0.001$), ** ($P < 0.01$); * ($P < 0.05$), or NS (not significant).

invasibility (Stachowicz et al. 1999; Naeem et al. 2000), and habitat provision. Many of these relationships are likely mediated by the functional traits of the species involved, both "response traits" that determine how a species responds to a change in environmental conditions and "effect traits" that determine how that species affects ecosystem properties (Hooper et al. 2005; Bonin and Zedler 2008; Funk et al. 2008). Using habitat provision as a relevant example in this study, the state-listed endangered Belding's Savannah Sparrow uses tall, dense vegetation in the high marsh zone for nesting, perching during territory defense, and as a supplemental food source (Massey 1979; Zembal 1986; Powell and Collier 1998). Although *S. pacifica* is their preferred habitat, they will also nest in *D. spicata, F. salina,* and *B. maritima* (Powell 1993). So-called functional redundancy should lead to compensation among species, as some will do better when others do worse in response to environmental variability, due to different tolerances or competitive release. The marsh plant species used by Belding's Savannah

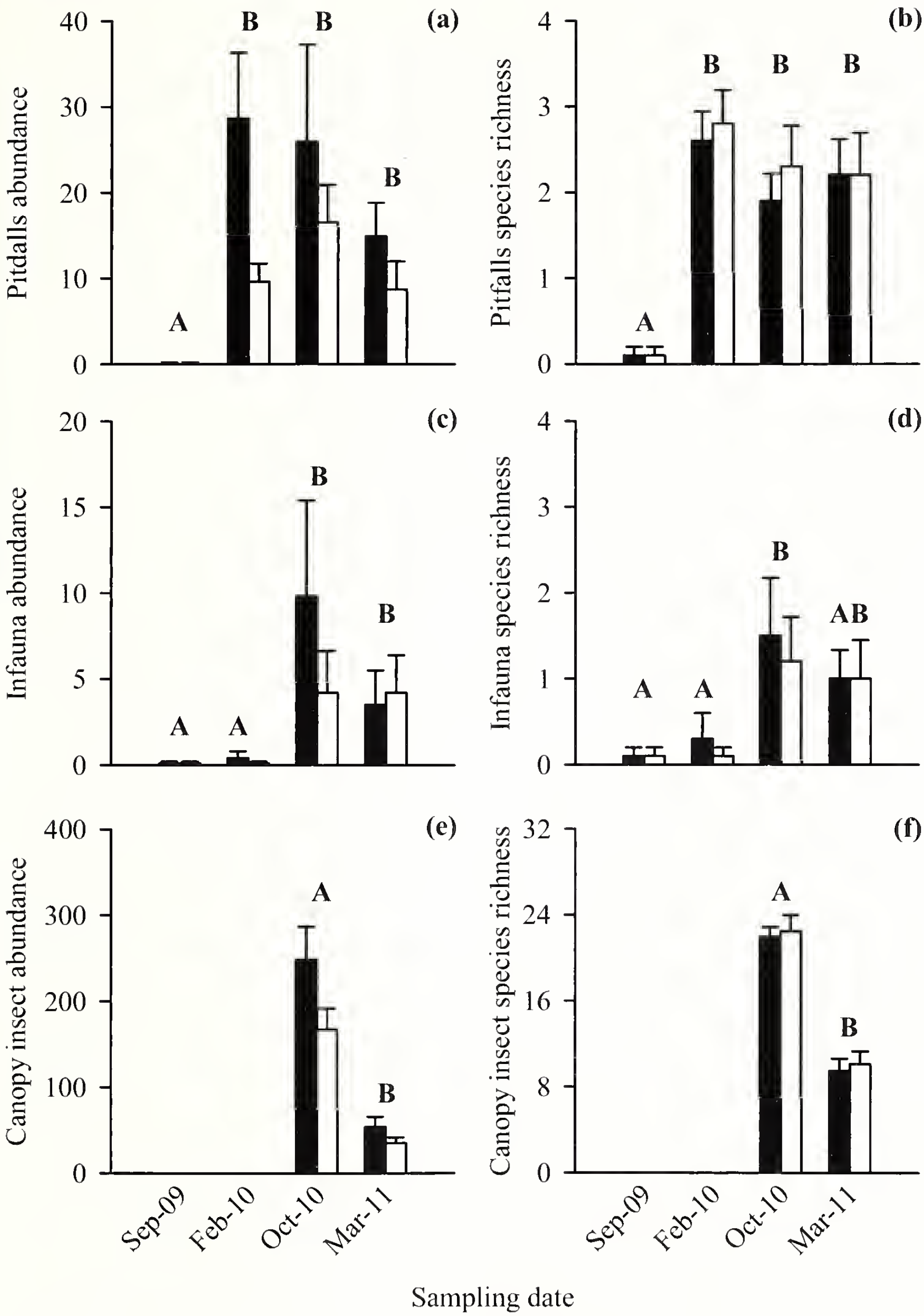


Fig. 5. Mean ± SE invertebrate abundances (a, c, e) and species richness (b, d, f) over time in experimental plots as a function of original plant species diversity (S, monoculture (*black bars*); S+, 9-species polyculture (*white bars*)): pitfalls (a, b), infauna (c, d), and canopy insects (e, f). Different letters indicate statistically significant differences among sampling dates at the $\alpha = 0.05$ level with Tukey's HSD test. There were no significant effects of treatment or interactions (all $P > 0.05$).

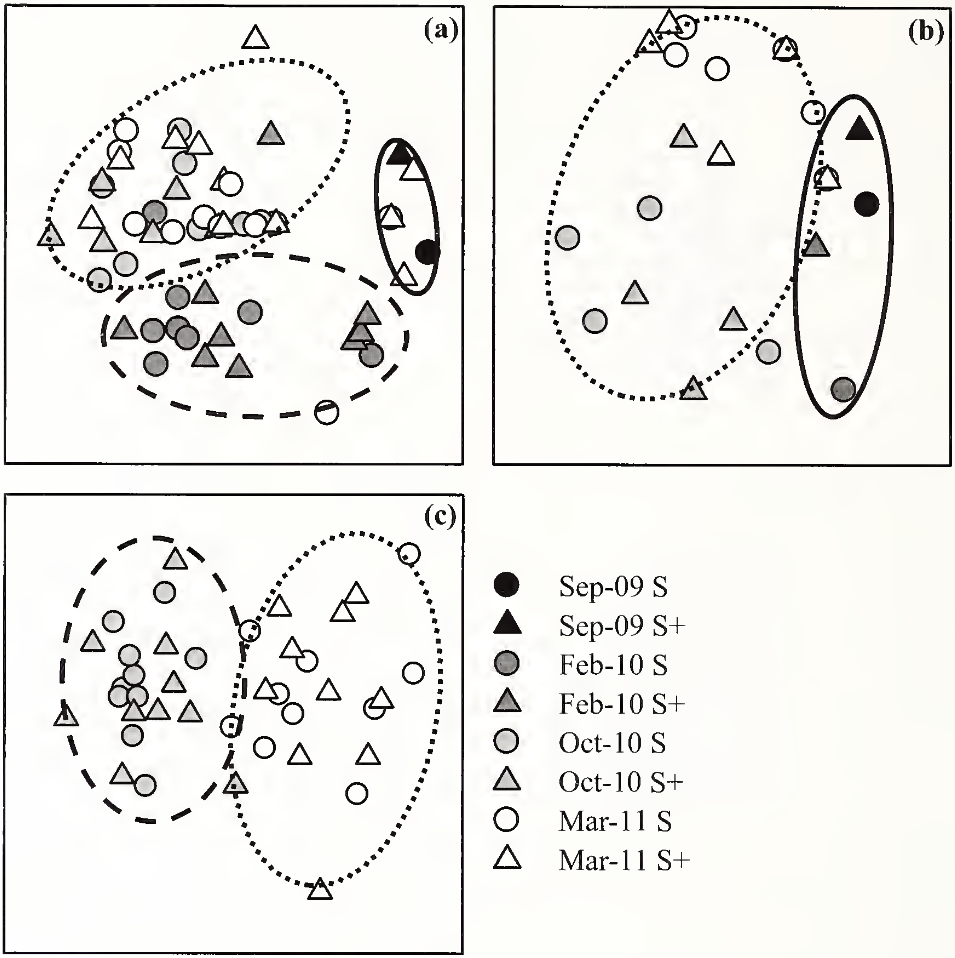


Fig. 6. Two-dimensional nMDS ordination plots of invertebrate community structure over time in experimental plots as a function of original plant species diversity (S, monoculture (*circles*); S+, 9-species polyculture (*triangles*)): pitfalls (a), infauna (b), and canopy insects (c). Ellipses drawn on graphs illustrate groups that were statistically significantly different at the $\alpha = 0.05$ level with ANOSIM tests.

Sparrows have been shown to respond differently to varying environmental stresses (e.g., high salinity, drought, or long-term inundation; Zedler and Nordby 1986), such that plantings with all species present should provide habitat for birds across a wider range of conditions than plantings limited to just *S. pacifica*.

In general, increasing species diversity is expected to result in increasing functional trait diversity, although the strength and shape of the relationship between taxonomic and functional diversity are poorly known for most systems (Hooper et al. 2005; Micheli and Halpern 2005). Diverse ecosystems that have multiple species performing similar roles should be relatively insensitive to species loss (at least initially) due to redundancy. Inherently low diversity systems like southern California salt marshes, however, may be much more vulnerable to the loss of even a few species. Inclusion of functional diversity and redundancy in restoration projects should therefore increase resilience to future climate change, facilitating the adaptation of local salt marshes to predicted alterations in temperature and precipitation levels. As a consequence, maximizing plant species diversity should be a key restoration goal to promote long-term persistence of critical ecosystem processes. More studies involving active restoration would help to determine the best plant species to utilize in a planting palette and thus aid in establishing planting protocols. Based on our results, active planting of high-diversity plots should be considered as a restoration tool to achieve management goals and speed functional recovery in southern California salt marshes.

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# Genetic structure of *Polycera alabe* and *P. atra* (Mollusca: Opistobranchia: Nudibranchia) in the Pacific coast of North America

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*Abstract.*—*Polycera alabe* and *Polycera atra* are closely related opisthobranch sea slugs found in coastal habitats along the eastern Pacific. Both species are extremely variable in external coloration and some of this variation appears to be correlated with geographic range. To determine the phylogenetic relationships and genetic structure of *P. alabe* and *P. atra* molecular phylogenies were generated using two genes: H3 (nuclear) and 16S (mitochondrial). Sequence data indicate that populations of *P. atra* are genetically homogeneous and lack geographic structure along the range of the species. In contrast, *Polycera alabe* consists of three previously unrecognized, distinct clades with overlapping ranges. The northernmost clade of *P. alabe* is sister to *P. atra*, thus the current definition of *P. alabe* constitutes a paraphyletic assemblage. The southernmost clade presents morphological differences in the radula compared to the other two clades. These data suggest that *P. alabe* is most likely a species complex.

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The opisthobranch mollusks *Polycera alabe* Collier & Farmer, 1964 and *Polycera atra* MacFarland, 1905 (family Polyceridae Alder & Hancock, 1845) are benthic marine invertebrates found in coastal habitats along the eastern Pacific. Anecdotal evidence suggests that El Niño Southern Oscillation (ENSO) plays significant roles in range expansions and contractions of both species (Kerstitch and Bertsch 2007), which otherwise have allopatric ranges, with the boundary at Punta Eugenia and Isla Cedros, Mexico (Angulo Campillo 2003, 2005). The known geographic range of *P. atra* spans from Cape Arago, Oregon (Goddard 1984) to La Paz, Mexico (Angulo Campillo 2003, 2005). However, the northernmost record of *P. atra* in Oregon was during the intense El Niño of 1982–1983 (Goddard 1984), and reports of this species south of Punta Eugenia are very rare (Angulo Campillo 2003, 2005). *Polycera alabe* is found from the Channel Islands in Southern California to Panama (Behrens and Hermosillo 2005), with an isolated record from northern Chile (Schrödl 2003), but the only record of *P. alabe* north of Punta Eugenia, in Southern California, was during the strong El Niño of 1997–1998 (Engle and Richards 2001).

Both *P. atra* and *P. alabe* are extremely variable in external coloration. Behrens and Hermosillo (2005) recognized four distinct color forms in *P. alabe* that they classified as variations A–D, each with slightly different geographic ranges. Variation A is found throughout the Gulf of California, the Pacific coast of Baja California and Southern California; variation B is found in the Pacific coast of Mexico; variation C is present from Mexico to Costa Rica and Panama; and variation D is only found in Central America. Based on these data, Behrens and Hermosillo (2005) suggested the possibility of the existence of several species. Animals of *P. atra* are also found to vary in coloration from

Table 1. List of specimens used in the study; including locality, voucher number, and GenBank Accession numbers. Specimens for which the radula was studied are marked with an asterisk (*).

| Species | Locality | Date | Voucher | 16S | H3 |
|---|---|---|---|---|---|
| *P.* cf. *capensis* | South Africa | - | CASIZ 176907 | HM162597 | HM162503 |
| *P. hedgpethi* | San Francisco, CA | 11 Sep 2009 | CPIC 00805 | KF425278 | KF425292 |
| *P. atra* | San Francisco, CA | 12 Sep 2009 | CPIC 00806 | KF425277 | KF425291 |
| *P. atra* | Monterey Bay, CA | 19 Aug 2010 | CPIC 00425 | KF425276 | KF425290 |
| *P. atra* | Santa Barbara, CA | 18 Aug 2010 | CPIC 00807 | KF425275 | KF425289 |
| *P. atra* * | Long Beach, CA | 17 Jul 2010 | CPIC 00808 | - | KF425288 |
| *P. atra* | La Paz, MX | 2 Apr 1974 | LACM 140740 | - | KF425287 |
| *P. alabe* | Sonora, MX | Mar 1975 | LACM 140737 | KF425272 | KF425284 |
| *P. alabe* * | Sonora, MX | Nov 1975 | LACM 140736 | KF425273 | KF425285 |
| *P. alabe* * | Sonora, MX | May 1976 | LACM 76-5 | KF425274 | KF425286 |
| *P. alabe* | La Paz, MX | 2 Apr 1974 | LACM 140738 | KF425267 | KF425279 |
| *P. alabe* | Jalisco, MX | 15 Feb 2008 | LACM 174944 | KF425271 | KF425283 |
| *P. alabe* * | Jalisco, MX | 18 Feb 2008 | LACM 174953 | KF425270 | KF425282 |
| *P. alabe* * | Colima, MX | 28 Jan 1976 | LACM 140739 | KF425268 | KF425280 |
| *P. alabe* | Guerrero, MX | 18 Mar 2004 | CPIC 00809 | KF425269 | KF425281 |

very dark to light; MacFarland (1966) indicated that southern animals tend to be lighter, suggesting some geographic variation. However, both our observations and unpublished data (H. Bertsch, pers. comm.) indicate a possible relationship between coloration and diet. Both species feed commonly on bryozoans of the genus *Bugula* and *Membranipora* (McDonald 1983), and *P. atra* collected on *Membranipora* are consistently lighter than those found on *Bugula*.

The objective of this paper is to examine the genetic structure of *P. alabe* and *P. atra* in the Pacific coast of North America, including specimens from northern California to the southern Mexican state of Guerrero. A mitochondrial (16S) and a nuclear (H3) gene were sequenced.

## Material and Methods

### *Source of Specimens*

Eight specimens of *P. alabe*, five specimens of *P. atra*, and one specimen of *Polycera hedgpethi* Marcus, 1964 were sequenced (Table 1). Specimens were obtained from the collections of the Natural History Museum of Los Angeles County (LACM) and the Cal Poly Pomona research collections (CPIC). Sequences for one specimen of *Polycera* cf. *capensis* Quoy & Gaimard, 1824 deposited at the California Academy of Sciences (CASIZ) were obtained from GenBank.

### *Morphological Examination*

Four specimens of *Polycera alabe* were dissected, and the radula of each was removed. Surrounding tissue on the radula was removed manually and then placed in low concentration [0.1] sodium hydroxide for approximately 24 hours to remove any remaining tissue. The radula was then dried, mounted with electrically conductive double-sided adhesive tape, and sputter coated with gold/palladium alloy for examination with a scanning electron microscope (SEM) Hitachi S-3000N at the Natural History Museum of Los Angeles County.

Table 2. Forward (F) and reverse (R) PCR primers used to amplify regions of the nuclear H3 gene and mitochondrial 16S and COI genes.

| Name | Sequence 5′–3′ | Source |
|---|---|---|
| H3 | | |
| HexAF (F) | ATG GCT CGT ACC AAG CAG ACG GC | Colgan et al. (1998) |
| HexAR (R) | ATA TCC TTG GGC ATG ATG GTG AC | Colgan et al. (1998) |
| 16S rRNA | | |
| 16Sar-L (F) | CGC CTG TTT ATC AAA AAC AT | Palumbi et al. (1996) |
| 16Sbr-H (R) | CCG GTC TGA ACT CAG ATC ACG T | Palumbi et al. (1996) |
| 16Sar-FAP (F) | AAA GAC GAG AAG ACC CTT AGA GTT TT | Ornelas-Gatdula et al. 2011 |
| 16Sbr-FAP (R) | AAA ACT CTA AGG GTC TTC TCG TCT TT | Ornelas-Gatdula et al. 2011 |

### *DNA Extraction*

DNA extraction was performed using either a hot Chelex® protocol or the DNeasy® Blood and Tissue Kit (Qiagen). Approximately 1–3 mg of tissue was taken from the foot or tail of the animals and cut into fine pieces for extraction for each of the two protocols. For the Chelex® extraction, the tissue was rinsed and rehydrated using 1.0 mL TE buffer (10 mM Tris, 1 mM EDTA, pH 8.0) for 15–20 minutes. A 10% (w/v) Chelex® 100 (100–200 mesh, sodium form, Bio-Rad) was prepared using TE buffer. After rehydration, the mixture was then centrifuged, 975.00 mL of the supernatant was removed, and 175.00 mL of the Chelex® solution was added. Samples were then heated in a 56°C water bath for 20 minutes, heated in a 100°C heating block for 8 minutes, and the supernatant was used for PCR. The DNeasy® protocol supplied by the manufacturer was followed, with some modifications. The elution step was modified such that the first elution was collected using 100.00 µL of Buffer AE and was allowed to incubate at room temperature for 5 minutes. In a new test tube, a second elution step was conducted using 200.00 µL of Buffer AE and was also allowed to incubate at room temperature for 5 minutes. The first elution was used for PCR. Such a variety of extraction protocols was implemented because not all tissue samples could be amplified when using the same extraction method. The use of the DNeasy® extraction protocol was only used as an alternative to the Chelex® extraction technique when it became apparent that the DNA could not be successfully extracted using that technique.

### *Primers*

Universal H3 (Colgan et al. 1998) and 16S primers (Palumbi et al. 1996) were used to amplify the regions of interest for all specimens (Table 2). Internal primers for 16S designed for another group of opisthobranchs (Ornelas-Gatdula et al. 2011) were used resulting in additional partial sequences for some specimens. Multiple attempts to obtain CO1 sequences using different primers (LCO1490/HCO2198, developed by Folmer et al. 1994 and NAF-COI/NAR-COI, developed by Ornelas-Gatdula et al. 2011) were unsuccessful.

### *PCR Amplification and Sequencing*

The master mix was prepared using 34.75 mL $H_2O$, 5.00 mL of either Buffer B (ExACTGene, Fisher Scientific) or Taq Buffer, 5.00 mL 25 mM $MgCl_2$, 1.00 mL 20mM dNTPs, 1.00 mL 10mM primer 1, 1.00 mL 10mM primer 2, 0.25 mL 5 mg/mL Taq, and

2.00 mL extracted DNA. Some master mixes included 2 mL 20mg/ml bovine serum albumin (Fermentas) and therefore 32.75 mL of $H_2O$ in order to maximize enzymatic activity. Reaction conditions for H3 and 16S rRNA were as follows: an initial denaturation for 2 min at 94°C, 35 cycles of 1) denaturation for 30 sec at 94°C, 2) annealing for 30 sec at 50°C, and 3) elongation for 1 min at 72°C, and a final elongation for 7 min at 72°C. PCR products yielding bands of appropriate size (approximately 375 bp for H3 and 195 bp for the 16S fragments) were purified using the Montage PCR Cleanup Kit (Millipore). Cleaned PCR samples were quantified using a NanoDrop 1000 Spectrophotometer (Thermo Scientific). PCR products were diluted to 6.0 ng/mL, and a sample of each primer was diluted to 2.0 pmol/mL. These samples were sequenced at the City of Hope DNA Sequencing Laboratory (Duarte, CA) using chemistry type BigDye V1.1 for fragments less than 500 bp.

### *Phylogenetic Analyses*

Sequences for each gene were assembled and edited using Geneious Pro 4.7.4 (Biomatters Ltd.). Geneious was also used to extract the consensus sequence between the primer regions and to construct the alignment for each gene using the default parameters. The sequences were not trimmed after alignment. A total of 395 bp for H3, and 495 bp for 16S were used for the phylogenetic analyses. Two other species of *Polycera*, *P.* cf. *capensis* and *P. hedgpethi*, were selected as outgroups. Because of the lack of comprehensive phylogenies for *Polycera*, outgroup choice was based on available sequences and specimens. An analysis was conducted for both genes concatenated. To assess whether H3 and 16S have significantly conflicting signals, the incongruence length difference (ILD) test (Mickevich and Farris 1981, Farris et al. 1994), implemented in PAUP*4.0 (Swofford 2002) as the partition homogeneity test (Swofford 2002), was conducted for all genes combined. The levels of saturation for each gene and for the first and second versus third codon positions of H3 were investigated using the substitution saturation test developed by Xia et al. (2003) and Xia and Lemey (2009) implemented in the program DAMBE (Xia and Xie 2001). The Akaike information criterion (Akaike 1974) was executed in jModelTest (Posada 2008) to determine the best-fit model of evolution. Maximum likelihood analyses were conducted using GARLI v0.96b8 (Zwickl 2006). Model parameters determined from jModelTest were entered into GARLI and the default parameters were used at 100 replicates each. Robustness of each clade was assessed by bootstrap support (Felsenstein 1985) based on 2000 replicates with heuristic search, TBR branch-swapping algorithm, multrees option, and 100 random additions. Bayesian analyses were executed in MrBayes 3.1.2 (Huelsenbeck and Ronquist 2001), partitioned by gene (unlinked). The Markov chain Monte Carlo analysis was run with two runs of six chains for five million generations, with sampling every 1000 generations. Convergence of runs was assessed using Tracer 1.5 (Rambaut and Drummond 2009). The default 25% burn-in was applied before constructing majority-rule consensus tree/s. Diagnostic nucleotides for each clade were identified visually in the alignments after collapsing identical haplotypes using the program Collapse 1.2 (Posada 2004).

## Results

### *Phylogenetic Analyses*

The phylogenetic analyses produced a resolved and well-supported phylogenetic hypothesis for the specimens examined (Figure 1). There is very little genetic diversity and no phylogenetic structure in *P. atra*. All specimens examined from San Francisco

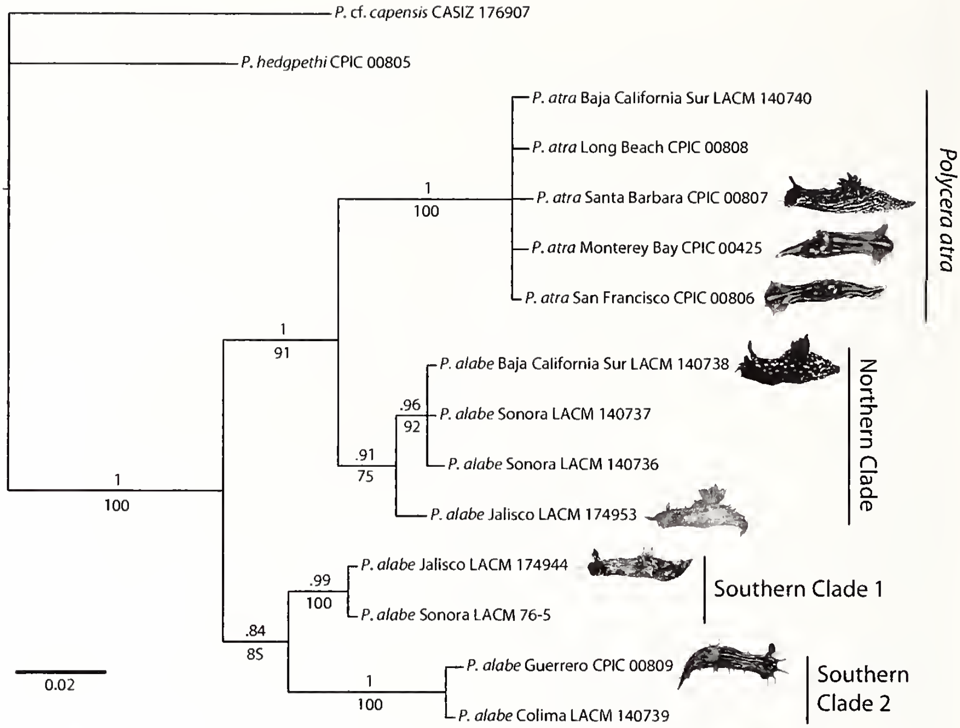


Fig. 1. Bayesian consensus tree of the specimens examined based on H3 gene and 16 gene sequences. Posterior probabilities and bootstrap values (from the maximum likelihood analysis) are indicated for each branch. Sequenced specimens for which photographs were available are illustrated. Photographs by David Behrens (CPIC 00809), Leroy Poorman (LACM 140738), and Ángel Valdés (all others).

Bay, California to La Paz, Mexico are identical for H3 and almost identical for 16S (only one nucleotide substitution was found in a specimen from Monterey Bay, California). The clade containing all the specimens identified as *P. atra* is well supported (posterior probability = 1). In contrast, *P. alabe* exhibits a large degree of variation in both genes, providing a strong phylogenetic signal. The phylogenetic analyses have recovered three distinct and well-supported clades including specimens identified as *P. alabe*. One of the clades (named the Northern Clade herein) includes specimens collected in Sonora and La Paz, Mexico (both in the Gulf of California) and Jalisco, Mexico. This clade is well supported (posterior probability = 0.95) and it is sister to *P. atra*. Within this Northern Clade three specimens from the Gulf of California form a well-supported subclade (posterior probability = 0.97). The clade containing the Northern Clade of *P. alabe* and *P. atra* is also well supported (posterior probability = 0.98). The two other clades of *P. alabe* are called Southern Clade 1 and 2 herein and they appear to be sister, but this is weakly supported (posterior probability = 0.8). Southern Clade 1 includes specimens collected in Sonora and Jalisco and is well supported (posterior probability = 0.96), whereas Southern Clade 2 includes animals collected in southern Mexico (Colima and Guerrero) and is also well supported (posterior probability = 0.97). The ranges of the Northern Clade and Southern Clade 1 overlap in the central Gulf of California (Figure 2). However, the specimen of Southern Clade 1 from Sonora was collected during the El Niño of 1977 and it could be the result of unusual oceanographic conditions. Based

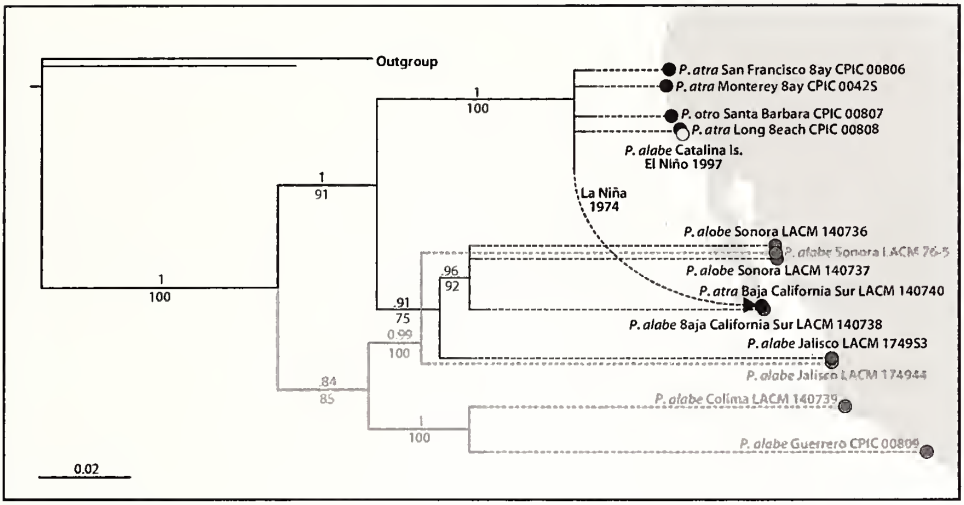


Fig. 2. Phylogeny of *Polycera alabe* and *P. atra* with a map showing the geographic location where the specimens were collected. Records representing large range shifts during ENSO events are labeled with bold font. In yellow is a record of *P. alabe* from Southern California not sequenced in this study.

on the information available, it appears that *P. atra* + the Northern Clade and the Southern Clade 2 are completely allopatric.

### *Morphological Analyses*

A morphological examination of representative specimens from the three *P. alabe* clades indicates some differences in radular morphology. All radulae examined have a hook-shaped innermost lateral tooth in each half-row, with a short, triangular cusp and a secondary cusp mid-length (Figure 3). The innermost tooth is followed by a larger tooth with a similar morphology. However, the number and morphology of the outer lateral teeth is different among clades. Northern Clade and Southern Clade 1 exhibit identical radula morphology, with 2–3 vestigial outer teeth (Figure 3A-D). However, specimens of Southern Clade 2 consistently have 7–8 large outer teeth (Figure 3E-F).

## Discussion

The sequence data and phylogenetic analyses presented here show that populations of *P. atra* from a broad geographic range (San Francisco Bay, California to La Paz, Mexico) are genetically very similar for 16S and H3. The 16S gene is variable enough to distinguish among species of opisthobranchs and is even informative in population genetics studies (Krug et al. 2012). The lack of geographic structure in *P. atra* suggests rampant gene flow across the range of the species. Alternatively, this pattern might have been caused by rapid postglacial range expansion of *P. atra* from refugia at the southern range of the species. This is a well-documented explanation for the lack of genetic structure in several other species of marine invertebrates along the Pacific Northwest (e.g., Marko 1998, Hellberg *et al.* 2001, Edmands and Harrison 2003). Although the northern range limit of *P. atra* is well south of the last glacial maximum, colder ocean temperatures during the Pleistocene in California (Bemis et al. 2002) might have restricted the range of this species, which could have rapidly expanded to the north during the

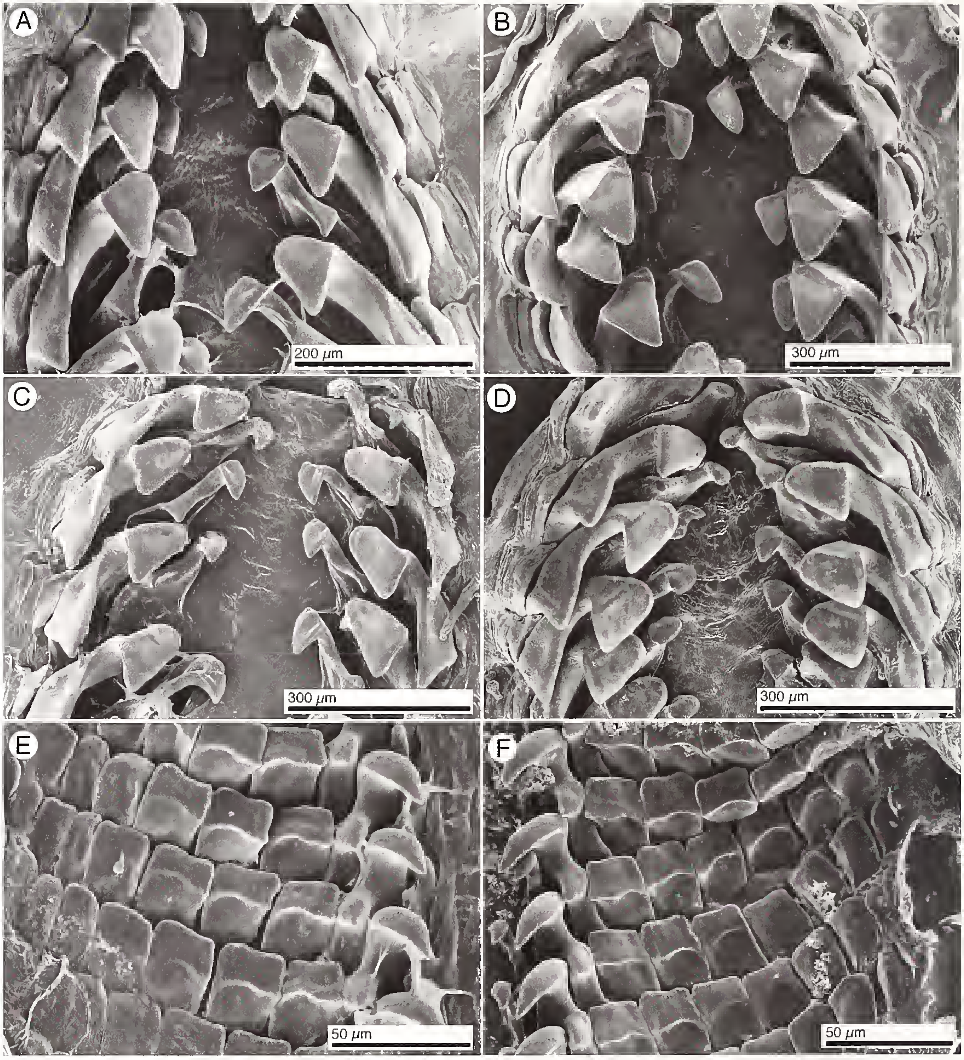


Fig. 3. Radula SEM photographs for representatives of each clade of *P. alabe* and *P. atra*. All photographs taken with the same orientation (distal above, proximal below). A, *P. atra* (CPIC 00808). B, *P. alabe* Southern Clade 1 (LACM 76-5). C, *P. alabe* Northern Clade (LACM 140736). D, *P. alabe* Nortern Clade (LACM 174953). E-F, *P. alabe* Southern Clade 2 (LACM 140739).

transition to the Holocene (see Jacobs *et al.* 2004). The specimen of *P. atra* from La Paz, Mexico (confirmed with both genetic markers) was collected in April 1974 during a strong La Niña, suggesting that this species has a broad dispersal potential and that water temperature may be an important factor limiting its range.

The same genetic markers demonstrate a completely different picture for *P. alabe*. In this case we have identified three well-supported clades with several molecular synapomorphies in the 16S and H3 genes. Southern Clade 2 is also supported by radula morphological differences, indicating that it is likely a distinct species. The other two clades could also possibly constitute different species based on their genetic synapomorphies. One of the clades of *P. alabe* (Northern Clade) is sister to *P. atra*, thus the current definition of *P. alabe* constitutes a paraphyletic assemblage. However, there is no available genetic information available for populations from the Pacific coast of Central and South America – the known range of *P. alabe* includes Costa Rica, Panama, and Chile – and the sample size and sequence data are relatively small. Therefore, we do not think it is appropriate to suggest taxonomic changes at this point.

Another problem is to elucidate which of the two clades found in the Gulf of California (Northern Clade or Southern Clade 1) is the original *P. alabe*, since the range of both clades includes the type locality of *P. alabe* (Isla de Cedros, Baja California). These taxonomic issues should be addressed in a comprehensive study including specimens from the entire range of *P. alabe* and detailed morphological examinations including the reproductive anatomy of all the species involved.

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# Decline to Near Extinction of the Endangered Scotts Valley Polygonum *Polygonum hickmanii* (Polygonaceae) in Coastal Central California

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*Abstract.*—Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) is a narrow endemic plant restricted to a specialized microhabitat (exposed bedrock in California prairie) in Santa Cruz County, California. The species was named in 1995 and subsequently listed as endangered under the U.S. Endangered Species Act and California Endangered Species Act in 2003 and 2005, respectively. Two occurrences exist on three properties in a recently urbanized area at the northern edge of the city of Scotts Valley, with a geographic range of 0.03 $km^2$. As of 2012 the species has declined to 128 plants on 61 $m^2$, having decreased from 604 plants in 2003, 1,612 plants in 1998 and 2,388 plants in 1997. In 2013 the primary threats to *P. hickmanii* are habitat alteration due to adjacent land uses and developments, and invasive plant species and accumulation of thatch. Cessation of grazing and fire suppression have likely contributed to the increasing presence of invasive plant species and accumulation of thatch. Intensive and adaptive management with monitoring will be necessary for *P. hickmanii* to survive. Unless management is implemented as a matter of urgency, the species will likely disappear within just a few years.

## Introduction

Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) is endemic to Santa Cruz County in coastal central California (Figure 1). It is a small annual plant (2 to 5 cm tall) with linear pointed leaves and a white flower in the axil of each leaf. The species was named in 1995 (Hinds and Morgan 1995) and subsequently listed as endangered in 2003 and 2005 under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service [USFWS] 2003) and California Endangered Species Act (California Fish and Game Commission 2005), respectively. It was not yet listed when a recovery plan for several other plant species in the Santa Cruz Mountains was issued in 1998 (USFWS 1998). However, the plan provided an interim objective for *P. hickmanii*: avert extinction by restricting activities to compatible land uses, and establishing conservation easements and/or acquiring all lands supporting this species.

At Federal listing in 2003, *P. hickmanii* was known from two occurrences in the vicinity of the city of Scotts Valley and 11 km inland from the Pacific Ocean. Based upon our data, the species was estimated to comprise ≈ 1,599 plants on three properties (USFWS 2003): Polo Ranch, 1,259 plants (1998); Salvation Army land, 200 plants (2002); and Scotts Valley High School Preserve, 140 plants (2002). Primary threats were the following (USFWS 2003): habitat alteration due to adjacent land uses and developments (a proposed housing development that would build within 18 m on Polo Ranch; an existing

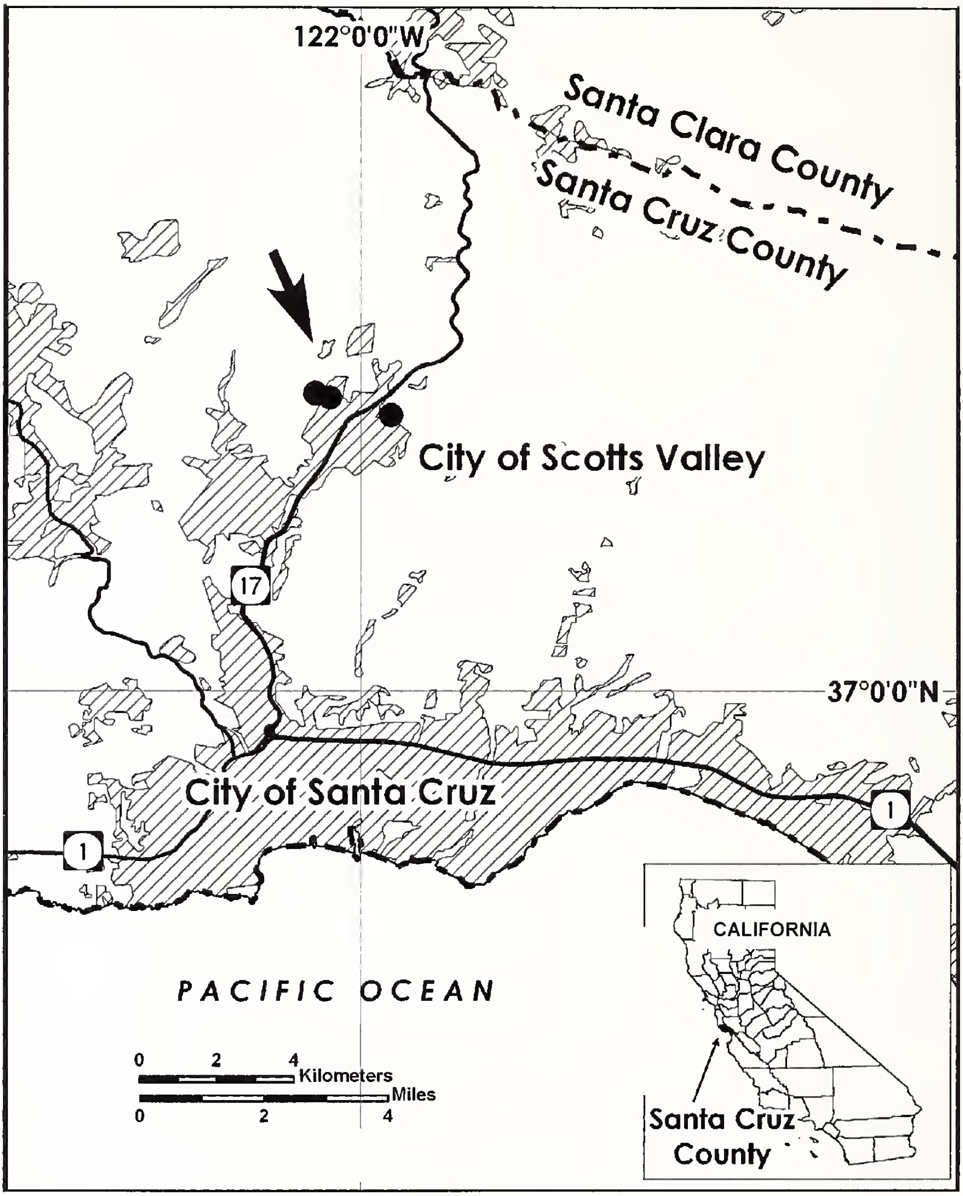


Fig. 1. Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) at the northern edge of the city of Scotts Valley, Santa Cruz County, California. The two occurrences are on three properties.

paved road upslope on Salvation Army land; and existing high school facilities and housing development bordering Scotts Valley High School Preserve on three sides); invasive plant species and thatch; inadequate legal protection; inadequate preserve design; and stochastic events. USFWS (2007) reported that *P. hickmanii* faced a high degree of threat and with low potential for recovery. USFWS (2009) reviewed the status of the species and recommended no change in its listing status. Our purpose is to review and enhance the knowledge of *P. hickmanii*, in particular its distribution, ecology, abundance, threats, management and conservation status in 2013.

## Methods

Throughout this paper, "we" refers to all or any one of the authors. The only primary publications are Hinds and Morgan (1995) and USFWS (1998, 2000a, 2003), for which we provided much of the information. We have additional and unpublished data because we surveyed, mapped and measured the colonies (spatial groups of separate individuals), censused and made observations during many years from 1990 to 2013. Our data since 1997 are especially robust because we surveyed and censused by systematic search and count when the plants were flowering (generally late May to Aug.), including five range-wide efforts in 1998, 2003, 2010, 2011 and 2012. Using all available information (published and our own unpublished), we summarize the knowledge of *P. hickmanii*, including its distribution, ecology, abundance, threats, management and conservation status in 2013. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the USFWS. Common and Latin names follow Baldwin et al. (2012).

## Review of the Species

*P. hickmanii* is a narrow endemic plant restricted to the specialized microhabitat of exposed bedrock in California prairie (as defined by Holstein 2011) in coastal central California (Figure 2). In 2013 the species is still known from only two occurrences 1.6 km apart in a recently urbanized area at the northern edge of the city of Scotts Valley, with one occurrence on each side of State Highway 17 (an expressway through the city; Figure 3). The eastern occurrence is on Polo Ranch (private land; 37°3′52.66″N, 121°59′36.90″W). The western occurrence is on Salvation Army land (private land; 37°4′11.32″N, 122°0′39.27″W) and Scotts Valley High School Preserve (public land; 37°4′9.40″N, 122°0′27.62″W), which are contiguous properties. Polo Ranch and Scotts Valley High School Preserve are within city limits, whereas Salvation Army land is not.

*P. hickmanii* occurs in colonies, with the largest recorded area of a single colony comprising 135 $m^2$. We have identified 17 colonies since 1990: 12 on Polo Ranch, 4 on Salvation Army land, and 1 on Scotts Valley High School Preserve. Hinds and Morgan (1995) stated the species occurs only in a very restricted microhabitat, and they were unable to find any other occurrences by extensive surveys in other areas or additional records in herbarium collections. The California Department of Fish and Game (2004) also searched herbarium collections and without success.

The landscape in which *P. hickmanii* occurs is inhabited also by three other endangered species: Scotts Valley spineflower *Chorizanthe robusta* var. *hartwegii* (USFWS 1994), San Francisco popcorn flower *Plagiobothrys diffusus* (California Department of Fish and Game 2012), and Ohlone tiger beetle *Cicindela ohlone* (USFWS 2001). We and others have conducted numerous searches for all four taxa. Although *P. hickmanii* is a small plant, its microhabitat is easy to identify. Some additional colonies may exist on other properties but have not been found. However, most areas likely to have supported this species are now developed, and it seems unlikely that any other colonies exist. Development of the city of Scotts Valley and construction of State Highway 17 probably removed any other occupied habitat.

*P. hickmanii* grows in patches of thin soil overlying and derived from exposed bedrock (Santa Cruz mudstone and Purisima sandstone) on gently sloping to nearly level ground in California prairie at 213 to 244 m elevation (Hinds and Morgan 1995). Based on data for the Ben Lomond weather station (≈ 6.3 km west northwest of Salvation Army land), mean annual rainfall at the two occurrences is ≈ 1,186 mm, along with rain primarily


Fig. 2. Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) grows in patches of thin soil overlying and derived from exposed bedrock in California prairie in Santa Cruz County, California. Top photo: A colony (a spatial group of separate individuals) of *P. hickmanii* is next to the exposed bedrock near the tip of the black arrow. Polo Ranch, 17 June 2010. Bottom photo: The colony of *P. hickmanii* that previously occupied this site until 2010 was not extant in 2011 and 2012. Scotts Valley High School Preserve, 15 March 2013.

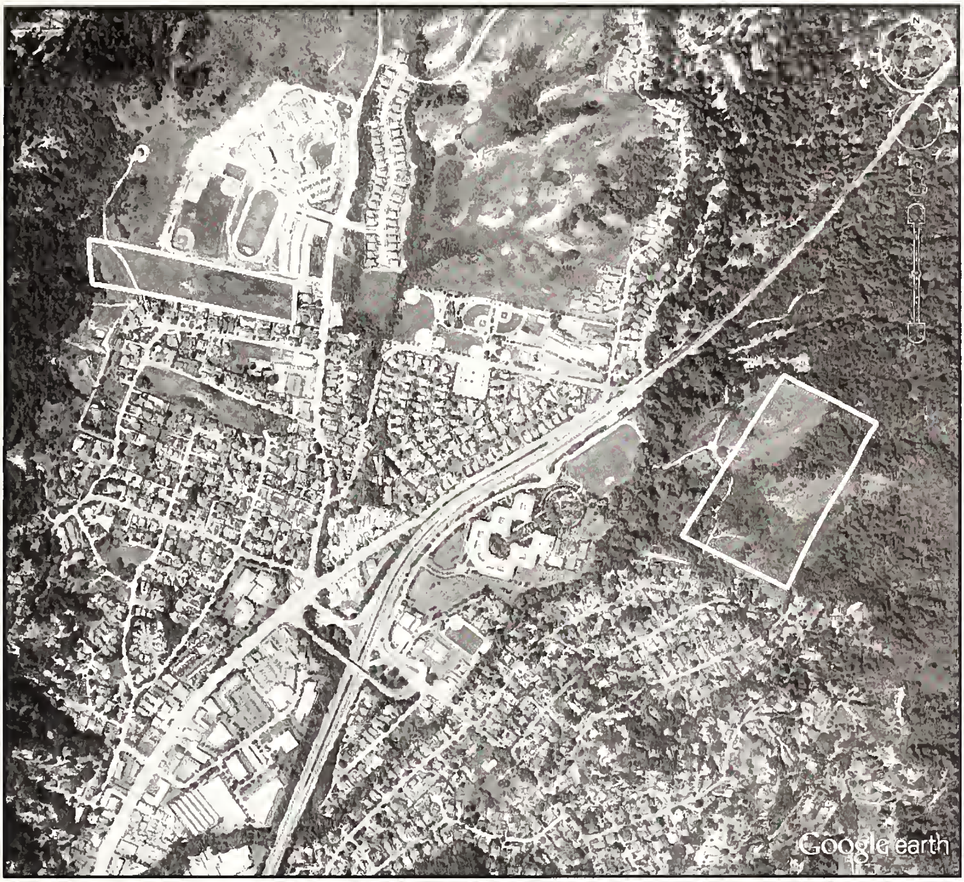


Fig. 3. The two occurrences of Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) at the northern edge of the city of Scotts Valley, Santa Cruz County, California. The Google Earth image is dated 5 May 2012.

from Nov. to Apr. (http://www.worldclimate.com 2013). In the vicinity of the city of Scotts Valley, California prairie is generally on the middle to lower slopes, with redwood *Sequoia sempervirens* and mixed forest on the higher slopes. Other important factors appear to be the particular characteristics of the thin soil: its fine texture, relative sterility, and distinctive hydrology. In addition, many of the patches of thin soil bear a cryptogamic crust (cyanobacteria, lichens, mosses and fungi on the soil surface). Cryptogamic crusts are important elements of semiarid and arid ecosystems (Beymer and Klopatek 1992) because they stabilize soil against erosion, fix atmospheric nitrogen, form organic matter (Eldridge and Greene 1994), retain soil moisture, discourage weed growth (Belnap et al. 2001) and provide favorable sites for growth of native plants (e.g., Lesica and Shelly 1992). Although the length of time that seeds of *P. hickmanii* remain viable in soil is not known, we suspect it is only a few years.

In 2013 the local California prairie is dominated by invasive annual grasses (monocots) that include slender wild oat *Avena barbata*, rattail sixweeks grass *Festuca myuros*, soft chess *Bromus hordeaceus*, silver hair grass *Aira caryophyllea* and rattlesnake grass *Briza maxima* (Figure 4), which produce thatch. However, some patches of thin soil associated

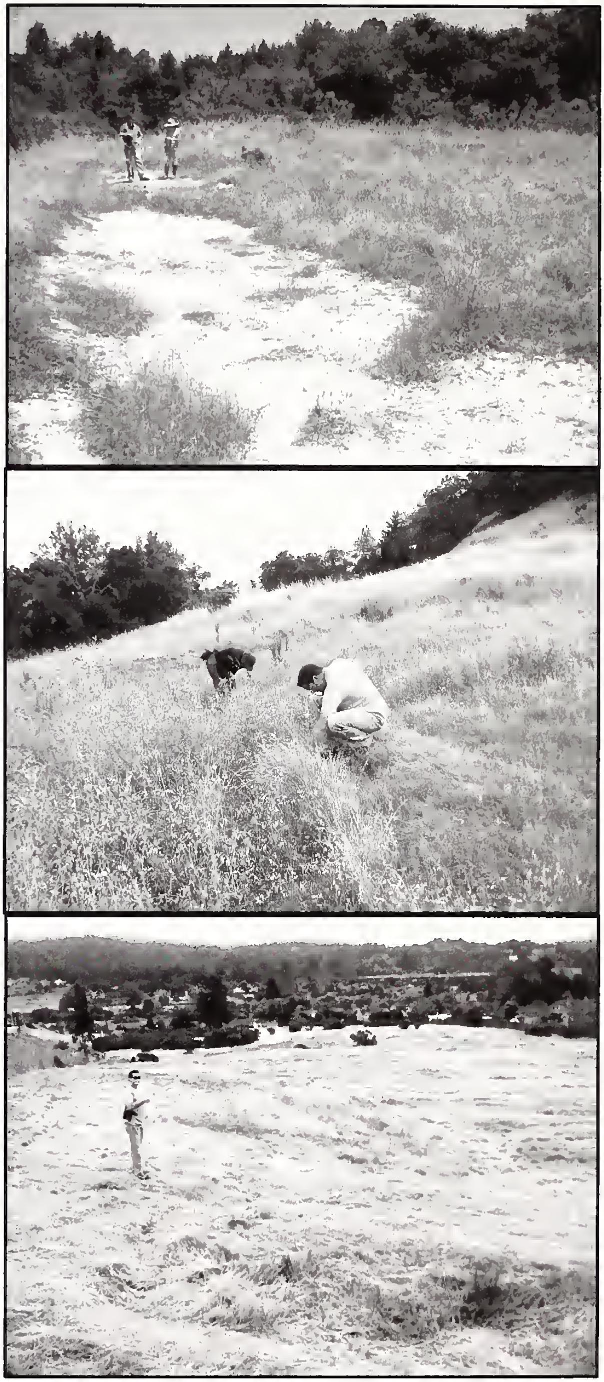

Fig. 4. California prairie at the northern edge of the city of Scotts Valley, Santa Cruz County, California, is now dominated by invasive annual grasses. The tall invasive annual grasses and the thatch that they produce are primary threats to Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae). Top photo: Polo Ranch, 15 June 2011. Middle photo: Salvation Army land, 16 June 2011. Bottom photo: Scotts Valley High School Preserve, recently mowed and without removing the cut biomass, 16 June 2011.

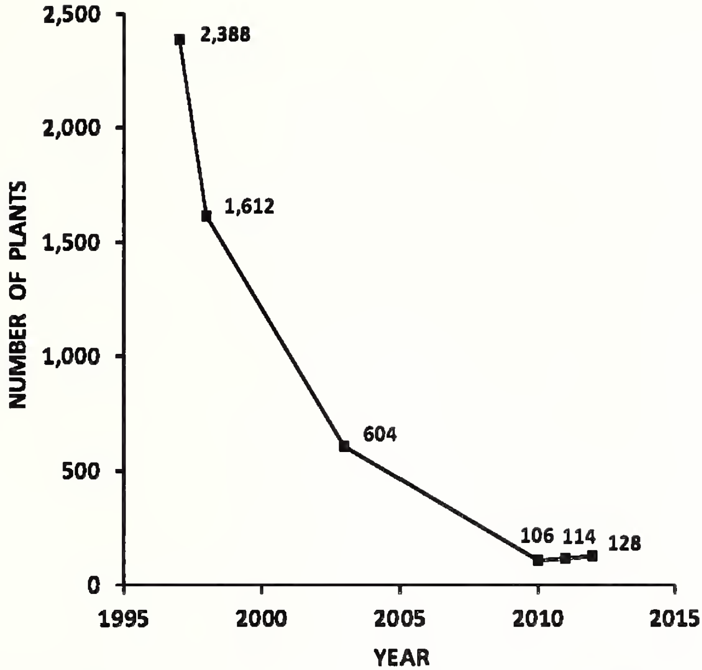


Fig. 5. Decline in numbers of Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) from 1997 to 2012. The data for 1997 include only the Polo Ranch and Scotts Valley High School Preserve. The data for 1998 to 2012 include the Polo Ranch, Salvation Army land and Scotts Valley High School Preserve.

with the exposed bedrock are still dominated by native annual forbs (eudicots) and comprise a distinct community of native wildflowers, which USFWS (2000a) referred to as wildflower fields. The native species associated with *P. hickmanii* in this plant community include the equally narrow endemic *C. robusta hartwegii*, owl's-clover *Castilleja densiflora*, tarplant *Deinandra corymbosa*, common goldfields *Lasthenia gracilis*, peppercress *Lepidium nitidum*, California sandwort *Minuartia californica* and Gray's clover *Trifolium grayi*. Within the wildflower fields, the greatest diversity of native plants is generally on the thinner soil, and *P. hickmanii* is often next to bare rock. The soil underlying most other parts of the local California prairie is thicker and with more humus and nitrogen. USFWS (2003) considered the following habitat components essential to conservation of *P. hickmanii*: the thin soils in the Bonnydoon series over outcrops of Santa Cruz mudstone and Purisima sandstone; the wildflower fields on the thin soils; the plant community of the California prairie, along with the pollinators and seed dispersal mechanisms; the areas around each colony for re-colonizing suitable habitat; and the landscape in the subwatersheds upslope to ridgelines for maintaining edaphic conditions, hydrology and slope stability.

In the 1990's the 17 colonies of *P. hickmanii* occupied up to 305 $m^2$ on three properties, and in 2012 the three observed colonies (each in cryptogamic crust) occupied 61 $m^2$ on only one property (Polo Ranch). Approximate numbers of plants during five range-wide surveys ranged from 1,612 (1998) to 106 (2010; Figure 5). The 12 colonies on Polo Ranch previously occupied 290 $m^2$, and the approximate numbers of plants ranged from 2,138 (1997) to 94 (2010). The four colonies on Salvation Army land previously occupied 14 $m^2$, and the approximate numbers of plants ranged from 267 (2004) to 0 (2010, 2012). The one colony on Scotts Valley High School Preserve previously occupied 1 $m^2$, and the approximate numbers of plants ranged from 250 (1997) to 0 (2011, 2012; Table 1).

Polo Ranch comprises 46 ha of California prairie and forest immediately north of residential development, and its natural ecosystem is now degraded by invasive plant species and accumulation of thatch. The property has been the subject of several development proposals since 1989, and the current owner is a homebuilding corporation that acquired it in 1997. From 1998 to 2005 we observed disturbances by off-highway vehicles, which the owner deterred by fencing in 2006. In 2009 the City of Scotts Valley approved a plan to construct 40 houses on 6 ha, along with establishing an open space preserve on 40 ha of which 14 ha of sensitive habitat would be fenced and under a conservation easement. The area under conservation easement will be managed by a conservation organization to benefit the listed plant species (*P. hickmanii*, *C. robusta hartwegii*, *Plagiobothrys diffusus*), including reducing invasive plants by grazing along with other adaptive management practices. Although the development will not destroy any occupied area, its footprint (a graded fire road) will extend to ≈ 22 m from the nearest colony of *P. hickmanii* (Huffman-Broadway Group, Inc. 2010). Vegetation clearing for construction commenced shortly after our survey and census in June 2012.

Salvation Army land comprises 83 ha of California prairie and forest immediately west of Scotts Valley High School. The four colonies are ≈ 292 m west of the colony on Scotts Valley High School Preserve. Scotts Valley Water District constructed a recycled water system on this property in 1999 (USFWS 2003), including a paved road ≈ 16 m upslope of the colonies. The occupied area is subject to a management plan, however, we have observed only irregular mowing of invasive grasses and without removing the cut biomass. Although persons on motorcycles and bicycles previously trespassed through the occupied area, we saw no evidence from 2010 to 2013.

Scotts Valley High School Preserve comprises 3.2 ha of California prairie immediately east of Salvation Army land. The high school was built in 1998, with the preserve established to conserve the sensitive plant species (*P. hickmanii*, *C. robusta hartwegii*, *Plagiobothrys diffusus*). The preserve is subject to a management plan in perpetuity, and mowing of invasive grasses without removing the cut biomass occurred annually from 1998 to 2011. At our recommendation, the cut biomass was removed in 2012. Development surrounds the preserve on three sides: high school facilities, paved road and athletic fields immediately north; and houses immediately east and south. The single colony of *P. hickmanii* is ≈ 36 m from the preserve boundary. Although now fenced, students previously crossed the preserve, bicycle jumps were erected in it, golfers used it for practice, and concrete and other waste were dumped in it (Cheap in USFWS 2009). We saw no evidence of unauthorized activities from 2009 to 2013.

In the mid 1990's, the California Department of Fish and Game recommended that one large preserve be established for the colonies on Salvation Army and Scotts Valley High School lands. However, negotiations for a conservation easement on Salvation Army land were not successful (California Department of Fish and Game 2004). At only 3.2 ha in area and with development on three sides, Scotts Valley High School Preserve is not large enough to sustain a natural ecosystem. The land uses immediately north, east and south are not compatible with the small preserve. A preserve should be large enough to maintain the target species and its natural ecosystem, and adjacent land uses should be compatible (USFWS 2003). The natural ecosystem on Salvation Army and Scotts Valley

Table 1. Approximate numbers of Scotts Valley polygonum *Polygonum hickmanii* (Polygonaceae) at the northern edge of the city of Scotts Valley, Santa Cruz County, California, from 1997 to 2012. We surveyed and censused by systematic search and count when the plants were flowering (generally late May to Aug.).

| Occurrence | Year | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2009 | 2010 | 2011 | 2012 |
| 1 Polo Ranch | 2,138 | 1,259 | | | | | 294 | 333 | 254 | | 94 | 111 | 128 |
| 2 a. Salvation Army land | | 200 | | 200 | 225 | 200 | 222 | 267 | | | 0 | 3 | 0 |
| b. Scotts Valley High School Preserve | 250 | 153 | 100 | 120 | 150 | 140 | 88 | | | 9 | 12 | 0 | 0 |
| TOTAL | | 1,612 | | | | | 604 | | | | 106 | 114 | 128 |

High School lands is now impacted by development and degraded by invasive plant species and accumulation of thatch.

The cessation of grazing (Polo Ranch, early 1990's; Salvation Army and Scotts Valley High School lands, 1970's) and fire suppression have likely contributed to the increasing presence of invasive plant species (and also rank natives such as coyote brush *Baccharis pilularis*) and accumulation of thatch. We suspect that grazing and fire previously benefited *P. hickmanii* by reducing the invasive plant species and thatch. The mechanisms by which the invasive plant species impact *P. hickmanii* are not known; however, they may inhibit germination and seedling survival (e.g., Thomson 2005), or compete for limited resources. Also, it seems likely that thatch from the tall invasive annual grasses will soon completely cover its microhabitat.

Hayes (1998) demonstrated that removing thatch can benefit some native plant species in the California prairie. After an absence of 5 y and the mechanical removal of thatch and associated topsoil (2.5 cm), 7,000 individuals of the threatened Santa Cruz tarplant *Holocarpha macradenia* (USFWS 2000b) emerged in the treated plot (232 m$^2$). Maron and Jefferies (2001) used mowing with biomass removal to reduce invasive grasses at a coastal California site. Hayes and Holl (2003) reported that grazing can benefit some native plant species in the California prairie while adversely affecting others. Kimball and Schiffman (2003) reported that grazing harmed native plant species and promoted the growth of invasive plant species in arid central California. Klinger et al. (2006) reported that fire can be used to help manage some invasive plant species in California, however, it can also assist the invasion of others.

Species with small populations are vulnerable to extinction by stochastic events (Ricklefs 2008), which include severe storms, freezes, harsh winters, fires and droughts (Mangel and Tier 1994). In 2013, *P. hickmanii* is a species with few individuals (128 plants in 2012), a small occupied area (61 m$^2$ in 2012) and a small geographic range (0.03 km$^2$). With these attributes, *P. hickmanii* is especially vulnerable to stochastic events. In addition, USFWS (2009) identified climate change as a new threat. Species with small geographic ranges are more vulnerable to changing climatic conditions (Loarie et al. 2008), in particular extreme weather events (e.g., severe storm, harsh winter, severe drought).

## Conclusions and Recommendations

*P. hickmanii* is one of 2,125 endemic plant species in the California Floristic Province. This bioregion is a "biodiversity hotspot" (Myers et al. 2000) because it has an exceptional concentration of endemic species that are experiencing an exceptional loss of habitat. In 2013 the primary threats to *P. hickmanii* are habitat alteration due to adjacent land uses and developments, and invasive plant species and accumulation of thatch. Although *P. hickmanii* is now listed as endangered under the U.S. Endangered Species Act (USFWS 2003) and California Endangered Species Act (California Fish and Game Commission 2005), these laws provide little protection against the threats in 2013. Using our information and international standards (IUCN 2011, 2012), *P. hickmanii* in 2013 meets the IUCN criteria for critically endangered. Over 15 y from 1998 (1,612 plants) to 2012 (128 plants), the species experienced a population reduction of 92%. The extent of occurrence is 0.03 km$^2$, and the area of occupancy was 61 m$^2$ in 2012. The area of occupancy and the quality of habitat are continuing to decline, along with the number of individuals. With these attributes, *P. hickmanii* faces an extremely high risk of extinction.

Intensive and adaptive management with monitoring will be necessary for *P. hickmanii* to survive. We recommend reducing and controlling invasive plant species and thatch using a combination of methods: mowing with biomass removal, cutting by hand tools with biomass removal, pulling by hand with biomass removal, prescribed grazing, prescribed mini-burns, and spot-treating invasive grasses with a grass-specific herbicide. Unless management is implemented as a matter of urgency, the species will likely disappear within just a few years. In addition, as a precaution for extinction in the wild, we recommend that a collection of seeds be made and deposited with the Center for Plant Conservation network.

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# Correction of Locality Records for the Endangered Arroyo Toad (*Anaxyrus californicus*) from the Desert Region of Southern California

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*Abstract.*—The recovery strategy for an endangered species requires accurate knowledge of its distribution and geographic range. Although the best available information is used when developing a recovery plan, uncertainty often remains in regard to a species actual geographic extent. The arroyo toad (*Anaxyrus californicus*) occurs almost exclusively in coastal drainages, from Monterey County, California, south into northwestern Baja California, Mexico. Through field reconnaissance and the study of preserved museum specimens we determined that the four reported populations of the arroyo toad from the Sonoran Desert region of Riverside, San Diego, and Imperial counties, California are in error. Two additional sites in the Sonoran Desert are discussed regarding the possibility that the arroyo toad occurs there. We recommend the continued scrutiny of arroyo toad records to maintain a high level of accuracy of its distribution and geographic extent.

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The arroyo toad (*Anaxyrus californicus*) is considered a habitat specialist that is restricted to drainage segments characterized by low gradient (ca. 2% slope) river beds, with substrate predominantly composed of sand, gravel, and cobble. The distribution of the arroyo toad includes drainages along the Coast Ranges from Monterey County, California, south to the Transverse Ranges and south along the Peninsular Ranges into northwestern Baja California, Mexico, from near sea level up to 2440 m (Stebbins 2003; Sweet and Sullivan 2005). The species geographic range is almost entirely within areas with a semi-arid Mediterranean climate except for a few disjunct populations that are located in the arid desert. As a result of a severe population decline throughout its range, the arroyo toad was listed as endangered by the U.S. Fish and Wildlife Service (USFWS) in 1994.

The geographic range of the arroyo toad had been determined by the use of locality records from museum specimens, published peer reviewed literature, unpublished studies, archived field notes, and/or input from experts (Grinnell and Camp 1917; Stebbins 1951; Price and Sullivan 1988; Sweet 1992; Jennings and Hayes 1994; Campbell et al. 1996; USFWS 1999b). The species account and accompanying locality map published by Jennings and Hayes (1994) included two previously recognized desert populations located

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Fig. 1. A red-spotted toad (*Anaxyrus punctatus*) photographed on 10 April 1992 in Whitewater Canyon. University of Kansas Herpetology collection (KU 10123).

in the Mojave Desert (e.g., Little Rock Creek and Mojave River), as well as four additional desert populations in the Sonoran Desert (e.g., Whitewater River, San Felipe Creek, Vallecito Creek and Pinto Canyon). Of the six desert locations, both records from the Mojave Desert are corroborated by field observations and preserved museum specimens. The four records from the Sonoran Desert are supported by museum specimens (e.g., San Felipe Creek, Vallecito Creek) or by photographic vouchers (e.g., Whitewater River), while an observation only record is reported from Pinto Canyon. Because the Sonoran Desert records represented localities that seemed uncharacteristic for the species, we conducted an investigation to verify the validity of these records.

## Methods

The USFWS Recovery Plan (1999b) for the arroyo toad provided supporting details of occupied areas (e.g., date reported, observer name(s), and institutions name and catalogue numbers of voucher specimens). To verify the identity of the preserved specimens, representing three of the four questionable populations, we requested loans from the following institutions: University of Kansas; Museum of Zoology, University of Michigan; Museum of Vertebrate Zoology, University of California. We provide photographs of all records supported by museum vouchers (figures 1, 2, 3). The three preserved tadpoles, representing the Vallecito Creek record, were examined and photographed using a digital microscope, Model QX3, Mattel + Intel, at 60 × magnification. Terminology and numerical representation for preserved tadpoles follows Altig (1970). The observer for the undocumented record from Pinto Canyon was interviewed. We also visited all four of the reported localities. The Pinto Canyon locality was surveyed once at night in March 2000, the Palm Spring locality was visited once during the day in May 2000, the Borrego Springs locality was surveyed once at night in

Fig. 2. A series of 18 whole specimen adult western toads (*Anaxyrus boreas*) collected on 25 July 1950 from Borrego Springs. University of Michigan Museum of Zoology (UMMZ 102332).

May 2001, and finally, the Whitewater Creek locality was surveyed on multiple dates in 2001 and 2003. We also include brief discussions of two additional sites that are relevant to the clarification of the range boundary at the coastal-desert interface. Names used for the four Sonoran Desert locations are from the USFWS Recovery Plan (1999b). Taxonomy follows Frost et al. (2008).

## Results

### *Whitewater River Basin / Whitewater River*

The Whitewater River record from Riverside County was first reported by Patten and Myers (1992). In an updated species account by Jennings and Hayes (1994), the Whitewater River population was included as one of six desert populations. Additional details of the Whitewater River record were provided in the USFWS Recovery Plan (1999b). Following the initial report of the Whitewater River record, conversations among regional biologists suggested that despite many independent visits to the area, no additional observations of the arroyo toad had been made. In 2001 and 2003, toad surveys conducted by the U.S. Geological Survey (Brown and Fisher 2002; Hitchcock et al. 2004), did not detect the species, although other anurans, such as the western toad (*Anaxyrus boreas*), red-spotted toad (*A. punctatus*), California treefrog (*Pseudacris cadaverina*), and Baja California treefrog (*P. hypochondriaca*) (previously the Pacific treefrog, *Pseudacris regilla*) were present. The initial report of the Whitewater River record included photo documentation (Patten and Myers 1992). Upon examination of the original photographs, we determined that the individual depicted was an adult red-spotted

Fig. 3. Mouth parts of a California treefrog (*Pseudacris cadaverina*) tadpole collected on 12 April 1954 from Palm Spring, Anza-Borrego Desert State Park. Museum of Vertebrate Zoology, University of California (MVZ 61061).

toad, not a juvenile arroyo toad (figure 1). Our determination was based on diagnostic characteristics such as the compressed body form, nearly round parotid glands and the nose shape as more pointed than blunt and rounded as it is in the arroyo toad. Based on our reevaluation of the photographic vouchers (KU 10123–10125), the record for the arroyo toad from the Whitewater River is considered in error. There is also no evidence for the occurrence of the arroyo toad from any other locations within the Coachella Valley, Riverside County. Based on recommendations by one of us (RNF), the U.S. Fish and Wildlife Service has reconsidered the critical habitat designation for the arroyo toad for the Whitewater River area, making the determination that the area does not meet the criteria for critical habitat for the species (USFWS 2011).

*San Felipe Creek Basin / Borrego Springs*

Jennings and Hayes (1994) reported the San Felipe Creek record from San Diego County in a list of six reported desert locations. Additional details on the San Felipe Creek population were provided in the USFWS Recovery Plan (1999b). This record is represented by a series of 18 preserved specimens in the Museum of Zoology, University of Michigan (UMMZ 102332). On 25 July 1950, during a visit to San Diego, W. Duellman and R. Porter collected a series of 18 adult toads from 'Country Club at Borrego', San Diego County (USFWS 1999b). At the time these toads were collected and accessioned into the UMMZ collection, there was considerable disagreement over the taxonomic relationships within the Americanus group of genus *Bufo* (*sensu lato*).

The specimens (UMMZ 102332) were originally deposited and cataloged as "arroyo toads", *Bufo californicus*, following the taxonomy of Myers (1930). The scientific name of these specimens in the collection was subsequently updated to *Bufo woodhousii* ssp. *californicus*, following the taxonomy of Linsdale (1940) and Shannon (1949) (G. Schneider, pers. comm.). We requested a loan of the series of 18 specimens. All specimens of lot UMMZ 102332 were re-identified as western toads, not arroyo toads (figure 2). This identification error is also supported by five decades of field surveys at this location by J. Copp, California Academy of Sciences, who has only observed western toads at this location (J. Copp, pers. comm.). Additionally, this locality was included in a study that examined an amphibian community within a desert environment and the only amphibian species detected at this site was the western toad (Warburton et al. 2004). Based on our reevaluation of the series of UMMZ specimens, the record for the arroyo toad at 'Country Club at Borrego' location is in error. There is no evidence that the species occurs within the San Felipe Creek watershed, San Diego County.

*Vallecito Creek Basin / Palm Spring*

The collection location of the single record within the Vallecito Creek Basin is Palm Spring, a freshwater oasis that occurs adjacent to the main dry wash of Vallecito Creek. The Vallecito Creek record was included on distribution maps in an unpublished report for the U.S. Forest Service, Los Padres National Forest (Sweet 1992) and by Jennings and Hayes (1994). Sweet (1992) based his record on a re-identification of three tadpoles (MVZ 61061) collected on 12 April 1954, by R.C. Stebbins from Palm Spring (Anza-Borrego Desert State Park), Vallecito Creek Basin, San Diego County that were originally identified as the canyon treefrog, *Hyla arenicolor* (now the California treefrog, *Pseudacris cadaverina*). Additional information for this record was provided in the USFWS Recovery Plan (1999b).

We examined R.C. Stebbins's original field notes and they corroborate his original identification as "*Hyla arenicolor*". It should be noted that during the tadpole phase both the California treefrog and arroyo toad can share a similar pattern and color scheme that closely resembles the sandy substrate of the pools they occupy (Ervin 2005; Sweet and Sullivan 2005). We used a digital microscope (QX3, Mattel + Intel) to view and photograph the morphological characteristics of the three preserved tadpoles. Because preserved tadpoles undergo some degree of integument deformation through time, which may alter eye position and or vent position relative to other features, and cause fading of color pattern and other markings, we used oral disc morphology to determine the identity of the tadpoles. We used illustrations in Storer (1925) and Gaudin (1964), and a color macrophotograph in Lemm (2006) as identification resources of mouth shape and labial tooth row pattern. Terminology and numerical representation in Altig (1970) were used to describe the tadpoles. The tadpoles, composing lot MVZ 61061, all had two rows of anterior labium, the second row had a median gap, three rows on the posterior labium, with the third row about ½ the length of the second, with sub-marginal papilla, and an oral disk lacking lateral emargination (indented). These characteristics are consistent with the mouth parts of the California treefrog shown in Storer (1925), Gaudin (1964), and Lemm (2006). Lateral emargination of the oral disc is lacking in the California treefrog (consistent with our findings) and is present in the arroyo toad (figure 3). Therefore, based on diagnostic mouthpart characteristics, the three tadpoles (MVZ 61061) cannot be attributed to North American Bufonidae (Lemm 2006; Altig and McDiarmid 1999), and are that of the California treefrog, which concurs with the original identification of R.C.

Stebbins. Based on our reevaluation of the tadpole specimens, the single record for the arroyo toad within the Vallecito Creek Basin is in error. There is no evidence that the arroyo toad occurs in the Vallecito Creek Basin, Palm Spring, San Diego County.

*Pinto Wash Basin / Pinto Canyon*

Jennings and Hayes (1994) reported the Pinto Wash basin record, located in Imperial County, and included it in a list of desert populations. The location and some additional information for this record were provided in the USFWS Recovery Plan (1999b). This record is based on the observation made in 1992 by M. Feldner who observed recently transformed toadlets in Pinto Canyon at the second palm oasis upstream from the mouth of the canyon. On 27 March 2000, eight years after the original observation had been made, J. Stephenson (USFWS) corresponded with M. Feldner, regarding his observation of toads in Pinto Canyon, and was able to obtain additional information regarding his observations; M. Feldner stated that the toads that he observed were most likely red-spotted toads (M. Feldner, in litt.). On 31 March 2000, one of us (ELE) and J. Stephenson, visited the Pinto Canyon location where the toadlets had been observed. Between 1948–2055 hrs (PST), 11 adult red-spotted toads were observed along a short stretch of the stream in quiet pools and another 32 adult toads in a series of pools near the "second palm oasis" (E. Ervin, unpub. field notes). Males were observed calling, although no amplexus was observed. California treefrogs were also present at both locations, but were not observed at the breeding pools. It was determined that this location did not support suitable habitat for the arroyo toad (described above); however the habitat was typical for the red-spotted toad (Sullivan 2005). The original observers did not document their observations by either photographs or collecting voucher specimens, which made it difficult to reevaluate what species of anuran was originally observed. Based on our evaluation of these circumstances, the report of arroyo toads in Pinto Canyon is considered in error. There is no evidence that the species occurs in Pinto Canyon, Imperial County, which concurs with the USFWS revised rule for critical habitat for the arroyo toad (USFWS 2011).

*Coyote Creek, San Diego County*

Although we are not aware of any validated reports of arroyo toads from Coyote Creek, Anza-Borrego Desert State Park, San Diego County, the riparian habitat is similar (e.g., low gradient channel, sandy substrate, and seasonal hydrology) to sites in coastal San Diego County, where the species is known to occur. We provide a brief discussion of the Coyote Creek survey results because they are relevant to the clarification of the range boundary of the arroyo toad at the coastal-desert interface. This location was part of a study that examined an amphibian community within a desert environment (Warburton et al. 2004). In 2000 and 2001 daytime habitat assessment and nighttime amphibian surveys were conducted in the Upper, Middle, and Lower Willows areas of Coyote Creek. Despite favorable environmental conditions during the surveys, no arroyo toads were observed. Other anuran species observed included, western toad, red-spotted toad, California treefrog, and Baja California treefrog (Warburton et al. 2004). Based on the results of the habitat assessment and nighttime surveys our conclusion is that the arroyo toad does not occur in this drainage.

*Banner Canyon, San Diego County*

While investigating historic arroyo toad localities from San Diego County, a previously unreported observation was discovered. On 1 June 1935, L.M. Klauber recorded in his field notes (http://archive.org/details/1935fieldnotesla00klau):

"At the foot of Banner Grade at 11:45 [pm]. Much colder here than on the desert. Lost a large snake at this point by not stopping quickly enough. I didn't see it at all but Cy did, and we found the track. Heard *Bufo californicus* trill at this point. Quite cold going up the grade."

However, based on preliminary assessments of the landscape, the area "at the foot of Banner Grade" is similar (e.g., low gradient channel, sandy substrate, seasonal hydrology and suitable upland habitat) to sites in coastal San Diego County, where the species is known to occur. There have been no subsequent reports or documentation of the arroyo toad from this locality (R. Fisher, pers. obs.).

## Discussion

Due to the endangered status of the arroyo toad, it is critical that proper validation be employed by anyone detecting the species in the wild. Contingent upon environmental conditions this species can be difficult to detect at night, with major differences in detection between nights and also across years at the same sites (Sweet 1992, 1993; Miller et al. 2012). The larval stage can be easier to detect than transformed stages, although they are useful only when breeding habitat is present, which is highly variable inter-annually (Miller et al. 2012). Since the tadpoles can be confused with other species validation should include high resolution photos *in situ*. Or in the case where the observer is permitted to do so, a tadpole should be collected and deposited into the collection of a regional natural history museum to represent the breeding arroyo toad population at that location on that date. Additional benefits of having the tadpole in a publicly accessible collection are that it would be available for future examination as well as for genetic investigations.

We also support the position that it is not enough to be a skilled and knowledgeable biologist to correctly identify an arroyo toad in the field; in most cases it requires an individual that has firsthand experience with and knowledge of the given life history stage at issue (adult, recently transformed toad, larvae, egg strings). Firsthand experience with and knowledge of the seasonal male advertisement call characteristics is also important so it can be distinguished with certainty from the other natural "trilling" sounds produced by sympatric or parapatric species (red-spotted toad, *Anaxyrus punctatus*; Lesser Nighthawk, *Chordeiles acutipennis*; and possibly insects).

Natural history museums are in the business of biodiversity science and archived voucher specimens constitute their foundation, allowing researchers the ability to reconstruct the past and make predictions regarding the future (Shaffer et al. 1998). These specimens document the identity, ecology, spatial distribution, and natural history of this biodiversity, and provide important material for addressing questions related to ecology and evolution (Duellman 1999; Krishtalka and Humphrey 2000; Suarez and Tsutsui 2004). Specifically, our results emphasize the critical and fundamental role that museum vouchers (e.g., adult and larval specimens, photographic images) and archived field notes serve. They enabled us to reexamine vouchered material that led to our conclusion that there never was evidence that the arroyo toad occurs within the Sonoran Desert.

## Conclusions

Herein we present evidence that the arroyo toad (*Anaxyrus californicus*) is not confirmed to occur within the Sonoran Desert portions of Riverside, San Diego, and Imperial counties, California. In the Mojave Desert, the species is currently known from two areas, Littlerock Creek, Los Angeles County and the Mojave River Watershed, San

Bernardino County. The validity of the Banner Canyon record reported here remains in question. This locality and other sites along the coastal Sonoran Desert ecotone that support the combination of characteristics of occupied habit elsewhere (coastal vegetation, low stream gradient, sandy substrate), where potential habitat loss may occur, can be addressed with USFWS arroyo toad protocol surveys (USFWS 1999a).

The information presented herein is important for the continued management and recovery of the endangered arroyo toad. Due to a reevaluation of the evidence supporting four previously recognized populations, there are no longer any valid records of the arroyo toad within the Sonoran Desert bioregion. Two of the four purported Sonoran Desert localities, previously included in critical habitat designation for the species (Whitewater Creek, Riverside County; Pinto Canyon, Imperial County), were not included in the revised critical habitat designation (USFWS 2011). It is suggested that all resource agencies and conservation groups with arroyo toad management programs can reflect the adjusted range boundary to no longer include the Sonoran Desert bioregion. This change reflects a more accurate delineation of the geographic range for the endangered arroyo toad in the area of the coastal-desert interface.

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# Distribution of the Coast Horned Lizard, *Phrynosoma coronatum*, in Southern California

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*Abstract.*—In order to access the endangered species status of any organism it is essential to know its past and present distribution. The Coast Lizard, *Phrynosoma coronatum,* was presumed to be threatened by habitat destruction due to human activities. I used historical literature and museum records to access past, and lizard survey teams to access current range and population numbers of *P. coronatum* in the five counties of Southern California between 1989–1991. The species occurs from sea level to 8,000′ (2348m) in a wide variety of habitats. Fieldwork and questionnaires increased by a third the number of locations (from 672 to 1148) where horned lizards are known to occur. There are (post 1985) records of the species throughout its range and from all habitats. The lizard occurred in about 75% of its original range, and of that, more than 50% is in public lands where the lizard is protected or could be protected by effective management and enforcement.

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The Coast Horned Lizard, *Phrynosoma coronatum* (CHL), occurs from the Sacramento Valley, southward to the tip of Baja California. There has been concern (Jennings, 1987; Fisher and Case, 2000; Fisher, et al., 2002: Lemm, 2006; McGurty, 1980) that increasing human populations and consequent habitat destruction may have caused a rapid decline in the populations of horned lizards in San Diego, Orange, Riverside, Los Angeles, and San Bernardino Counties. If a species is thought to be endangered, it is important to know the exact distribution of the species. This is fairly easy for larger animals, but is more difficult with cryptic species or species with long periods of inactivity such as, *Phrynosoma coronatum* (Brattstrom, 2001; Hager and Brattstrom, 1997).

The Coast Horned Lizard (CHL) is found in California coastal and inland regions from sea level to 8000 feet (2348m), hence from grasslands and Coastal Sage Scrub (CSS) vegetation to pine forest (Jennings, 1988). It is the only species of horned lizard within its range. It meets the Desert Horned Lizard, *P. platyrhinos* at the high desert edge north of the San Gabriel Mountains from Palmdale to Adelanto. The ranges of the two species apparently do not overlap as the CHL is restricted here to the Juniper-Desert Chaparral habitat and the Desert Horned Lizard is found mostly in creosote bush scrub vegetation. A similar close proximity may occur in the Little San Bernardino Mountains and in northwestern Joshua Tree National Monument. The CHL is separated in range and habitat from the other two California Horned Lizards, *P. mcallii* of the low desert and *P. douglassii* of the Modoc-Klamath plateau area (Sherbrook, 2003; Stebbins, 1985).

## Materials and Methods

A 2.5 (1989–91) year study on the Coast Horned Lizard, *Phrynosoma coronatum* (=CHL), was conducted in Orange, Riverside, San Diego, and San Bernardino Counties, California, hence within the range of what was formerly known as *P. c. blainvillii* (Brattstrom, 1997). Distributional data were collected from museum records, field surveys, questionnaires, and additional specific studies were done on three military bases: Miramar Naval Air Station, Fallbrook Naval Weapons Depot, and Camp Pendleton, San Diego County, California.

*Past Distribution: Museum, Literature and Database Search*

The distributional localities from museum records, the literature, and the California Department of Fish and Game (CDFG) California Natural Diversity Database (NDDB) were compiled. All major United States and local museum records were examined. A list of these institutions, and all locality records, can be found in Brattstrom (1993) and CDFG and US Navy Data Base Computer Files. The localities have been incorporated in a Geographic Information System (GIS). Records collected by Brian McGurty (to 1980) and Mark Jennings (to 1982) have been verified by either examination of specimens, checking the location or checked for presence of CHL by field teams. Corrections have been sent to museum curators. Dot locations were placed on Delorme maps for Southern California. Each map is based on four 7 ½″, USGS quad maps. Copies of the maps are in Brattstrom, (1993). A copy of which is in the San Diego Natural History Museum and maps are also available from the author.

*GIS Analysis*

GIS maps of vegetation, soils, past fires, and current land use were prepared using OSUMAP software. GIS maps, including the horned lizard locality map, were used to estimate percent of horned lizard localities remaining or associated with land use, fire, land ownership, vegetation, and history. Locality data for lizards on the military bases was put directly into the U.S. Navy Environmental Data GIS system by Tierra Data Inc. where other ecological data was stored.

*Questionnaires*

The present distribution and current status of the lizards were also determined by a survey questionnaire. The survey was sent to local professional and amateur herpetologists and herpetological clubs. A list of these people is provided in Brattstrom (1993). In addition, the San Diego Herpetological Society and Southwestern Herpetological Society reprinted the questionnaire in their respective newsletters. A total of 115 surveys were sent out and 50 surveys (or 43%) were returned. Of those returned, 33 or 29% had information on horned lizards.

## Results

*Distribution Past and Present*

The range of *Phrynosoma coronatum* in California and Baja California is shown in Jennings (1988) and that for the former *P. c. blainvillii* in Southern California (Figure 1). The range of the species is described by Jennings (1988) as: West of the Sierra Nevada crest from Kennett (now under Shasta Reservoir), Shasta County, California, south throughout all of Southern California (west of the Mojave Desert) and the Baja California peninsula at elevations from near sea level to over 1,830 m. A disjunct population occurs at Grasshopper Flat, near Medicine Lake, Siskiyou County, California. Attempted introductions into Yosemite Valley, San Clemente Island, Hawaii, Colombia, and Guatemala have failed (Jennings, 1988). Horned lizards were first collected in Southern California in 1880 in San Bernardino County, in 1884 in Los Angeles County (a collection record of 1863 cannot be confirmed), 1893 and 1907 for

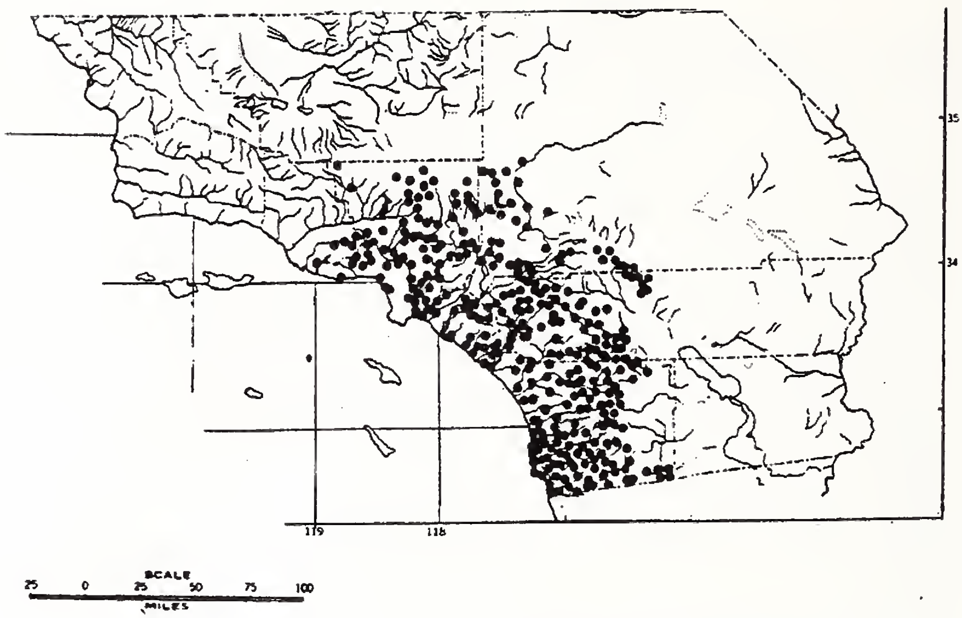


Fig. 1. Map of Southern California showing all known localities for *Phrynosoma coronatum*.

Riverside and Orange Counties respectively (Jennings, 1988). Table 1 presents a summary of the numbers of localities in Southern California where *P. coronatum* has been found. This table includes historical, museum, and literature records found during this study. The table does not include 1147 records of localities for Baja California, Mexico, nor about an equal number of localities known from Central and Northern California. This study almost doubled the knowledge of the number of localities known for this horned lizard from 672 records to 1148. Most of these additional records were post-1985 records. These Southern California records are plotted in Figure 1. The post 1985 records indicate that records of viable or, at least, reproducing populations (many were records of young) occur through the range of the horned lizard and include recent records in habitat islands surrounded by houses and industry. All locality records for Southern California have been sent to the CDFG NDDB, though not yet (as of 2013) entered into their database (Brattstrom, 1993). Locality records have been entered into the databases of: the Bureau of Land Management (BLM), several counties, agencies, environmental companies, and the U.S. Navy and Marine Corps databases. Localities from the three military bases are only listed by the name of the base. Detailed locations of lizards on each base are found in US Navy Data Bases. Detailed location maps (Dot maps on Delorme, 4 USGS 7 ½″ quads/ page) are presented in Brattstrom, (1993), a copy of which is in the herpetological collection of the San Diego Natural History Museum, lists and maps are also available from the author. After this paper is published, all databases, locality, and museum records will be placed in the herpetology section of the Los Angeles County Museum of Natural History. The species occurs from sea level to 8,000 feet (2348m) at Tahquitz Meadow in the San Jacinto Mountains, Riverside County, though 55% of all locations are below 2,000 feet (610m), 81% below 4,000 feet (1220m), and 99% are below 7,000 feet (2135m) in elevation.

Table 1. Total known localities for *Phrynosoma coronatum* for each of the Southern California Counties*.

| County: | Riverside | San Diego | Orange | San Bernardino | Los Angeles | Total |
|---|---|---|---|---|---|---|
| Historical Locations:** | 168 | 177 | 6 | 113 | 208 | 672 |
| Recent and Additional Locations:*** | 105 | 137 | 46 | 66 | 122 | 476 |
| Totals: | 273 | 314 | 52 | 179 | 330 | 1148 |

* Does not include known localities north of Los Angeles County, or 1147 localities in Baja California, Mexico.

** From museum records and the literature. These are pre-1985 records.

*** From questionnaires, CDFG NDDB, correspondence, field work, and field surveys. Most of these are post-1985 records.

Post-1985 records, study plot data, and field observations made during this study have found the horned lizard throughout its known range in Southern California. Thus, while the lizard does not occur within central urban areas, there are recent records of reproducing populations (based on presence of young) within and around cities. For example, while the species is absent from central portions of the City of San Diego, it does occur in pockets within that city (e.g., Point Loma), and in environs north, east, and south of the city (Torrey Pines State Park, NAS Miramar, Border Field State Park, north, south and east of El Cajon, south of Lemon Grove, and Otay Mesa; see maps in Brattstrom, 1993).

Horned lizard distribution seems to imply that the horned lizard is extirpated from much of its former range (fide: McGurty, 1980). The San Diego example just mentioned suggests that this in part is due to a matter of scale. An example from the broad Los Angeles-Orange County Basin illustrates the problem. The Los Angeles-Orange County Basin was greatly altered through grazing and agriculture for the first three centuries of European history in the state; long before the first historical records (1884) of horned lizards in the area. Historical records in this basin (Figure 1) are from Malibu to the Manhattan Beach coastal strip, and along the Arroyo Seco, Los Angeles, Santa Ana, and San Gabriel Rivers. The species was historically absent from other locations in the basin, except for in sandy river and stream areas draining into these rivers or in isolated hills. There are no known historical or recent records, from the Palos Verdes area. Four students did projects in the Palos Verdes Peninsula in 1950 and 1954 as part of a herpetology course that I taught at UCLA. No horned lizards were found on the peninsula in any of the studies. The horned lizard did occur in the Central Los Angeles Basin in the Late Pleistocene time in the La Brea Tar Pits, but even that record was along a stream (Brattstrom, 1953). This means that, either the horned lizard never occurred in the Los Angeles-Orange County Basin, except along sandy coastal areas and along major rivers; or, if it did occur in the basin, it was eliminated by human activities prior to the first historical records. The horned lizard's apparent absence from much of the basin today therefore, cannot be ascribed to the recent impact of urbanization. Reproducing populations still occur today in undeveloped areas along the San Gabriel River and in the northern part of the drainage of the Los Angeles River. Much of the urbanization in Orange County over the past 50 years (described by Brattstrom, 1988), while spectacular, has eliminated, probably, less than 10% of the historical range of the species in the county. This is due to the fact that historically at least, the horned lizard did not occur in most of Orange County that is now urbanized. The species still occurs in more than 60% of the Orange County, or 90% of its known historical range in the county.

*Details of Distribution*

The following describes the distribution of *P. coronatum* for the southern five counties in more detail, and points out some of the more interesting aspects of its distribution.

*Los Angeles County.*—The species occurs from the Ventura County line south and east throughout the County. As just described, there are no records for the Los Angeles Basin, except along the coastal strip below Santa Monica (to Manhattan Beach) and along the major rivers and tributaries that pass through the Basin. The species is absent from the high cold regions of Los Padres and Angeles National Forests, but this absence may be due as much to fire history and rugged terrain (which may restrict horned lizards and/or collectors) as it could be too cold, since the species does occur just east of Gorman. There are no records along the Ridge Route, (i.e. along and especially just east of I-5). The species extends out into the desert, in pinyon-juniper and/or desert chaparral areas (occasionally associated with Joshua Trees). Records for Elizabeth Lake, Palmdale, Little Rock, Phelan, Adelanto, and Hesperia occurred in areas of coastal scrub and chaparral, not creosote vegetation. The habitat for the records north of Palmdale and north of Lancaster is now urban and agricultural, but coastal vegetation did extend in fingers on low ridges out past Palmdale in the 1950's (personal observations). The record for Adelanto was accurately located in L. M. Klauber's field notes. Subsequently, the site was located and visited during this study. The record is just within (by 300 meters) desert chaparral vegetation. Even though much of this vegetation was burned and re-burned in a series of recent fires, stumps and stump sprouts of *Quercus dumosa*, *Ceanothus*, and *Juniperus* were verified in the field. The record for Oro Grande north of Victorville is either an invalid record for the species, or more likely, another example of a San Bernardino Mountain species (such as the pond turtle, *Clemmys marmorata* and the western toad, *Bufo Boreas*) that had been carried accidentally to the Victorville area (where water and lush riparian vegetation occur) by one of many floods of the Mojave River. The record could even have reflected a former finger-like projection of the species along the river. The Coast Horned Lizard occurs throughout the Santa Monica and San Gabriel Mountains.

*San Bernardino County.*—The horned lizard occurs associated with the sandy areas of the flood plains of major rivers and in the foothills and the mountains of the Los Angeles Basin through San Bernardino, Redlands, Beaumont, and Banning, to the desert edge within coastal chaparral or coastal sage scrub vegetation, just south of Cabazon. The species appears to be absent from the northeast San Bernardino Mountains (Big Bear Lake, Baldwin Lake) and from the higher elevations in the south part of these mountains.

The species occurs in the central and eastern San Bernardino Mountains and eastward in pinyon-juniper, desert chaparral, and occasionally Joshua Trees (*Yucca brevifolia*), through the Morongo Valley and the Little San Bernardino Mountains within Joshua Tree National Monument. It does not occur in Creosote Scrub Desert or in classical Joshua Tree Woodlands or at lower elevations. It does not occur east of Yucca Valley, and the records for the Yucca Valley region are all from higher slopes.

*Orange County.*—There are only a few historical records for Orange County. Most of those were from along the reaches and flood plain of the Santa Ana River. Old records from Garden Grove and Anaheim may have been collected from anywhere in the cities, but more than likely, they were collected from one of the open areas along any one of many stream channels draining the nearby Chino and Puente Hills. A few old historical records in coastal Orange County have now been enhanced with recent (post-1985) records along the coast, the Laguna Hills, and the San Joaquin Hills. Most of the other records come from the foothill area of the county and locations in the Cleveland National Forest. Many recent records come from northeast and southeast of San Juan Capistrano as part of biological surveys for possible future development and a proposed Transportation Corridor.

*Riverside County*.—Horned lizard records are found throughout western Riverside County. They are absent from the Temecula area, but are common near Lake Elsinore. This may be because of more than a century of overgrazing by sheep and cattle in the Temecula area. CHL records are common for the Perris Basin and the San Jacinto River drainage system. Records also occur in the San Jacinto Mountain region with the highest elevation record, 8,000 feet (2348m), coming from this mountain range. Other species of reptiles, *Crotalus viridis*, also have their highest elevation records in the San Jacinto Mountains. Many of the locality records for the horned lizard in Riverside County occur in National Forest, Wildlife Reserves, or other public and private conservation areas.

*San Diego County*.—Except within city centers the lizard occurs almost everywhere in San Diego County except in the low desert and high rugged mountains. It is found in the Palomar Foothills, Lake Henshaw area, and the Cuyamaca and Laguna Mountain high plateau (See Fisher, et al., 2002). Many of the locality records are on public lands.

The species extends toward the desert, though in desert chaparral, in broad open valleys, such as south of Warner's Springs and towards Scissors Crossing. Elsewhere, as at the eastern edge of the Laguna Mountains and east of Jacumba, the species stops its easternmost distribution atop the abrupt high plateau. The descent to the desert in these places, as it is on the east side of the San Jacinto and Santa Rosa Mountains in Riverside County, is notably abrupt (a 3,000+-foot drop in about 5 miles (915m in 8km), and the slopes are covered with large granite boulders or consist of steep decomposed granite talus. This topography may restrict the horned lizard and/or collectors as no records of the lizard occur in this area.

*Interesting or Erroneous Records*.—In placing localities on maps, the difficulty of where to actually place a dot becomes a problem. Where does one place a locality record for "San Diego" collected in 1890? In the city center? Balboa Park? By practice, such records are placed in the center of the city. Some old records for San Diego and Riverside County have had their name changed, because, what was once an outlying village is now within the city. Fortunately, old maps provide the solutions to many of these problems. It was, however, impossible to find "El Nido" until informed by Mark Jennings (pers. comm.) that the location is now located under lower Otay Lake. It was originally an important stage stop on the road from San Diego to Dulzura. It was flooded out at the turn of the century by the original dam on Otay River when waters reached the dam on January 27, 1916, during the major floods of that year. Many of John Van Denburgh's (a former herpetologist at the California Academy of Sciences) collecting localities were obscure, and detective work by Jennings and Brattstrom have found some of these localities. While again searching through the California Academy of Sciences files, Jennings found a box labeled "maps showing routes traveled by John Van Denburgh in California". Unfortunately, they do not indicate the location of two San Diego localities that have plagued horned lizard map plotters for years: Clogston's Valley and Gulion.

Based on other Van Denburgh records, the locations are probably in southern San Diego County along, or south of, what is now Interstate 8.

A specimen from LACM is recorded as coming from 30 miles east of 29 Palms. I have checked the specimen, and it is a *P. coronatum* and not the expected *P. platyrhinos*. Either the locality is wrong or the specimen is mislabeled, because *P. coronatum* does not occur within 60 miles of this site. A specimen from LACM labeled "Baker, Los Angeles County" has to be totally in error. The latitude and longitude data indicate that the location is for "Baker, San Bernardino County". That town is along I-15 in the Mojave Desert, more than 100 miles from the nearest other *P. coronatum* location. It is a town where travelers stop, and the specimen may have been a pet accidentally dropped. In any event, the locality is in error and is eliminated from all lists. Since the species was common in the pet trade (Jennings, 1987), such records are to be expected. There is even a 1934 record for the species for the State of Montana (Missoula, MT; Harbaugh, 1935), which is clearly a record based on the accidental dispersal of a pet!

Another peculiar record is that for "6 mi. N. Bush, San Bernardino County" (SDSMH-LMK 39903). This specimen presumably collected by L. M. Klauber in 1949, has been verified by me as being a *P. coronatum*. It is, however, far outside its range. It is east of 29 Palms and in Creosote Bush Scrub. Klauber's diaries are in the library of the Natural History Museum in San Diego. He kept excellent records and wrote in his diary almost every day of his life. On this trip in 1949, he recorded collecting a *P. platyrhinos* 10 miles east of 29 Palms, a Patch-nosed Snake 17 miles east, and both Whiptails and Desert Iguanas 19 miles east of 29 Palms. From this last locality on the road, ascends a hill and it is here that the *P. coronatum* was supposed to have been collected. Yet he recorded for June 4, 1949, at 6 mi. N Bush, "1 Whiptail shot on road, and rocky desert with scattered brush". Later, at 8 mi. north of Bush, at the base of the Sheep Hole Mountains, he recorded taking 2 *Xantusia vigilis* under *Yucca*. The next record in the diary is for Amboy Crater where he caught a *P. platyrhinos* 19 mi. S. of the town of Amboy. He pickled the specimen in Ludlow. His records indicate no locations for *P. coronatum* in this area. On the same trip, he did catch a *P. coronatum* at 10 mi. S. Adelanto (#40003). All other specimens from the trip are numbered and preserved in the order that he collected them, except the *P. coronatum*, erroneously given the locality of 6 mi. N. Bush presumably by some cataloger. This locality is therefore considered to be an error.

## Discussion

The best way to preserve or protect a species is to protect its habitat. The habitat for an animal is a resource for food, water, shelter (from heat and cold as well as shelter from predators), and for lizards a habitat must provide heat, basking sites, egg-laying sites, the opposite sex, and enough space to carry out normal behavior (Brattstrom, 1994). Extinction rates are greater on small habitat "islands" (Soule, et al., 1988; Crooks, et al., 2001). A general rule of habitat conservation is that it is better to protect habitat in a few large islands rather than many small islands (Shafer, 1991). It is also true that islands are smaller for some species, such as the California Gnatcatcher which needs 20 acres (49ha)/pair (Atwood, 1992) than they are for horned Lizards where a single acre may contain 3–20 horned lizards (7–48 ha), or more; (Gerson, 2011; Jennings, 1987; Hager, 1992; McGurty, personal communications). It is further wise to try to protect as many species as possible in a given area (Multispecies Habitat Conservation) than face the management problems associated with protecting a single target species.

Predation on CHL by people for pets is now minimal and while CHLs are eaten by many predators (often with difficulty), their inactivity and crypsis (Sherbrooke, 2003, 2008; Brattstrom, 1996) makes predation a minimal threat. The exception occurs in the urban/wildlands interface where domestic cats, *Felis catus,* prey on horned lizards (Fisher and Case, 2000; Fisher, et al. 2002). While this study was done over 20 years ago, and in spite of housing developments, there has been no major or significant change in Southern California in the intervening years that affect distribution. The exception is the actual impact of introduced Argentine Ants, *Linepithema humile* (Bolger, 2002: Foster, et al. 2007; Holway, 1999; Menke et al. 2009; Pitt, et al. 2009 and Suarez, et al. 1998). CHLs still live in city island habitats (parks, rivers) and at the urban/wild land interface. It is here, especially associated with moist soil, that the impact of introduced Argentine Ants, *Linepitheme humile*, may be severe (Fisher, et al. 2002; Suarez, et al. 2000). CHLs do not eat these ants and the ants reduce the populations of native ants, which CHLs do eat (Bolger, 2002; Holway, 1999; Suarez, et al., 1998). The sympatric Western Fence Lizard, *Sceloporus occidentalis* actually eats Argentine Ants (Foster, et al. 2007). Argentine Ants also probably eat CHLs. Argentine Ants will continue to be a problem for CHL, but CHL occur in many habitats and areas where Argentine Ants do not occur. The ants occur in moist soil areas where CHLs do not occur now or ever did occur (Menke, et al. 2009; Miltrovich, et al. 2010). Because soil moisture is critical to Argentine Ant survival, the urban/wild lands interface will be the most impacted area. Much of the rest of the range of the Horned Lizard will not be impacted.

It is recommended that land managers of forests, parks, and reserves should try to assure that horned lizard and harvest ant habitats are undisturbed.

## Conclusions

1. The original range of the horned lizard was throughout Southern California but with no historical or recent records from the Los Angeles-Orange county basin and the Pomona, Ontario, San Bernardino area except along river flood plains and isolated hills. There are no historical or recent records or the area about Temecula.
2. The horned lizard occurs in the coastal and inland physiographic provinces and in the extension of the latter into the Little San Bernardino Mountains to Joshua Tree National Park.
3. The horned lizard localities occur in habitats including some urban habitats.
4. The horned lizard localities occur in areas with and without past fires, through survey data from this study how that more horned lizards were found in unburned areas (see Matsuda, et al., 2011: Rochester, et al. 2010).
5. The horned lizard localities show that the lizard never occurred in many areas that are now urban and suburban except along river flood plains (where it still occurs in patches). Pockets of horned lizards do occur in suburban areas as well, but are not discriminated in the GIS program. The locality data and GIS analysis show that about 25% of the total original range and habitat of the horned lizard in now occupied by development. The lizard occurs in 75% of its range, and 50% of these localities occur in National Monuments and Parks, National Forests, State Parks and other public lands and reserves. The remaining 50% of CHL range occurs on private lands. It is recommended that land managers of forests, parks, and reserves should try to assure that horned lizard and harvest ant habitats are undisturbed.

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# Morphometric Relationships of Marine Fishes Common to Central California and the Southern California Bight

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Length-weight relationships have several applications in fish stock assessments and ecological studies (e.g., Ricker 1975, Newman et al. 2006). Particularly, they are important for visual surveys of fish populations where the estimated total lengths are converted to weights to estimate fish biomass (e.g., Hamilton et al. 2010, Sala et al. 2012). The available information on length-weight relationships and length-length conversions for marine fishes in California are mostly limited to commercial catch (RecFIN 2009) or the occasional ecological survey (Miller et al. 2008), and a recent compilation of these parameters (Cailliet et al. 2000) demonstrated many species are lacking this basic information. Fishes used in this study were collected in various large- and small-scale projects by the Vantuna Research Group, Occidental College and California State University Northridge from 1984 to 2012. These included state-mandated programs dedicated to assessing the biological and economic impacts of its stocking efforts (ORHEP) and localized fisheries surveys (San Diego and Morro Bay) where a variety of species were caught. Measurements of lengths and weights provide the opportunity to generate information on morphometric relationships that will be useful to other researchers. Here we provide standard length (SL) to total length (TL) conversions (Table 1) for 32 near-shore marine fish species (Class Actinopterygii) and length-weight equation parameters (Table 2) for 71 near-shore marine fish species (57 from Class Actinopterygii and 14 from Subclass Elasmobranchii), common to central and southern California (Miller and Lea 1972).

Fishes were collected by several methods. (*White Seabass Gill Net Survey*) Collections using monofilament gill nets were made at 19 stations dispersed throughout the Southern California Bight from 1995–2005 in shallow (5–14 m) depths at the edge of rocky reefs as part of the Nearshore Gill Net Sampling Program for White Seabass (Age I-IV). For detailed methods see Pondella and Allen (2000). (*San Diego Bay Fisheries Inventory and Utilization Surveys*) Fish assemblages in San Diego Bay were assessed using a variety of methods (large seine, small seine, square enclosure, purse seine, beam trawl and otter trawl) (Allen et al. 2002). The bay is divided into four unique ecoregions that were sampled in April and July of 2005, 2008 and 2012, and by purse seine and square enclosure only in June 2009. (*Morro Bay Fish Survey*) Fish populations were surveyed in Morro Bay using methods similar to the San Diego Bay Fisheries Inventory and

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Table 1. Standard length (SL; in mm) to total length (TL; in mm) conversion parameters (see main text for equation description), sample size (N) and length characteristics of the sampled population for 32 fish species (Class Actinopterygii) common to southern and central California.

| | | *length characteristics* | | | *parameters of the relationship* | | |
|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Clupeiformes | | | | | | | |
| Engraulidae - anchovies | | | | | | | |
| *Anchoa compressa* (Girard, 1858) | b | 63 | 45 | 114 | 7.22 | 1.16 | 0.95 |
| *Anchoa delicatissima* (Girard, 1854) | b | 633 | 19 | 67 | 2.42 | 1.16 | 0.91 |
| Aulopiformes | | | | | | | |
| Synodontidae - lizardfishes | | | | | | | |
| *Synodus lucioceps* (Ayers, 1955) | abc | 20 | 68 | 193 | −1.66 | 1.15 | 0.99 |
| Batrachoidiformes | | | | | | | |
| Batrachoididae - toadfishes | | | | | | | |
| *Porichthys myriaster* Hubbs & Schultz, 1939 | ab | 23 | 16 | 327 | −0.44 | 1.16 | 0.99 |
| Atheriniformes | | | | | | | |
| Atherinopsidae - New World silversides | | | | | | | |
| *Atherinops affinis* (Ayers, 1860) | abc | 1745 | 11 | 193 | −0.02 | 1.19 | > 0.99 |
| *Atherinopsis californiensis* (Girard, 1854) | abc | 11 | 31 | 282 | −2.33 | 1.22 | > 0.99 |
| *Leuresthes tenuis* (Ayers, 1860) | bc | 16 | 62 | 166 | 1.36 | 1.15 | 0.99 |
| Beloniformes | | | | | | | |
| Hemiramphidae - halfbeaks | | | | | | | |
| *Hyporhamphus rosae* (Jordan & Gilbert, 1880) | b | 14 | 24 | 127 | −0.17 | 1.13 | 0.99 |
| Belonidae - needlefishes | | | | | | | |
| *Strongylura exilis* (Girard, 1854) | ab | 3 | 51 | 337 | 1.22 | 1.08 | > 0.99 |
| Cyprinodontiformes | | | | | | | |
| Fundulidae - topminnows | | | | | | | |
| *Fundulus parvipinnis* Girard, 1854 | bc | 195 | 14 | 78 | 1.91 | 1.11 | 0.99 |
| Gasterosteiformes | | | | | | | |
| Syngnathidae - pipefishes | | | | | | | |
| *Syngnathus leptorhynchus* Girard, 1854 | bc | 799 | 33 | 248 | 1.20 | 1.02 | > 0.99 |
| Scorpaeniformes | | | | | | | |
| Scorpaenidae - scorpionfishes | | | | | | | |
| *Scorpaena guttata* Girard, 1854 | abd | 3 | 85 | 230 | 1.15 | 1.23 | > 0.99 |
| Cottidae - sculpins | | | | | | | |
| *Leptocottus armatus* Girard, 1854 | abc | 763 | 11 | 119 | 0.63 | 1.16 | 0.99 |
| Perciformes | | | | | | | |
| Polyprionidae – wreckfishes | | | | | | | |
| *Stereolepis gigas* Ayers, 1859 | ag | 35 | 336 | 1450 | −10.87 | 1.21 | 0.99 |
| Serranidae – sea basses | | | | | | | |
| *Paralabrax clathratus* (Girard, 1854) | abcd | 76 | 19 | 165 | 1.31 | 1.19 | 0.99 |
| *Paralabrax maculatofasciatus* (Steindachner, 1868) | abd | 348 | 32 | 306 | 1.71 | 1.22 | 0.99 |
| *Paralabrax nebulifer* (Girard, 1854) | abd | 154 | 43 | 180 | 4.77 | 1.15 | 0.98 |
| Haemulidae - grunts | | | | | | | |
| *Anisotremus davidsonii* (Steindachner, 1876) | abde | 623 | 20 | 328 | 5.78 | 1.23 | 0.99 |
| Sciaenidae – drums and croakers | | | | | | | |
| *Atractoscion nobilis* (Ayers, 1860) | abf | 6513 | 71 | 1220 | 11.29 | 1.15 | 0.99 |

Table 1. Continued.

| | | length characteristics | | | parameters of the relationship | | |
|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| *Cheilotrema saturnum* (Girard, 1858) | ab | 6 | 35 | 178 | 1.40 | 1.19 | > 0.99 |
| *Roncador stearnsii* (Steindachner, 1876) | abe | 493 | 138 | 542 | 11.85 | 1.20 | 0.99 |
| Embiotocidae – sea perches | | | | | | | |
| *Cymatogaster aggregata* Gibbons, 1854 | abc | 828 | 26 | 112 | 1.83 | 1.24 | 0.98 |
| *Micrometrus minimus* (Gibbons, 1854) | abc | 43 | 21 | 113 | 3.35 | 1.19 | 0.99 |
| Blenniidae – combtooth blennies | | | | | | | |
| *Hypsoblennius gentilis* (Girard, 1854) | bcd | 20 | 44 | 109 | 3.99 | 1.15 | 0.99 |
| Clinidae – kelp blennies | | | | | | | |
| *Gibbonsia elegans* (Cooper, 1864) | bd | 10 | 23 | 106 | −0.37 | 1.15 | > 0.99 |
| *Heterostichus rostratus* Girard, 1854 | abcd | 329 | 23 | 315 | 1.23 | 1.13 | > 0.99 |
| Gobiidae - gobies | | | | | | | |
| *Clevelandia ios* (Jordan & Gilbert, 1882) | bc | 310 | 10 | 56 | 0.37 | 1.16 | 0.99 |
| *Quietula y-cauda* (Jenkins & Evermann, 1889) | bc | 64 | 22 | 64 | 1.17 | 1.16 | 0.97 |
| Pleuronectiformes | | | | | | | |
| Paralichthyidae – sand flounders | | | | | | | |
| *Citharichthys stigmaeus* Jordan & Gilbert, 1882 | abc | 263 | 22 | 101 | 0.65 | 1.17 | 0.99 |
| *Paralichthys californicus* (Ayers, 1859) | abc | 62 | 57 | 430 | 8.26 | 1.16 | 0.98 |
| Pleuronectidae – right-eyed flounders | | | | | | | |
| *Pleuronicthys guttulatus* Girard, 1854 | abc | 48 | 17 | 204 | 2.31 | 1.21 | > 0.99 |
| *Pleuronichthys ritteri* Starks & Morris, 1907 | abd | 24 | 78 | 156 | 0.17 | 1.25 | 0.97 |
| Cynoglossidae - tonguefishes | | | | | | | |
| *Symphurus atricaudus* (Jordan & Gilbert, 1880) | ab | 18 | 64 | 138 | −0.88 | 1.08 | > 0.99 |

a, White Seabass Gill Net Survey; b, San Diego Bay Fisheries Inventory and Utilization Survey; c, Morro Bay Fish Survey; d, Cryptic reef fish collections from King Harbor and Agua Hedionda; e, Heat Treatments from Encina Generating Station, Cabrillo Power Plant, and Huntington Beach Generation Station; f,Opportunistic non-scientific hook and line and spear catches; g, Data provided by Michael Domeier

Utilization Surveys in April, August and November of 2005–2007 and in May of 2008. (*Cryptic reef fish collections from King Harbor, Redondo Beach and Agua Hedionda, San Diego*) Collections of cryptic benthic fishes in King Harbor, Redondo Beach have been made periodically (1–12 times per year) since 1984 by divers using anesthetic and air lifts (Stephens et al. 1994). A similar collection was made from Agua Hedionda Lagoon in 2005. (*Heat Treat and Impingement Surveys*) Samples were also collected during heat treatments in 2005 at Encina Generating Station, Cabrillo Power Plant, and Huntington Beach Generating Station. For detailed methods see Pondella et al. (2008). Some white seabass (*Atractoscion nobilis*) specimens were also collected opportunistically by hook and line or spear. Additionally, data for giant sea bass (*Stereolepis gigas*) collected by hook and line was included (Michael Domeier, pers. comm.). While fishes caught during some of these studies were batch weighed by species, all individuals used here were measured individually: TL and/or SL or disc width (DW) were typically recorded to the nearest millimeter (mm) or occasionally centimeter (cm) and weight was recorded to the

Table 2. Length and weight parameters, sample size (N), input length type, and length characteristics of the sample for 14 cartilaginous fish species (Subclass Elasmobranchii) and 57 ray-finned fish species (Class Actinopterygii) common to southern and central California.

| | | | *length characteristics* | | | *parameters of the relationship* | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Heterodontiformes | | | | | | | | |
| Heterodontidae - bullhead sharks | | | | | | | | |
| *Heterodontus francisci* (Girard, 1855) | ab | 651 | TL | 170 | 870 | 1.18E-05 | 2.94 | 0.98 |
| Lamniformes | | | | | | | | |
| Alopiidae - thresher sharks | | | | | | | | |
| *Alopias vulpinus* (Bonnaterre, 1788) | a | 16 | TL | 870 | 2560 | 3.11E-04 | 2.36 | 0.90 |
| Carcharhiniformes | | | | | | | | |
| Scyliorhinidae - cat sharks | | | | | | | | |
| *Cephaloscyllium ventriosum* (Garman, 1880) | a | 307 | TL | 335 | 950 | 3.00E-06 | 3.13 | 0.92 |
| Triakidae - hound sharks | | | | | | | | |
| *Galeorhinus galeus* (Linnaeus, 1758) | a | 102 | TL | 250 | 1900 | 7.78E-06 | 2.93 | 0.95 |
| *Mustelus californicus* Gill, 1864 | ab | 441 | TL | 345 | 1200 | 7.27E-07 | 3.22 | 0.95 |
| *Mustelus henlei* (Gill, 1863) | a | 387 | TL | 340 | 1100 | 8.07E-07 | 3.21 | 0.95 |
| *Triakis semifasciata* Girard, 1855 | a | 736 | TL | 160 | 1545 | 5.95E-06 | 2.95 | 0.97 |
| Hexanchiformes | | | | | | | | |
| Hexanchidae - cow sharks | | | | | | | | |
| *Notorynchus cepedianus* (Bonnaterre, 1788) | a | 30 | TL | 1185 | 1900 | 8.61E-07 | 3.22 | 0.88 |
| Squaliformes | | | | | | | | |
| Squalidae - dogfish sharks | | | | | | | | |
| *Squalus acanthias* Linnaeus, 1758 | a | 191 | TL | 320 | 1200 | 8.29E-08 | 3.57 | 0.94 |
| Squatiniformes | | | | | | | | |
| Squatinidae - angel sharks | | | | | | | | |
| *Squatina californica* Ayers, 1859 | ab | 206 | TL | 320 | 1200 | 7.81E-06 | 3.02 | 0.94 |

Table 2. Continued.

| | | | *length characteristics* | | | *parameters of the relationship* | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Rajiformes | | | | | | | | |
| Rhinobatidae – guitarfishes | | | | | | | | |
| *Rhinobatos productus* Ayres, 1854 | ab | 111 | TL | 225 | 1340 | 3.43E-06 | 3.01 | 0.95 |
| Myliobatiformes | | | | | | | | |
| Urotrygonidae - American round stingrays | | | | | | | | |
| *Urobatis halleri* (Cooper, 1863) | abc | 556 | DW | 74 | 275 | 5.73E-05 | 3.02 | 0.96 |
| Gymnuridae - butterfly rays | | | | | | | | |
| *Gymnura marmorata* (Cooper, 1864) | ab | 26 | DW | 250 | 1010 | 2.74E-06 | 3.20 | 0.98 |
| Myliobatidae - eagle rays and mantas | | | | | | | | |
| *Myliobatis californica* Gill, 1865 | abc | 270 | DW | 180 | 1000 | 2.32E-05 | 2.94 | 0.95 |
| Albuliformes | | | | | | | | |
| Albulidae - bonefishes | | | | | | | | |
| *Albula gilberti* Pfeiler & Van der Heiden, 2011 | ab | 42 | SL | 55 | 360 | 2.05E-07 | 3.77 | 0.98 |
| Clupeiformes | | | | | | | | |
| Engraulidae - anchovies | | | | | | | | |
| *Anchoa compressa* (Girard, 1858) | b | 63 | SL | 45 | 114 | 1.11E-05 | 3.05 | 0.94 |
| *Anchoa delicatissima* (Girard, 1854) | b | 637 | SL | 19 | 67 | 7.55E-06 | 3.09 | 0.90 |
| Clupeidae - herrings | | | | | | | | |
| *Sardinops sagax* (Jenyns, 1842) | abc | 247 | SL | 75 | 280 | 1.19E-05 | 3.02 | 0.91 |
| Aulopiformes | | | | | | | | |
| Synodontidae – lizardfishes | | | | | | | | |
| *Synodus lucioceps* (Ayres, 1855) | abc | 80 | SL | 61 | 360 | 2.12E-06 | 3.26 | 0.98 |
| Batrachoidiformes | | | | | | | | |
| Batrachoididae - toadfishes | | | | | | | | |
| *Porichthys myriaster* Hubbs & Schultz, 1939 | ab | 328 | SL | 16 | 490 | 1.38E-05 | 2.98 | 0.99 |
| *Porichthys notatus* Girard, 1854 | ab | 77 | SL | 23 | 460 | 2.21E-05 | 2.92 | 0.92 |

Table 2. Length and weight parameters, sample size (N), input length type, and length characteristics of the sample for 14 cartilaginous fish species (Subclass Elasmobranchii) and 57 ray-finned fish species (Class Actinopterygii) common to southern and central California.

| | | | *length characteristics* | | | *parameters of the relationship* | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Heterodontiformes | | | | | | | | |
| Heterodontidae - bullhead sharks | | | | | | | | |
| *Heterodontus francisci* (Girard, 1855) | ab | 651 | TL | 170 | 870 | 1.18E-05 | 2.94 | 0.98 |
| Lamniformes | | | | | | | | |
| Alopiidae - thresher sharks | | | | | | | | |
| *Alopias vulpinus* (Bonnaterre, 1788) | a | 16 | TL | 870 | 2560 | 3.11E-04 | 2.36 | 0.90 |
| Carcharhiniformes | | | | | | | | |
| Scyliorhinidae - cat sharks | | | | | | | | |
| *Cephaloscyllium ventriosum* (Garman, 1880) | a | 307 | TL | 335 | 950 | 3.00E-06 | 3.13 | 0.92 |
| Triakidae - hound sharks | | | | | | | | |
| *Galeorhinus galeus* (Linnaeus, 1758) | a | 102 | TL | 250 | 1900 | 7.78E-06 | 2.93 | 0.95 |
| *Mustelus californicus* Gill, 1864 | ab | 441 | TL | 345 | 1200 | 7.27E-07 | 3.22 | 0.95 |
| *Mustelus henlei* (Gill, 1863) | a | 387 | TL | 340 | 1100 | 8.07E-07 | 3.21 | 0.95 |
| *Triakis semifasciata* Girard, 1855 | a | 736 | TL | 160 | 1545 | 5.95E-06 | 2.95 | 0.97 |
| Hexanchiformes | | | | | | | | |
| Hexanchidae - cow sharks | | | | | | | | |
| *Notorynchus cepedianus* (Bonnaterre, 1788) | a | 30 | TL | 1185 | 1900 | 8.61E-07 | 3.22 | 0.88 |
| Squaliformes | | | | | | | | |
| Squalidae - dogfish sharks | | | | | | | | |
| *Squalus acanthias* Linnaeus, 1758 | a | 191 | TL | 320 | 1200 | 8.29E-08 | 3.57 | 0.94 |
| Squatiniformes | | | | | | | | |
| Squatinidae - angel sharks | | | | | | | | |
| *Squatina californica* Ayers, 1859 | ab | 206 | TL | 320 | 1200 | 7.81E-06 | 3.02 | 0.94 |



Table 2. Continued.

| | | | *length characteristics* | | | *parameters of the relationship* | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Rajiformes | | | | | | | | |
| Rhinobatidae – guitarfishes | | | | | | | | |
| *Rhinobatos productus* Ayres, 1854 | ab | 111 | TL | 225 | 1340 | 3.43E-06 | 3.01 | 0.95 |
| Myliobatiformes | | | | | | | | |
| Urotrygonidae - American round stingrays | | | | | | | | |
| *Urobatis halleri* (Cooper, 1863) | abc | 556 | DW | 74 | 275 | 5.73E-05 | 3.02 | 0.96 |
| Gymnuridae - butterfly rays | | | | | | | | |
| *Gymnura marmorata* (Cooper, 1864) | ab | 26 | DW | 250 | 1010 | 2.74E-06 | 3.20 | 0.98 |
| Myliobatidae - eagle rays and mantas | | | | | | | | |
| *Myliobatis californica* Gill, 1865 | abc | 270 | DW | 180 | 1000 | 2.32E-05 | 2.94 | 0.95 |
| Albuliformes | | | | | | | | |
| Albulidae - bonefishes | | | | | | | | |
| *Albula gilberti* Pfeiler & Van der Heiden, 2011 | ab | 42 | SL | 55 | 360 | 2.05E-07 | 3.77 | 0.98 |
| Clupeiformes | | | | | | | | |
| Engraulidae - anchovies | | | | | | | | |
| *Anchoa compressa* (Girard, 1858) | b | 63 | SL | 45 | 114 | 1.11E-05 | 3.05 | 0.94 |
| *Anchoa delicatissima* (Girard, 1854) | b | 637 | SL | 19 | 67 | 7.55E-06 | 3.09 | 0.90 |
| Clupeidae - herrings | | | | | | | | |
| *Sardinops sagax* (Jenyns, 1842) | abc | 247 | SL | 75 | 280 | 1.19E-05 | 3.02 | 0.91 |
| Aulopiformes | | | | | | | | |
| Synodontidae – lizardfishes | | | | | | | | |
| *Synodus lucioceps* (Ayres, 1855) | abc | 80 | SL | 61 | 360 | 2.12E-06 | 3.26 | 0.98 |
| Batrachoidiformes | | | | | | | | |
| Batrachoididae - toadfishes | | | | | | | | |
| *Porichthys myriaster* Hubbs & Schultz, 1939 | ab | 328 | SL | 16 | 490 | 1.38E-05 | 2.98 | 0.99 |
| *Porichthys notatus* Girard, 1854 | ab | 77 | SL | 23 | 460 | 2.21E-05 | 2.92 | 0.92 |

Table 2. Continued.

| | | | length characteristics | | | parameters of the relationship | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Mugiliformes | | | | | | | | |
| Mugilidae - mullets | | | | | | | | |
| *Mugil cephalus* Linnaeus, 1758 | abc | 40 | SL | 53 | 520 | 2.96E-05 | 2.93 | 0.99 |
| Atheriniformes | | | | | | | | |
| Atherinopsidae - New World silversides | | | | | | | | |
| *Atherinops affinis* (Ayers, 1860) | abc | 1756 | SL | 11 | 193 | 3.83E-06 | 3.24 | 0.99 |
| *Atherinopsis californiensis* (Girard, 1854) | abc | 420 | SL | 31 | 360 | 1.03E-05 | 3.01 | 0.94 |
| *Leuresthes tenuis* (Ayers, 1860) | bc | 17 | SL | 32 | 166 | 8.25E-07 | 3.52 | 0.98 |
| Beloniformes | | | | | | | | |
| Hemiramphidae - halfbeaks | | | | | | | | |
| *Hyporhamphus rosae* (Jordan & Gilbert, 1880) | b | 18 | SL | 24 | 127 | 6.23E-07 | 3.32 | 0.94 |
| Belonidae - needlefishes | | | | | | | | |
| *Strongylura exilis* (Girard, 1854) | ab | 10 | SL | 51 | 760 | 1.36E-07 | 3.39 | > 0.99 |
| Cyprinodontiformes | | | | | | | | |
| Fundulidae - topminnows | | | | | | | | |
| *Fundulus parvipinnis* Girard, 1854 | bc | 198 | SL | 14 | 78 | 1.49E-05 | 3.08 | 0.99 |
| Gasterosteiformes | | | | | | | | |
| Syngnathidae - pipefishes | | | | | | | | |
| *Syngnathus leptorhynchus* Girard, 1854 | bc | 814 | SL | 33 | 248 | 8.45E-08 | 3.35 | 0.95 |
| Scorpaeniformes | | | | | | | | |
| Scorpaenidae - scorpionfishes | | | | | | | | |
| *Scorpaena guttata* Girard, 1854 | abd | 618 | SL | 30 | 305 | 3.66E-05 | 2.98 | 0.94 |
| *Sebastes atrovirens* (Jordan & Gilbert, 1880) | a | 102 | SL | 125 | 270 | 9.44E-06 | 3.22 | 0.92 |
| *Sebastes carnatus* (Jordan & Gilbert, 1880) | a | 36 | SL | 110 | 240 | 1.72E-04 | 2.68 | 0.91 |
| *Sebastes rastrelliger* (Jordan & Gilbert, 1880) | ab | 225 | SL | 52 | 350 | 2.93E-05 | 3.01 | 0.91 |

Table 2. Continued.

| Scientific Name | Survey | N | length characteristics Type | Min. (mm) | Max. (mm) | parameters of the relationship a | b | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| Hexagrammidae - greenlings | | | | | | | | |
| *Oxylebius pictus* Gill, 1862 | ad | 17 | SL | 27 | 150 | 1.52E-05 | 3.11 | 0.98 |
| Cottidae - sculpins | | | | | | | | |
| *Artedius corallinus* (Hubbs, 1926) | d | 20 | SL | 12 | 59 | 3.19E-05 | 2.88 | 0.99 |
| *Leptocottus armatus* Girard, 1854 | abc | 827 | SL | 11 | 190 | 2.32E-05 | 2.98 | 0.99 |
| *Ruscarius creaseri* (Hubbs, 1926) | d | 174 | SL | 10 | 44 | 1.49E-05 | 3.17 | 0.99 |
| *Scorpaenichthys marmoratus* (Ayres, 1854) | ad | 136 | SL | 44 | 390 | 2.06E-05 | 3.06 | 0.95 |
| Perciformes | | | | | | | | |
| Polyprionidae - wreckfishes | | | | | | | | |
| *Stereolepis gigas* Ayers, 1859 | ag | 96 | SL | 125 | 2003 | 1.07E-04 | 2.80 | 0.99 |
| Serranidae - sea basses | | | | | | | | |
| *Paralabrax clathratus* (Girard, 1854) | abcd | 636 | SL | 19 | 575 | 2.09E-05 | 3.01 | 0.98 |
| *Paralabrax maculatofasciatus* (Steindachner, 1868) | abd | 430 | SL | 32 | 350 | 2.16E-05 | 3.03 | 0.99 |
| *Paralabrax nebulifer* (Girard, 1854) | abd | 635 | SL | 27 | 410 | 2.89E-05 | 2.95 | 0.99 |
| Haemulidae - grunts | | | | | | | | |
| *Anisotremus davidsonii* (Steindachner, 1876) | abde | 750 | SL | 20 | 330 | 1.64E-05 | 3.13 | 0.98 |
| Sciaenidae - drums and croakers | | | | | | | | |
| *Atractoscion nobilis* (Ayres, 1860) | abf | 6548 | SL | 71 | 1220 | 2.97E-05 | 2.87 | 0.96 |
| *Cheilotrema saturnum* (Girard, 1858) | ab | 344 | SL | 35 | 365 | 3.83E-05 | 2.91 | 0.92 |
| *Cynoscion parvipinnis* Ayres, 1861 | b | 10 | SL | 179 | 465 | 6.52E-05 | 2.74 | 0.99 |
| *Menticirrhus undulatus* (Girard, 1854) | ab | 432 | SL | 165 | 520 | 2.58E-05 | 2.91 | 0.94 |
| *Roncador stearnsii* (Steindachner, 1876) | abe | 577 | SL | 138 | 542 | 3.96E-05 | 2.91 | 0.96 |
| Kyphosidae - sea chubs | | | | | | | | |
| *Hermosilla azurea* Jenkins & Evermann, 1889 | a | 53 | SL | 165 | 310 | 1.14E-05 | 3.21 | 0.85 |

Table 2. Continued.

| Scientific Name | Survey | N | length characteristics | | | parameters of the relationship | | |
|---|---|---|---|---|---|---|---|---|
| | | | Type | Min. (mm) | Max. (mm) | a | b | $R^2$ |
| Mugiliformes | | | | | | | | |
| Mugilidae - mullets | | | | | | | | |
| *Mugil cephalus* Linnaeus, 1758 | abc | 40 | SL | 53 | 520 | 2.96E-05 | 2.93 | 0.99 |
| Atheriniformes | | | | | | | | |
| Atherinopsidae - New World silversides | | | | | | | | |
| *Atherinops affinis* (Ayers, 1860) | abc | 1756 | SL | 11 | 193 | 3.83E-06 | 3.24 | 0.99 |
| *Atherinopsis californiensis* (Girard, 1854) | abc | 420 | SL | 31 | 360 | 1.03E-05 | 3.01 | 0.94 |
| *Leuresthes tenuis* (Ayers, 1860) | bc | 17 | SL | 32 | 166 | 8.25E-07 | 3.52 | 0.98 |
| Beloniformes | | | | | | | | |
| Hemiramphidae - halfbeaks | | | | | | | | |
| *Hyporhamphus rosae* (Jordan & Gilbert, 1880) | b | 18 | SL | 24 | 127 | 6.23E-07 | 3.32 | 0.94 |
| Belonidae - needlefishes | | | | | | | | |
| *Strongylura exilis* (Girard, 1854) | ab | 10 | SL | 51 | 760 | 1.36E-07 | 3.39 | > 0.99 |
| Cyprinodontiformes | | | | | | | | |
| Fundulidae - topminnows | | | | | | | | |
| *Fundulus parvipinnis* Girard, 1854 | bc | 198 | SL | 14 | 78 | 1.49E-05 | 3.08 | 0.99 |
| Gasterosteiformes | | | | | | | | |
| Syngnathidae - pipefishes | | | | | | | | |
| *Syngnathus leptorhynchus* Girard, 1854 | bc | 814 | SL | 33 | 248 | 8.45E-08 | 3.35 | 0.95 |
| Scorpaeniformes | | | | | | | | |
| Scorpaenidae - scorpionfishes | | | | | | | | |
| *Scorpaena guttata* Girard, 1854 | abd | 618 | SL | 30 | 305 | 3.66E-05 | 2.98 | 0.94 |
| *Sebastes atrovirens* (Jordan & Gilbert, 1880) | a | 102 | SL | 125 | 270 | 9.44E-06 | 3.22 | 0.92 |
| *Sebastes carnatus* (Jordan & Gilbert, 1880) | a | 36 | SL | 110 | 240 | 1.72E-04 | 2.68 | 0.91 |
| *Sebastes rastrelliger* (Jordan & Gilbert, 1880) | ab | 225 | SL | 52 | 350 | 2.93E-05 | 3.01 | 0.91 |



Table 2. Continued.

| Scientific Name | Survey | N | length characteristics | | | parameters of the relationship | | |
|---|---|---|---|---|---|---|---|---|
| | | | Type | Min. (mm) | Max. (mm) | a | b | $R^2$ |
| Hexagrammidae - greenlings | | | | | | | | |
| *Oxylebius pictus* Gill, 1862 | ad | 17 | SL | 27 | 150 | 1.52E-05 | 3.11 | 0.98 |
| Cottidae - sculpins | | | | | | | | |
| *Artedius corallinus* (Hubbs, 1926) | d | 20 | SL | 12 | 59 | 3.19E-05 | 2.88 | 0.99 |
| *Leptocottus armatus* Girard, 1854 | abe | 827 | SL | 11 | 190 | 2.32E-05 | 2.98 | 0.99 |
| *Ruscarius creaseri* (Hubbs, 1926) | d | 174 | SL | 10 | 44 | 1.49E-05 | 3.17 | 0.99 |
| *Scorpaenichthys marmoratus* (Ayres, 1854) | ad | 136 | SL | 44 | 390 | 2.06E-05 | 3.06 | 0.95 |
| Perciformes | | | | | | | | |
| Polyprionidae - wreckfishes | | | | | | | | |
| *Stereolepis gigas* Ayers, 1859 | ag | 96 | SL | 125 | 2003 | 1.07E-04 | 2.80 | 0.99 |
| Serranidae - sea basses | | | | | | | | |
| *Paralabrax clathratus* (Girard, 1854) | abcd | 636 | SL | 19 | 575 | 2.09E-05 | 3.01 | 0.98 |
| *Paralabrax maculatofasciatus* (Steindachner, 1868) | abd | 430 | SL | 32 | 350 | 2.16E-05 | 3.03 | 0.99 |
| *Paralabrax nebulifer* (Girard, 1854) | abd | 635 | SL | 27 | 410 | 2.89E-05 | 2.95 | 0.99 |
| Haemulidae - grunts | | | | | | | | |
| *Anisotremus davidsonii* (Steindachner, 1876) | abde | 750 | SL | 20 | 330 | 1.64E-05 | 3.13 | 0.98 |
| Sciaenidae - drums and croakers | | | | | | | | |
| *Atractoscion nobilis* (Ayres, 1860) | abf | 6548 | SL | 71 | 1220 | 2.97E-05 | 2.87 | 0.96 |
| *Cheilotrema saturnum* (Girard, 1858) | ab | 344 | SL | 35 | 365 | 3.83E-05 | 2.91 | 0.92 |
| *Cynoscion parvipinnis* Ayres, 1861 | b | 10 | SL | 179 | 465 | 6.52E-05 | 2.74 | 0.99 |
| *Menticirrhus undulatus* (Girard, 1854) | ab | 432 | SL | 165 | 520 | 2.58E-05 | 2.91 | 0.94 |
| *Roncador stearnsii* (Steindachner, 1876) | abc | 577 | SL | 138 | 542 | 3.96E-05 | 2.91 | 0.96 |
| Kyphosidae - sea chubs | | | | | | | | |
| *Hermosilla azurea* Jenkins & Evermann, 1889 | a | 53 | SL | 165 | 310 | 1.14E-05 | 3.21 | 0.85 |

Table 2. Continued.

| | | | length characteristics | | | parameters of the relationship | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Embiotocidae - surfperches | | | | | | | | |
| *Cymatogaster aggregata* Gibbons, 1854 | abc | 879 | SL | 26 | 140 | 2.08E-05 | 3.07 | 0.97 |
| *Micrometrus minimus* (Gibbons, 1854) | abc | 88 | SL | 21 | 135 | 2.91E-05 | 3.02 | 0.96 |
| Pomacentridae – damselfishes | | | | | | | | |
| *Chromis punctipinnis* (Cooper, 1863) | ad | 148 | SL | 24 | 210 | 2.69E-05 | 3.02 | 0.98 |
| *Hypsypops rubicundus* (Girard, 1854) | a | 139 | SL | 90 | 220 | 3.07E-05 | 3.11 | 0.88 |
| Labridae - wrasses and parrotfishes | | | | | | | | |
| *Semicossyphus pulcher* (Ayres, 1854) | a | 194 | SL | 45 | 455 | 8.45E-05 | 2.80 | 0.92 |
| Blenniidae - combtooth blennies | | | | | | | | |
| *Hypsoblennius gentilis* (Girard, 1854) | bcd | 30 | SL | 34 | 109 | 1.58E-05 | 3.10 | 0.95 |
| *Hypsoblennius jenkinsi* (Jordan & Evermann, 1896) | d | 73 | SL | 13 | 80 | 8.64E-06 | 3.20 | 0.98 |
| Clinidae - kelp blennies | | | | | | | | |
| *Gibbonsia elegans* (Cooper, 1864) | bd | 115 | SL | 16 | 107 | 4.80E-06 | 3.24 | 0.99 |
| *Heterostichus rostratus* Girard, 1854 | abcd | 521 | SL | 23 | 400 | 3.97E-06 | 3.17 | 0.99 |
| Labrisomidae - labrisomid blennies | | | | | | | | |
| *Paraclinus integripinnis* (Smith, 1880) | bcd | 489 | SL | 9 | 58 | 1.11E-05 | 3.10 | 0.98 |
| Gobiesocidae - clingfishes | | | | | | | | |
| *Gobiesox rhessodon* Smith, 1881 | d | 42 | SL | 7 | 25 | 2.11E-05 | 3.04 | 0.96 |
| Gobiidae - gobies | | | | | | | | |
| *Clevelandia ios* (Jordan & Gilbert, 1882) | bc | 329 | SL | 6 | 56 | 2.55E-06 | 3.42 | 0.95 |
| *Quietula y-cauda* (Jenkins & Evermann, 1889) | bc | 64 | SL | 22 | 64 | 1.22E-05 | 3.05 | 0.95 |
| *Rhinogobiops nicholsii* (Bean, 1882) | d | 58 | SL | 24 | 86 | 6.28E-06 | 3.26 | 0.99 |
| Sphyraenidae - barracudas | | | | | | | | |
| *Sphyraena argentea* Girard, 1854 | ab | 436 | SL | 300 | 965 | 2.46E-05 | 2.76 | 0.94 |
| Scombridae - mackerels | | | | | | | | |
| *Scomber japonicus* Hottuyn, 1782 | ab | 274 | SL | 160 | 395 | 1.93E-05 | 2.93 | 0.92 |

Table 2. Continued.

| | | | *length characteristics* | | | *parameters of the relationship* | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
| Pleuronectiformes | | | | | | | | |
| Paralichthyidae - sand flounders | | | | | | | | |
| *Citharichthys stigmaeus* Jordan & Gilbert, 1882 | abc | 285 | SL | 22 | 135 | 8.33E-06 | 3.20 | 0.98 |
| *Paralichthys californicus* (Ayers, 1859) | abc | 623 | SL | 57 | 810 | 2.55E-05 | 2.91 | 0.95 |
| *Xystreurys liolepis* Jordan & Gilbert, 1880 | ab | 36 | SL | 105 | 400 | 3.07E-06 | 3.36 | 0.94 |
| Pleuronectidae - right-eye flounders | | | | | | | | |
| *Pleuronicthys guttulatus* Girard, 1856 | abc | 118 | SL | 17 | 340 | 5.80E-05 | 2.85 | 0.99 |
| *Pleuronichthys ritteri* Starks & Morris, 1907 | abd | 107 | SL | 17 | 230 | 2.95E-05 | 2.98 | 0.96 |
| Cynoglossidae - tonguefishes | | | | | | | | |
| *Symphurus atricaudus* (Jordan & Gilbert, 1880) | ab | 32 | SL | 34 | 185 | 1.07E-05 | 3.00 | 0.94 |

a, White Seabass Gill Net Survey; b, San Diego Bay Fisheries Inventory and Utilization Survey; c, Morro Bay Fish Survey; d, Cryptic reef fish collections from King Harbor and Agua Hedionda; e, Heat Treatments from Encina Generating Station, Cabrillo Power Plant, and Huntington Beach Generation Station; f,Opportunistic non-scientific hook and line and spear catches; g, Data provided by Michael Domeier

Table 2. Continued.

| | | | length characteristics | | | parameters of the relationship | | |
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| Pomacentridae - damselfishes | | | | | | | | |
| *Chromis punctipinnis* (Cooper, 1863) | ad | 148 | SL | 24 | 210 | 2.69E-05 | 3.02 | 0.98 |
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| *Semicossyphus pulcher* (Ayres, 1854) | a | 194 | SL | 45 | 455 | 8.45E-05 | 2.80 | 0.92 |
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| Gobiesocidae - clingfishes | | | | | | | | |
| *Gobiesox rhessodon* Smith, 1881 | d | 42 | SL | 7 | 25 | 2.11E-05 | 3.04 | 0.96 |
| Gobiidae - gobies | | | | | | | | |
| *Clevelandia ios* (Jordan & Gilbert, 1882) | bc | 329 | SL | 6 | 56 | 2.55E-06 | 3.42 | 0.95 |
| *Quietula y-cauda* (Jenkins & Evermann, 1889) | bc | 64 | SL | 22 | 64 | 1.22E-05 | 3.05 | 0.95 |
| *Rhinogobiops nicholsii* (Bean, 1882) | d | 58 | SL | 24 | 86 | 6.28E-06 | 3.26 | 0.99 |
| Sphyraenidae - barracudas | | | | | | | | |
| *Sphyraena argentea* Girard, 1854 | ab | 436 | SL | 300 | 965 | 2.46E-05 | 2.76 | 0.94 |
| Scombridae - mackerels | | | | | | | | |
| *Scomber japonicus* Hottuyn, 1782 | ab | 274 | SL | 160 | 395 | 1.93E-05 | 2.93 | 0.92 |



Table 2. Continued.

| | | | length characteristics | | | parameters of the relationship | | |
|---|---|---|---|---|---|---|---|---|
| *Scientific Name* | *Survey* | *N* | *Type* | *Min. (mm)* | *Max. (mm)* | *a* | *b* | $R^2$ |
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| *Paralichthys californicus* (Ayers, 1859) | abc | 623 | SL | 57 | 810 | 2.55E-05 | 2.91 | 0.95 |
| *Xystreurys liolepis* Jordan & Gilbert, 1880 | ab | 36 | SL | 105 | 400 | 3.07E-06 | 3.36 | 0.94 |
| Pleuronectidae - right-eye flounders | | | | | | | | |
| *Pleuronicthys guttulatus* Girard, 1856 | abc | 118 | SL | 17 | 340 | 5.80E-05 | 2.85 | 0.99 |
| *Pleuronichthys ritteri* Starks & Morris, 1907 | abd | 107 | SL | 17 | 230 | 2.95E-05 | 2.98 | 0.96 |
| Cynoglossidae - tonguefishes | | | | | | | | |
| *Symphurus atricaudus* (Jordan & Gilbert, 1880) | ab | 32 | SL | 34 | 185 | 1.07E-05 | 3.00 | 0.94 |

a, White Seabass Gill Net Survey; b, San Diego Bay Fisheries Inventory and Utilization Survey; c, Morro Bay Fish Survey; d, Cryptic reef fish collections from King Harbor and Agua Hedionda; e, Heat Treatments from Encina Generating Station, Cabrillo Power Plant, and Huntington Beach Generation Station; f,Opportunistic non-scientific hook and line and spear catches; g, Data provided by Michael Domeier nearest gram (g) either in the field or from frozen specimens that were brought back to the laboratory.

All statistical analyses were performed using R (R Core Development Team 2012). Standard length to total length conversion equations were established using linear regression analyses. Length-length models were fitted to the equation $TL = a+bSL$ where $SL$ is standard length (mm) and $TL$ is total length (mm) (Table 1). Length-weight models were fitted to the equation $W = aL^b$, where $W$ is the wet body weight (g) and $L$ is the total length (mm) or disc width (mm) (Table 2) by log-transforming both the length and weight data, performing linear regression analyses. Estimated parameters were then back-transformed to the original scale for reporting. Obvious outliers were removed prior to model fitting. While some species had a low sample size ($N < 30$), we report parameters here for those where 1) the naturally occurring size range was adequately represented in the sample, 2) the models fit the data well (Tables 1, 2), and 3) the lack of published information on the species made the parameter estimates of high value (Froese 2006). Parameters for some species described here have been previously published (e.g. Miller et al. 2008, Love 2011). However, there is value in including parameters for all species that we had sufficient data for where sampling locations differ across studies and/or larger sample sizes were available, permitting future users of the parameters more options depending on their intended use.

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## CONTENTS



Cover: A series of 18 whole specimen adult western toads (*Anaxyrus boreas*) collected on 25 July 1950 from Borrego Springs.