

## LIFE HISTORY AND HISTORIC TRENDS IN SALEMA (*HAEMULON CALIFORNIENSIS*) IN SOUTHERN CALIFORNIA

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### ABSTRACT

The Salema, *Haemulon californiensis*, is a small coastal marine fish whose southern California abundances vary considerably interannually. To better understand Salema biology and ecology, life history studies were executed and historic data reviewed to construct Salema's ecological profile in southern California, the northern extent of its biogeographic range. From these investigations, a von Bertalanffy growth model was developed for all fish ( $n = 475$ ):  $L_{\infty} = 159.367$  mm SL,  $k = 0.90$ ,  $t_0 = 0.047$ . The growth rate was fast with fish reaching  $L_{\infty}$  by six years of age with maximum age of 14 years. Reproductive studies confirmed summer spawning in southern California with a similar gonosomatic index in both males and females during spawning season,

averaging 8–9.5% of gonad-free body weight. Histological examination identified evidence of serial spawning, but no confirmatory studies were conducted. Scientific gill net sampling caught individuals as far north as Santa Barbara along the mainland coast and Santa Catalina Island, but the majority of catches occurred on the Palos Verdes Peninsula and south. Substantially more fish were taken near rocky reef habitat than soft-bottom open coastal or harbor habitats. Coastal sampling results were inconsistent as the two primary areas, Palos Verdes Peninsula and Newport. Recorded catch per unit efforts negatively correlated with each other over time. Long-term power plant entrapment monitoring in the area documented an increase in Salema abundance beginning in earnest in 1989 and continu-

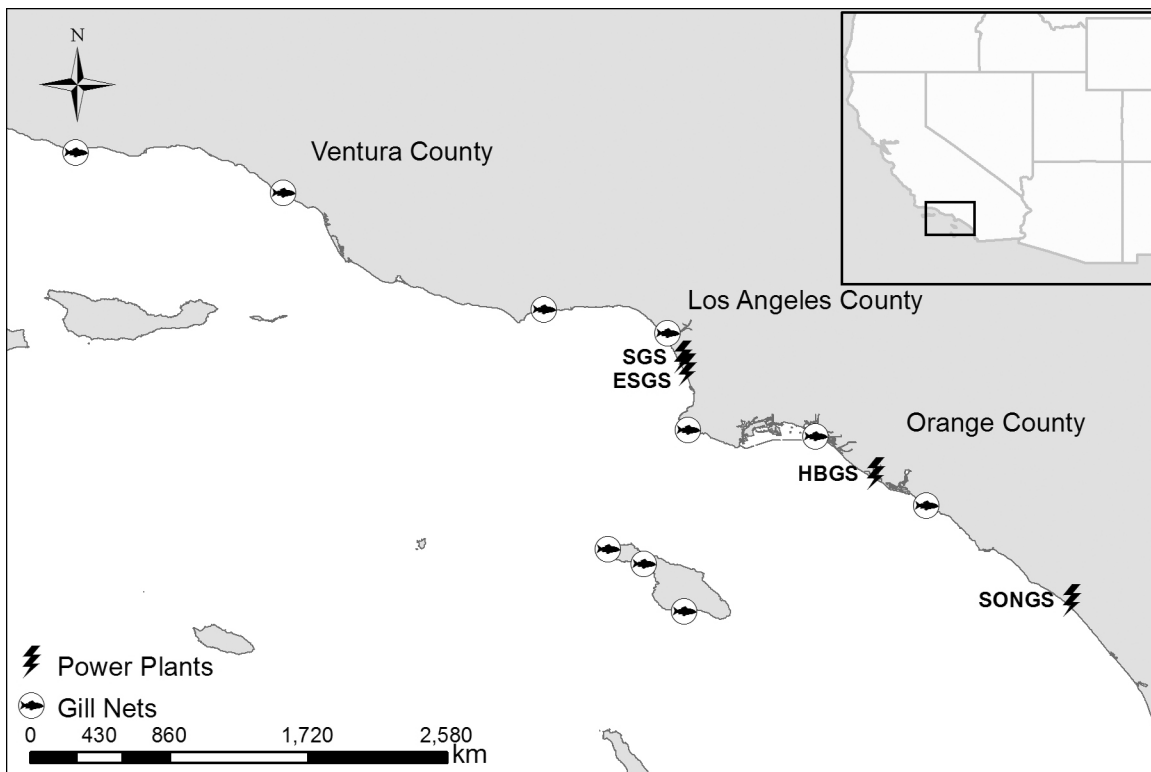


Figure 1. Map of the southern California sampling area indicating the location of each power plant and gill net sampling station providing Salema abundance data and life history samples. Power plants include Scattergood Generating Station (SGS), El Segundo Generating Station (ESGS), Huntington Beach Generating Station (HBGS), and San Onofre Nuclear Generating Station (SONGS).

ing through 2006 before abundance declined again. The area's population was dominated by year classes from 1994–95 and 2004–06. Juveniles remained in the area sampled by the power plants year-round until reaching 125 mm SL while larger individuals were rarely taken outside of the summer months when they became seasonally abundant.

## INTRODUCTION

Rocky reef communities are well known for their productivity and high biodiversity throughout the world (Stephens Jr. et al. 2006). This biodiversity, however, creates daunting challenges to adequately characterize many of the fishes in this community. While extensive effort has been expended on California rocky reef fishes, including surfperch (family Embiotocidae), bass (*Paralabrax* spp.), and California Sheephead (*Semicossyphus pulcher*), many of the lesser known species have not been rigorously examined (Cowen 1983; Carr 1994; Holbrook et al. 1997; Pondella et al. 2002; Erisman et al. 2011). Even less information on the life history and interannual variability was documented for many of these lesser-studied species.

Transient species that immigrate, either in a regular seasonal pattern or episodic events are linked to oceanographic conditions. Salema (*Haemulon californiensis*) likely represent a substantial contributor to southern California's marine environment. To date, no clear assessment of their abundance or distribution in California has been reported. Therefore, their inclusion as a resident or transient species cannot be fully evaluated and their role in the ecology of the southern California coastal ecosystem remains unclear. Salema range from northern Peru to the Monterey Bay in California and depths from the nearshore shallows out to 33 m (Love et al. 2005). Despite this distribution, surveys of the islands along the southern California and Baja California coast found Salema only at San Benito and Santa Catalina Islands, with two orders of magnitude more individuals at the more southern San Benito Island (Pondella et al. 2005).

Scientific gill nets and coastal power plant monitoring have been used in southern California to provide insight into similar, understudied species (Miller et al. 2008; Pondella et al. 2008; Miller et al. 2009; Miller et al. 2011; Miller and McGowan 2013). These sampling programs provide opportunities to assess trends in abundance over time, but also provide samples for life history analyses. Therefore, we executed a two-part investigation. The first aimed to characterize the Salema life history parameters including longevity, length at age, reproductive periodicity, and gonosomatic index. Second, we investigated spatiotemporal population effects of a changing environment on these trends.

## MATERIALS AND METHODS

### Data Sources

Life history samples were collected during nearshore scientific gill net surveys (described below) between April and November 2004; scientific purse seines in San Diego Bay in October 2004; and during southern California power plant entrapment monitoring (described below) at Scattergood Generating Station (SGS) in El Segundo, Huntington Beach Generating Station (HBGS) in Huntington Beach, and San Onofre Nuclear Generating Station (SONGS) in San Clemente between 2004 and 2007 (fig. 1). Spatial abundance indices were derived from the scientific gill net surveys. Temporal patterns were described from data collected during power plant entrapment surveys at El Segundo Generating Station (ESGS) in EL Segundo, California, HBGS, and SONGS.

Every April, June, August, and October 1995–2004, scientific gill nets were set overnight at three stations at Santa Catalina Island (west end, east end, and Catalina Harbor) while seven stations were sampled along the California coast: Santa Barbara, Ventura, Malibu, Palos Verdes, Seal Beach, and Newport (fig. 1). Sampling in Marina del Rey was added in October 1996. In 2005–07, all stations except the east end of Santa Catalina Island were sampled in June and October. Nets were set perpendicular to the shoreline at the open coast stations and parallel to the shoreline in bays and harbors to minimize impacts to navigation. Six horizontal gillnets were set on the bottom in 5–14 m of water outside of the surf zone at each station from dusk to dawn. Each net was 45.7 m long and 2.4 m deep, with two sets of three mesh-sized panels (25.4 mm, 38.2 mm, and 50.8 mm square mesh). The mesh sizes were chosen to target juvenile White Seabass (*Atractoscion nobilis*) and effectively captured 100–400 mm SL fishes.

These eight sampling sites (after combining all sites at Santa Catalina Island into one) represented a range of latitudes and habitats. The latitudinal distribution ranged from Newport at 33.5°N north to Santa Barbara at 34.4°N and offshore to Santa Catalina Island at 33.4°N. Sampled areas dominated by rocky reefs and often supporting kelp forests included Santa Catalina Island, Santa Barbara, Palos Verdes, and Newport. Ventura, Malibu, and Seal Beach were predominantly soft-bottom with hard substrate in the area, such as near a jetty in Seal Beach. Marina del Rey sampling occurred within the harbor at two locations, near the rocky riprap lining the entrance channel and near Mother's Beach located in a rear basin and dominated by soft-bottom sandy beach habitat. The three sites at Santa Catalina Island encompassed all three habitat types; rocky/kelp reef, soft-bottom near rocky substrate, and harbor.

Records from coastal power plant cooling water intake monitoring (entrapment data), were used both as a life history sample source and to characterize long-term abundance trends. Fish lengths (mm SL) were recorded only during the years 1992 to 2010. All fishes were exposed to lethal temperatures during routine heat treatment procedures at each the power plants listed above. Heat treatments were conducted to control biofouling growth in the cooling water system. Additional unique surveys (fish chase described below) at San Onofre Nuclear Generating Station (SONGS) were conducted since 1989. Both were surveys of opportunity and were conducted based on the plant's operational needs at a frequency of every 6–12 weeks, on average. At each power plant, intake conduits extended 500–900 m offshore terminating with a vertical intake riser along the 8–15 m isobaths extending 4 m above the seafloor. Inland, the conduits terminated in a forebay where water velocities slowed before passing through 1 cm square mesh traveling screens. Fishes > 10 mm SL were retained on the traveling screens until washed off and into a collection basket.

Forebay water velocities were low enough to allow fishes to take up residence until the next heat treatment, at which time all fishes within the forebay were exposed to temperatures >38°C and were subsequently impinged on the traveling screens and conveyed out of the forebay and deposited into a collection basket. All fish were identified, batch-weighed by species, and measured to the nearest mm SL (up to 200 individuals of each species only). The total abundance when >200 individuals were present was estimated by dividing the unmeasured fish aggregate weight by the mean weight of the 200-fish subsample (total weight/200). During a fish chase survey, forebay water temperatures were slowly raised to induce minimal, non-lethal stress in the fish. Once stressed, the fish accumulated in a hydrodynamically quiet area of the forebay where an elevator system was installed to raise the live fish that were in a steel tray of water and deposit them in a dedicated return conduit. All fishes in the tray were identified and a visual abundance estimate recorded by species prior to being released. No fish lengths were recorded during fish chases. Fish chases were limited to SONGS Units 2 and 3.

Annual Salema abundance offshore of SONGS was examined using lampara net sampling conducted from 1978 to 1986. Sampling methods were described in Allen and DeMartini 1983 but consisted of sampling in two areas offshore of the northern San Diego County coastline at depths of 5–11 m, 12–16 m, and 18–27 m with two lampara nets. The smaller net (4600 m<sup>2</sup>) was used at the two shallower isobaths while a larger net (6200 m<sup>2</sup>) was used at the deepest isobath with all nets fishing surface to bottom. Therefore, most sets were made over soft-bottom habitat. All nets had 15-cm stretch mesh

with a bag mesh of 1.25 cm. Nets were fished at night nearly monthly in all years.

Environmental indices over time periods and scales commensurate with the Salema studies were compiled. These environmental indices included sea surface temperature (SST) collected at the Scripps Institution of Oceanography Pier (SIO), sea surface density (SSD) derived from SST and sea surface salinity collected at SIO, Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), and the Multivariate ENSO Index (MEI) (Mantua et al. 1997; Wolter and Timlin 1998; Di Lorenzo et al. 2008; Scripps Institution of Oceanography 2012).

### Life History Sample Processing and Analysis

The following morphometric parameters were recorded for nearly all life history specimens: SL, HL, FL, TL. All lengths (regardless of source or study component) were measured to the nearest mm and wet weight to the nearest g. The relationship between each length measurement was derived in addition to the SL-weight relationship via linear or nonlinear regression as appropriate. Sagittal otoliths from each fish were removed and one otolith from each specimen was mounted on a wood block using cyanoacrylate glue and sectioned (0.7 mm thick section) on the transverse axis through the focus using a Buheler Isomet™ low speed saw. Sections were viewed in a black-bottomed watch glass filled with water and read under a stereoscope at 25× magnification using reflected light. Each otolith was read twice by a single reader, at least four months apart. The value from two identical readings was accepted as the best estimate of age. When necessary, a third reading was made when two consistent values were not obtained. In the event a consistent value could not be obtained after three readings, the sample was excluded from further analysis. Nearly all samples were collected in 2004, and edge analysis was used to verify annual increment formation (Campana 2001). The proportion of edge type in summer and fall was used as an indication that each pair does in fact represent an annual mark. No further annuli formation studies were attempted. Von Bertalanffy growth model parameters were derived for all individuals combined and by sex using VONBIT (Stamatopoulos and Caddy 1989). Immature or sex-undetermined individuals were excluded from the sex-specific analysis. Differences between sex-specific growth rates were tested using a likelihood ratio test (Kimura 1980) using package fishmethods in R (Nelson 2014).

The gonosomatic index (GSI) was derived for each individual (Barbieri et al. 1994) using field measurements of body and gonad weight. The sex ratio was tested for deviation from an expected 50:50 gonochoric pattern and was done using a Chi square test in MS Excel. Indi-

viduals used for spawning seasonality analysis were sexed macroscopically. Gonads were weighed to the nearest 0.5 g and preserved in a 10% buffered formalin-seawater solution. Samples were dehydrated in an ascending series of ethanol, cleared in toluene, embedded in paraffin, and histological sections cut at 5  $\mu\text{m}$  using a rotary microtome. Sections were mounted on glass slides and stained with Harris hematoxylin followed by eosin counterstain. Female stages were assigned as: 1) pre-spawn, 2) spawning, 3) post-spawn, 4) regressing. Testes were histologically classified into four stages: 1) spermiogenesis (cycloid spermatids, lumina occluded with sperm, germinal cysts line lumina); 2) late spermiogenesis (ovoid spermatids, lumina occluded with sperm, germinal cysts line lumina); 3) regression (germinal cysts exhausted); and 4) recrudescence (proliferation of germinal cysts).

### Population Data Analysis

Spatial patterns in Salema abundance were evaluated using the 13-year gill net series (1995–2007). The mean catch/net was derived for each regularly sampled site. June and October were the only months sampled in all years at all open coast mainland sites, therefore only data from these months were included. Marina del Rey and Santa Catalina Island sites were excluded from further analysis since they were not consistently sampled in all years. Spearman's rank correlation was used to examine similarities in annual catches among sites. Temporal abundance patterns were examined using the entrapment series (1972–2012) and compared against the lampara net series to confirm, to the extent possible, the entrapment series represents coastal population trends. Data from the lampara net sampling was used to verify the use of the entrapment data as a measure of coastal fish population dynamics. August lampara sampling results were used for comparisons with the July–September entrapment data as it was only month sampled in all years. Three months were used for the entrapment series to account for the fact that heat treatments were not conducted monthly at SONGS, but the fish accumulated over time since the last heat treatment. Lampara catch data was standardized to count/net set. Similarity between the entrapment rate and lampara net collection data sets was determined by least squares regression. No such comparisons were made with the later gill net data due to the differences in sampled size distributions. The gill nets targeted fishes >100 mm SL while both the power plant and lampara net sampling caught juvenile and adult fishes of all size classes.

Fish chases preceded heat treatments at SONGS, therefore the data from each fish chase and its subsequent heat treatment were combined prior to standardization to cooling water flow volumes. An entrapment index was derived to represent survey-specific abun-

dance standardized to the volume of cooling water circulated (filtered) since the last heat treatment. Mean annual and monthly entrapment indices were derived to examine interannual and intra-annual variability in their occurrence. Significance of the long-term entrapment rate trend was tested using the Microsoft Excel add-in developed by Bryhn and Dimberg 2011. The program creates new time series by calculating the moving average over ever-increasing time intervals of the original time series. Linear regressions through each of the new time series are executed to calculate the coefficient of determination ( $r^2$ ) and  $p$  value for each regression. The trend is statistically meaningful if  $r^2 \geq 0.65$  at  $p \leq 0.05$  in any of the regressions.

Fish were measured during all scientific gill nets (1995–2007) and heat treatments (1992–2012). Length differences between island and mainland sampling sites were tested using a Kolmogorov–Smirnov test. The power plant surveys were used to derive a young-of-the-year index (YOYI) to represent the number of one-year-old, or less, individuals ( $\leq 75$  mm SL size class) entrapped each year. Size at age 1 was defined in the length at age portion of our study. All YOY were assigned to their appropriate year class assuming a birthday of June 1 based on ichthyoplankton data (MBC 2005). Therefore, all YOY collected between June 1 and December 31 were assigned to the year of collection for their year class while those collected between January 1 and May 31 were assigned to the year prior, or collection year–1. The proportion of the total number of measured Salema represented by individuals  $\leq 75$  mm SL size class was multiplied by the entrapment rate for the year to derive the YOYI (count/ $10^6$  m<sup>3</sup>). Long-term trends in the YOYI were tested for significance per Bryhn and Dimberg 2011.

Environmental indices were compared with the annual mean entrapment rate and YOYI using Spearman's rank correlation. All values were tested for autocorrelation using a Durbin–Watson test before comparing to climate data. When the data were autocorrelated, correlation analyses were adjusted using the Modified Chelton Method (Pyper and Peterman 1998).

## RESULTS

### Life History

Size conversions between HL, SL, FL, TL, and weight are presented in Table 1. A total of 475 Salema measuring 30–190 mm SL were used for the otolith analysis. Otolith edge analysis recorded a greater than 2:1 ratio of opaque (101) to translucent (50) edges in the summer months suggesting the banding observed on the otolith sections were annual increments. Salema grew to an average of 148 mm SL by their fourth year and  $L_{\infty}$  (159 mm SL) by age six (table 2 and fig. 2). The old-

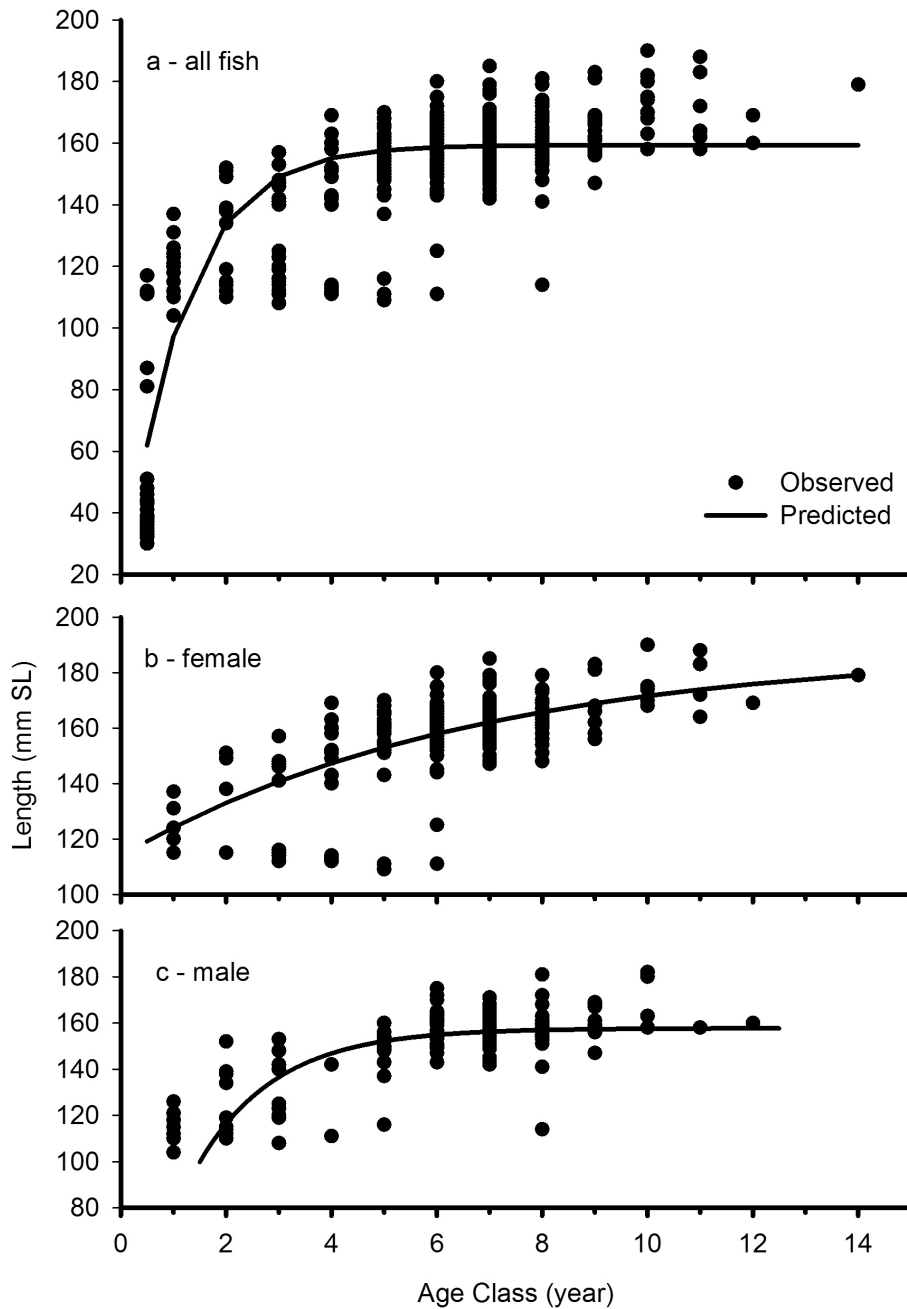
TABLE 1  
 Morphometric conversions between head length (HL), fork length (FL), standard length (SL), total length (TL), and weight (Wt), the best fit equation describing the relationship, goodness of fit ( $r^2$ ), and sample size for the relationship analysis.

Metrics	Equation	$r^2$	N
HL:SL	$SL = 3.0216HL + 10.198$	0.94	420
HL:FL	$FL = 3.5149HL + 9.6503$	0.94	415
HL:TL	$TL = 3.7995HL + 9.6036$	0.94	417
SL:FL	$FL = 1.1574SL - 1.4123$	>0.99	416
SL:TL	$TL = 1.2511SL + -2.3158$	0.99	418
FL:TL	$TL = 1.0787FL - 0.3871$	0.99	415
SL:Wt	$Wt = 7E-06SL^{3.2225}$	0.99	751

TABLE 2  
 Von Bertalanffy growth parameters for Salema sampled in southern California, 2004–07.

Parameter	All	Female	Male
k	0.90	0.15	0.26
$t_0$	0.047	-6.182	-3.254
$L_\infty$	159.367	188.155	168.805
n	475	228	169
$r^2$	0.82	0.44	0.60

Figure 2. Length at age for a) all samples, b) females, and c) males sampled in southern California, 2004–07. Von Bertalanffy growth parameters are listed in Table 2.





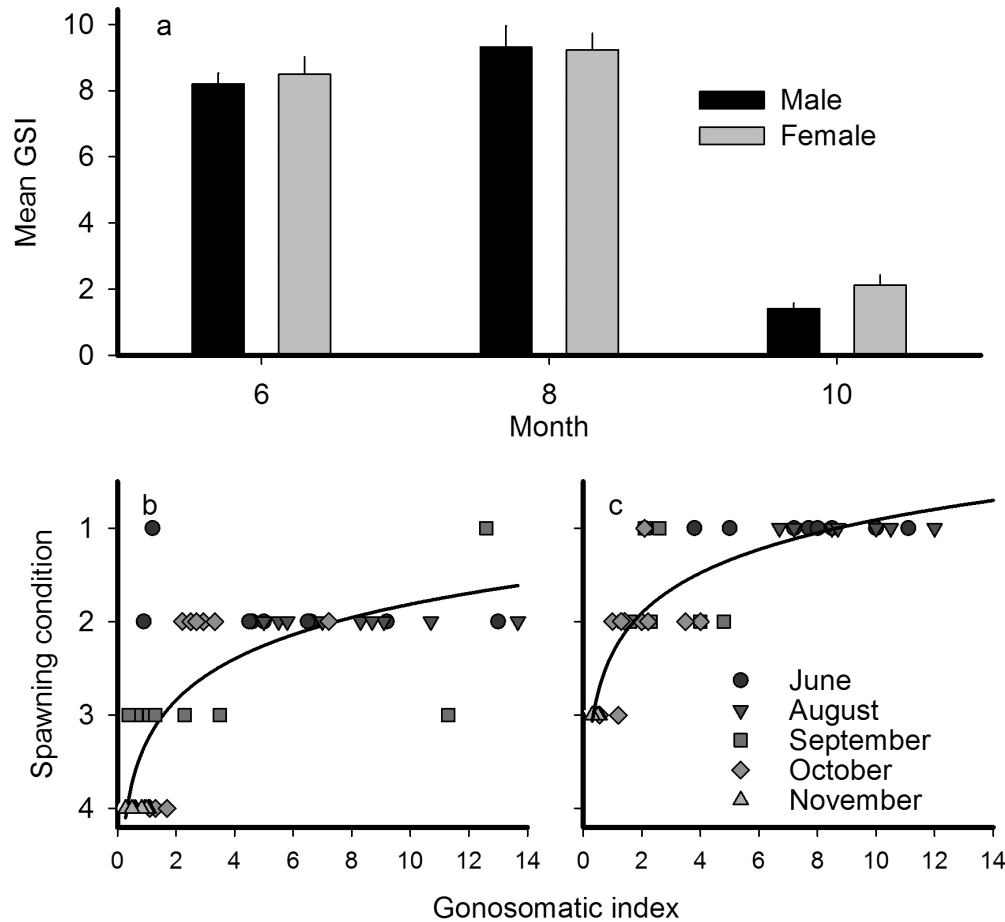


Figure 3. a) Gonosomatic Index (GSI) from the field processed (macroscopically sexed) samples. Histological preparations and analyses were conducted on 20 samples per month, when available. The GSI was derived for each sample and spawning condition assigned based on the histological preparations. Both parameters are presented by month as a function of each other for b) females and c) males. Spawning condition for females include: 1) pre-spawn, 2) spawning, 3) post-spawn, 4) regressing. Testes were classified into four stages: 1) spermiogenesis (lumina occluded with sperm, germinal cysts line lumina); 2) late spermiogenesis (lumina occluded with sperm, germinal cysts line lumina); 3) regression (germinal cysts exhausted); and 4) recrudescence (proliferation of germinal cysts). The line is the logarithmic curve through the data with a)  $r^2 = 0.54$  for females b) and  $r^2 = 0.82$  for males.

TABLE 3  
**Likelihood ratio test results comparing the von Bertalanffy model and parameters for 1) female and 2) male Salema.**

Hypothesis	chisq	df	p
$L_{\infty 1} = L_{\infty 2}$	3.78	1	0.052
$K_1 = K_2$	3.45	1	0.063
$t_0 1 = t_0 2$	5.35	1	0.021
$L_{\infty 1} = L_{\infty 2}, K_1 = K_2, t_0 1 = t_0 2$	22.66	3	0.000

est fish was taken at Santa Catalina Island and was aged to 14 years and measured 179 mm SL. One individual measuring 190 mm SL was 10 years old and also taken at Santa Catalina Island. After age six, up to 31 mm SL was added by age 14. The rapid growth to  $L_{\infty}$  was represented in the von Bertalanffy growth parameters, especially the growth coefficient (k). Most of the 35 fish taken in 2004 that were nine years or older were larger the  $L_{\infty}$ . These were split nearly 50:50 between the island and mainland

sites. The two sex-specific growth curves were significantly different (table 3) driven by significant differences between in  $t_0$  ( $p = 0.021$ ). Differences in  $L_{\infty}$  were substantial, but not significant ( $p = 0.052$ ). There was no significant difference between the growth coefficients.

Salema could not be reliably sexed in the field in winter and spring months due to black tissue and fluid surrounding the gonads as well as the small size/biomass of the winter-spring gonads. Therefore the GSI was limited to collections in June, August, and October (fig. 3a). The GSI was slightly higher in August than in June, but both were significantly higher than the October values (Female:  $H = 73.729$ ,  $df = 2$ ,  $p < 0.001$ ; Male:  $H = 53.256$ ,  $df = 2$ ,  $p < 0.001$ ). The mean female GSI was higher than the male GSI in June and October, but not in August. Furthermore, females were significantly ( $p < 0.01$ ) more common (314/565 individuals sexed) than males (251/565).

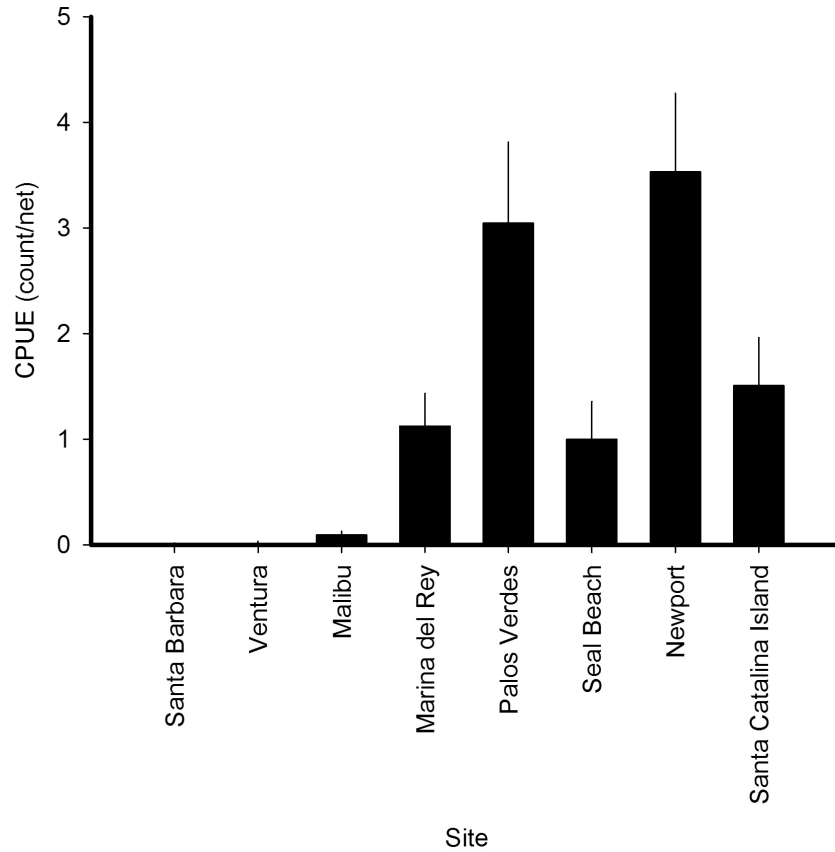


Figure 4. Mean catch per unit effort (CPUE; count/net) for all gill net sampling sites, 1995–2007. Standard error for each is presented. Santa Catalina Island includes three sites sampled, typically the west end, east end, and Catalina Harbor on the windward side of the island.

Female GSI for histologically examined individuals peaked in the summer months, coinciding with peak spawning while the minimal GSI was synchronous with no-spawning activity (fig. 3b). The GSI:spawning activity relationship followed a predictable logarithmic pattern ( $r^2 = 0.54$ ). While the number of spawning events for this species was not known, histological examination suggested serial spawning. Females were found to have both mature yolked oocytes (present spawn) and vitellogenic maturing oocytes (subsequent spawn). While samples were not available from all months, females in spawning condition were present in June (fig. 3b). The smallest female with yolk-filled ovarian follicles measured 144 mm SL and was collected in June. One female taken in June (149 mm SL) contained follicles with incomplete yolk deposition (accumulating yolk). The spawning period continued through August and concluded by September or October. The ovaries of five of eight females from September contained only rows of primary oocytes. Two September females contained atretic oocytes in the ovaries. One female from September collections contained hydrated eggs. Five of eight females collected at Seal Beach and one collected at Catalina Harbor in September were in spawning condi-

tion, suggesting some local geographic variation in the termination of spawning. All 13 Salema females collected in November had regressed ovaries containing primary oocytes.

Like the females, male GSI peaked during the summer spawning season (fig. 3c), again with a predictable logarithmic relationship between the two parameters ( $r^2 = 0.82$ ). All nine male Salema collected in June were undergoing spermiogenesis. Nine of ten from August were undergoing spermiogenesis with one exhibiting regression. September and October were transitional months indicating the male reproductive season was concluding. Two September males were undergoing spermiogenesis whereas five were in late spermiogenesis and seven of eleven males from October exhibited late spermiogenesis and three were regressed. All of the ten males from November contained regressed testes indicating the period of sperm formation had concluded.

#### Spatial Patterns

A total of 3750 Salema measuring 71–250 mm SL were caught in the gill net sampling program. Island samples were significantly larger (KS,  $F = 1.2638$ ,  $df =$

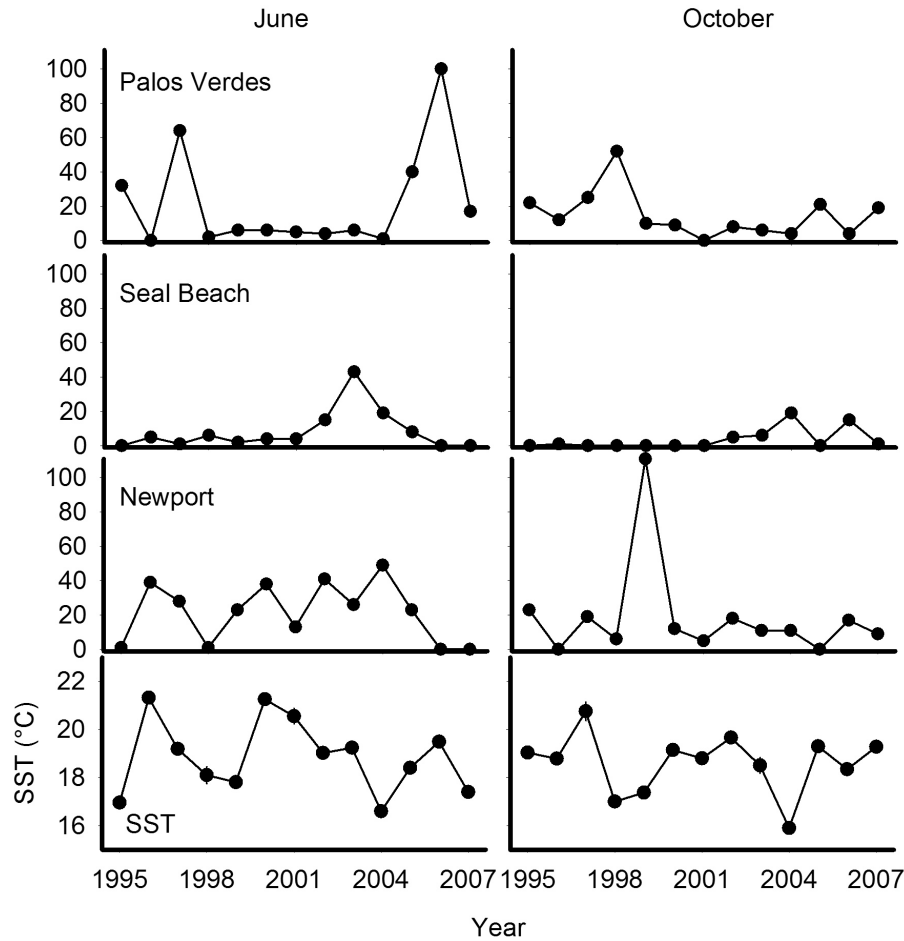


Figure 5. Total catch recorded at the three mainland gill net stations, with >5 fish caught in any year, by year for June and October. Six nets were set at each station in all years and nominally fished overnight. Mean sea surface temperature (SST °C) recorded during each net set across all sites is also presented.

2317, 1262,  $p < 0.001$ ) with a median length of 164 (0.3 standard error) mm SL while the median mainland fish length was 160 (0.2 standard error) mm SL. At least one individual was taken from all eight areas sampled by gill net, but their abundance substantially declined north of Marina del Rey (fig. 4). Peak catch per unit effort (CPUE) at sites from Malibu and southward occurred at Newport (3.5 fish/net) followed by Palos Verdes (3.0 fish/net) before a substantial decline to 1.5 fish/net, or less, at Santa Catalina, Marina del Rey, Seal Beach, and Malibu. Along the mainland, these sites segregated by habitat with the two rocky reef sites (Newport and Palos Verdes) numerically dominating the sampling while nets set at the soft-bottom areas (Marina del Rey and Seal Beach) caught substantially fewer individuals.

Of the six coastal sites, only sampling at Palos Verdes, Seal Beach, and Newport recorded CPUEs > 0 fish/net (fig. 5). Salema CPUE was not uniform at these three sites in both June and October; relatively elevated (depressed) CPUEs were not recorded at each site in the same years. June catches in Newport were the most

consistent, while catches at Palos Verdes in June were the most variable. Less than 10 fish/net were taken at Palos Verdes in June between 1998 and 2004 while the 1997 and 2005 CPUEs each exceeded 40 fish/net. During 1999–2004 period, above-average CPUEs were recorded at Seal Beach and Newport. Mean June CPUEs at Palos Verdes were negatively correlated with Seal Beach ( $r = -0.60$ ,  $p < 0.03$ ) and Newport ( $r = -0.54$ ,  $p = 0.05$ ). No significant correlation with SST was detected at any of the sites or for the cumulative annual means. In October, a similar pattern emerged, especially with the highest CPUE recorded at Newport in 1999. The Palos Verdes October annual CPUEs were negatively correlated to the Seal Beach CPUEs ( $r = -0.58$ ,  $p < 0.04$ ).

#### Temporal Patterns

Lampara net sampling over a shorter period than the power plant series (discussed below) corroborates the general appearance of Salema in the area with increasing numbers in 1980 with peak count/set in 1984 at



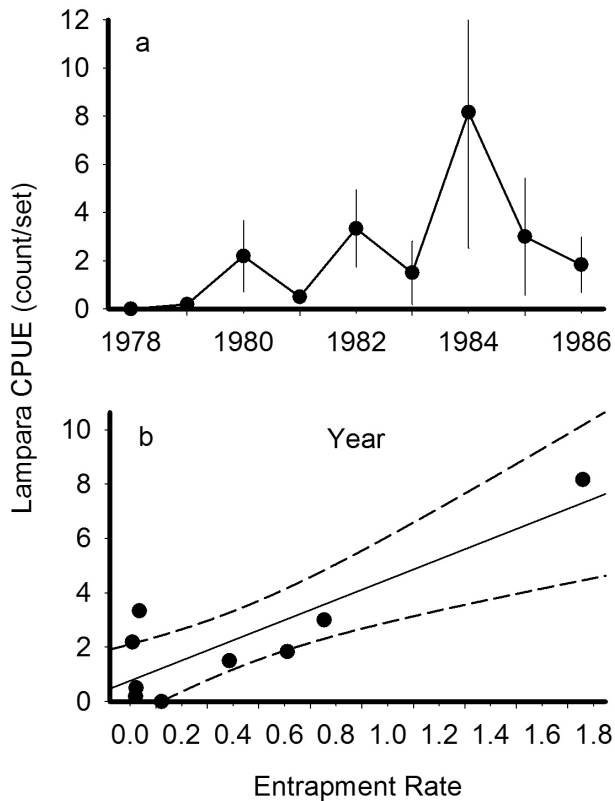


Figure 6. a) Mean August lampara catch per unit effort (CPUE; count/set) of Salema offshore of San Onofre Nuclear Generating Station during night sampling, 1978–86. b) Scatterplot and linear regression of mean August lampara CPUE versus mean annual entrapment rate during the overlapping years in both data sets. Dashed lines represent 95% confidence intervals.

8.2 fish/set (fig. 6a). Patterns in the power plant and lampara net data sets were significantly correlated ( $r^2 = 0.74$ ,  $p = 0.003$ ) during the brief period of overlapping sampling (fig. 6b). The power plant entrapment series recorded clear peaks during the summer months of July ( $3.5/10^6 \text{ m}^3$ ), August ( $5.3/10^6 \text{ m}^3$ ), and September ( $3.5/10^6 \text{ m}^3$ ) with CPUEs in the second one-half of the year considerably higher than five of the first six months. (fig. 7a). Looking at just the peak period, an entrapment rate  $> 1/10^6 \text{ m}^3$  was first recorded in 1983 (fig. 7b). The overall abundance remained low until the early 1990s after which it increased significantly over time ( $r^2 = 0.18$ ,  $p < 0.01$ ) and was statistically meaningful at a 4-year running mean ( $r^2 = 0.94$ ,  $p = 0.03$ ) despite substantial interannual variability. The increasing trend continued though 2006 before abundances declined substantially.

Power plant monitoring recorded 376,131 Salema during the 38 years included in this analysis. Measured individuals ranged 23–199 mm SL. The long-term pattern and multimodal distribution in the mean monthly entrapment rates suggested differential life stages occupying the nearshore waters at different times. The overall length-frequency distribution was dominated by fishes in

the 125-mm SL size class but additional large numbers ( $>15\%$  of the total) in the 75, 100, and 150 mm SL size classes were also taken (fig. 8a). Adults ( $>125 \text{ mm SL}$ ) were most common July–October with 17%, on average, of the total entrapped abundance occurring during these months versus 4% in the remaining months combined (fig. 8b). Monthly juvenile entrapment ranged from 5% to 13%, but averaged 8% of the total entrapped abundance each month.

Recruitment, or year-class strength, was estimated using the YOYI as a proxy. The YOYI was not autocorrelated ( $DW = 1.51$ ,  $p = 0.09$ ) with two clear peaks in the 18 years examined (fig. 9). The occurrence of two large year classes 11 years apart resulted in no significant trend in the long-term pattern ( $r^2 < 0.01$ ,  $p = 0.88$ ). Peak settlement occurred in 1995 ( $397/10^6 \text{ m}^3$ ) and 2005 ( $290/10^6 \text{ m}^3$ ) while the remaining years were commonly less than  $140/10^6 \text{ m}^3$ . Year class strength remained relatively high 2005–08 with each measuring at least  $105/10^6 \text{ m}^3$ . None of the five oceanographic or climate indices correlated with the YOYI after adjusting for autocorrelation in the climate index.

## DISCUSSION

Salema ranked among the 21 most commonly entrapped species in southern California power plants (1972–2010), and among the top ten since 1990 (Miller and McGowan 2013). Its diel behavior pattern created difficulties documenting their dynamics (Hobson and Chess 1976; Thomson et al. 2000). Salema are commonly taken using passive sampling devices such as scientific gill nets set overnight or coastal power plants operating cooling water intakes irrespective of diel period. Therefore, we used these two time series to assess Salema spatiotemporal patterns and collect samples for life history studies. As a result, the following overall profile emerges for Salema, with particulars discussed in further detail below. Salema is a fast-growing, summer-spawning species, potentially with high sperm competition, that lives to at least 14 years and exhibits clear preferences for rocky reef habitats in southern California. Salema became increasingly common in the area in the late-1980s with highly sporadic year-class strength, but evidence of juvenile residency. Adult Salema were seasonal transients in the sampling areas. Their recruitment patterns in the Southern California Bight were unrelated to generic climate indices such as water temperature or PDO, suggestive of more complex mechanisms regulating year-class strength (Asch and Checkley Jr. 2013).

Salema grow quickly through age six before stabilizing at approximately 190 mm SL with approximately 20 mm SL added during the remaining eight possible years of life. Our von Bertalanffy growth model  $L_\infty$  did not adequately represent fish older than eight years

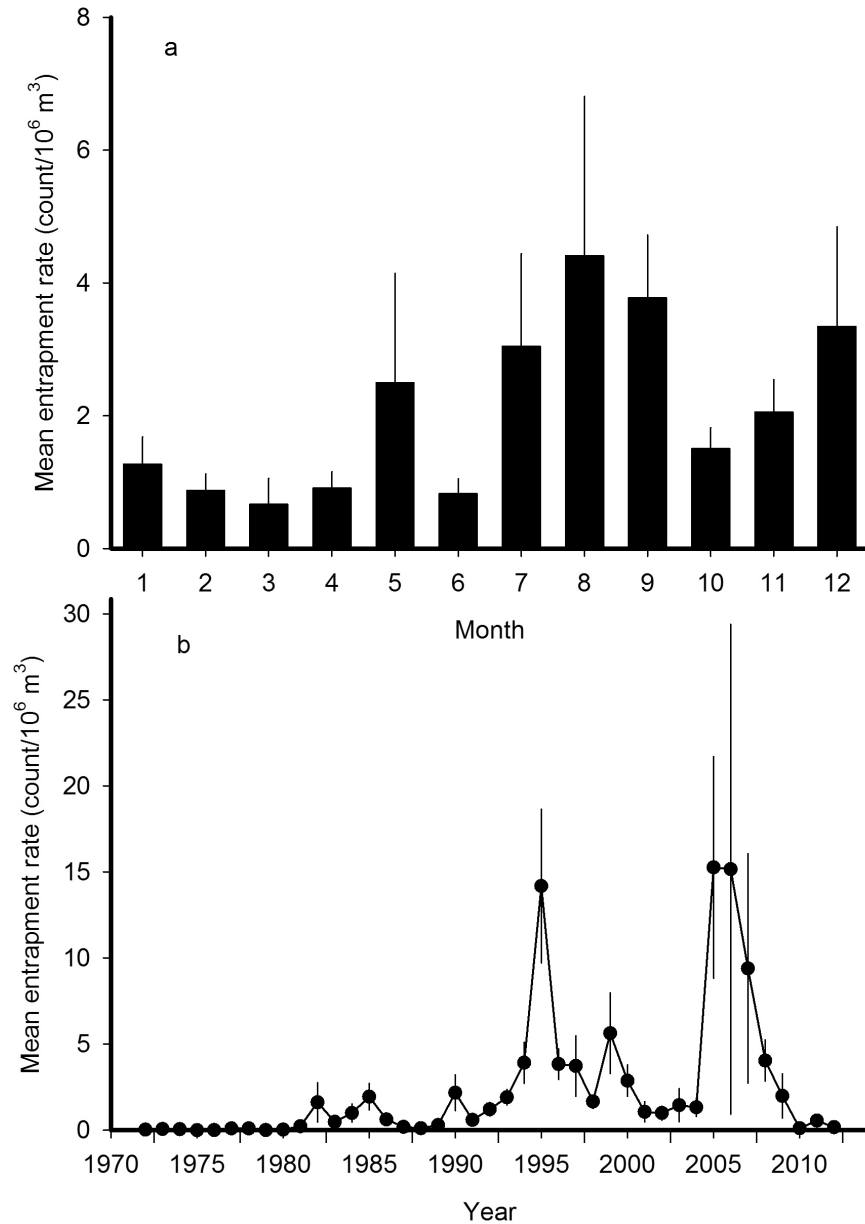


Figure 7. Mean ( $\pm$  standard error) power plant entrapment rates by a) month and b) year for Salema recorded during heat treatments at the three plants depicted in Figure 1, 1972–2012.

whose lengths exceeded the  $L_{\infty}$ . This may be an artifact of sampling location. The length at age samples in these older age classes were evenly sourced from island and mainland sampling sites in 2004. Over the full gill net time series, significantly larger Salema were taken at the island stations than those taken at the mainland stations. The possibility of spatial variation in growth is evident in Salema as has been found elsewhere (Schlosser and Angermeier 1995). Focused sampling targeting Salema from islands and the mainland is needed to better understand this process as a wide variety of biogeochemical factors can affect this, including: prey type and availability, water temperature, predator presence, etc.

The Salema growth coefficient was higher than most Southern California Bight species of similar maximum size, such as Queenfish (*Seriphus politus*) (Miller et al. 2009), but is consistent with other species in the family Haemulidae. Both the Bluecheek Silver Grunt (*Pomadourys argyreus*,  $k = 0.80$ ) and the Saddle Grunt (*P. maculatus*,  $k = 0.75$ ) common to the waters offshore of Brunei Darussalam have growth coefficients exceeding Salema's (Silvestre and Garces 2004). Rapid growth in early life is a common and well-founded theme in fish biology as size confers lower natural mortality (McGurk 1986). Salema reportedly grow to 300 mm TL (Thomson et al. 2000; Love et al. 2005) or approximately 238 mm SL

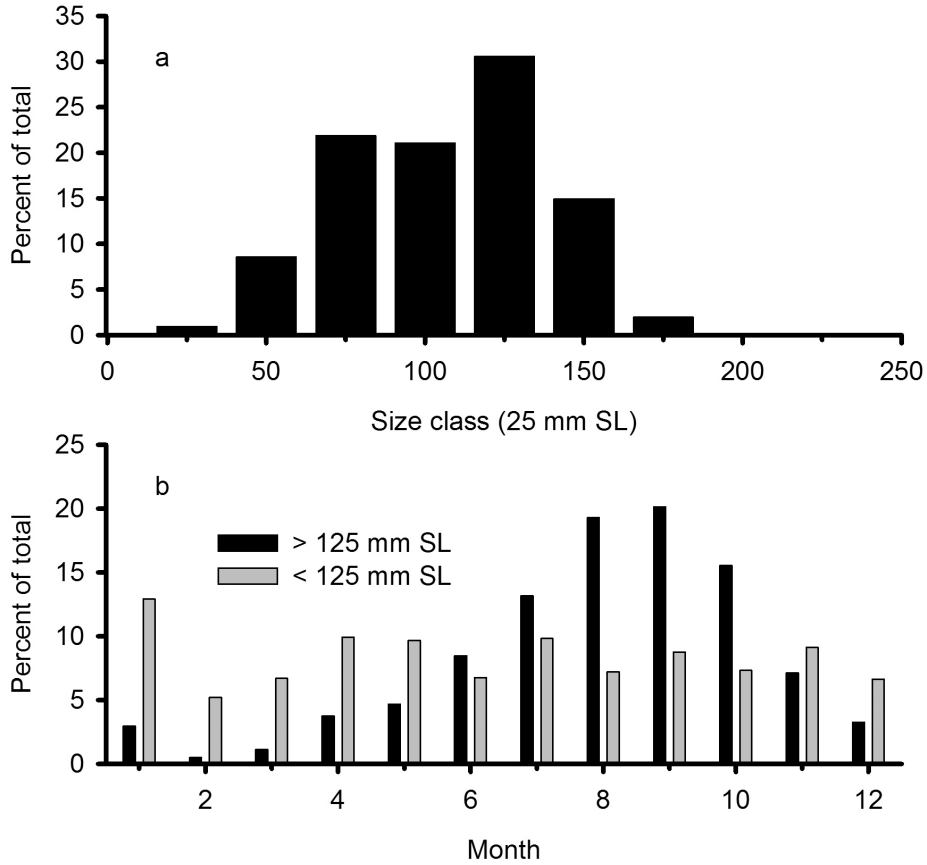


Figure 8. a) Length frequency of all Salema measured during surveys at the three coastal power plants depicted in Figure 1, 1992–2009. b) Percent of all measured Salema, 1992–2009, measuring > or < 125 mm SL by month.

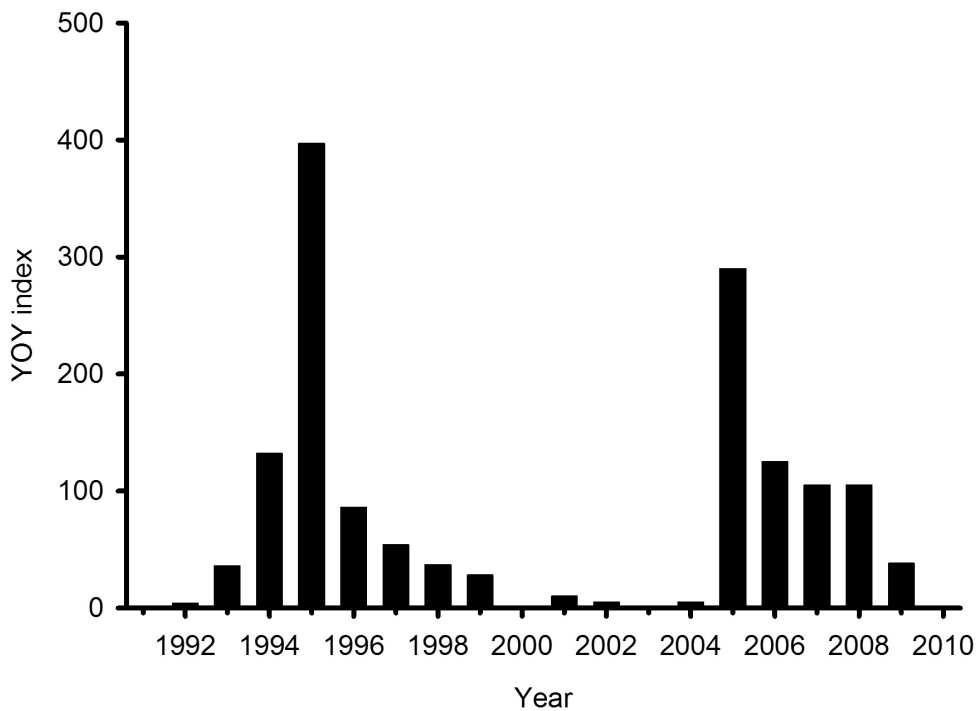


Figure 9. Annual young-of-the-year index (YOYI; count/10<sup>6</sup> m<sup>3</sup>) derived from power plant surveys.

after converting using our derived relationship. We did not have a fish this large in our age and growth sample, but the gill net sampling did catch one fish measuring 250 mm SL (315 mm TL) in August 2004 at Seal Beach, California. Out of the 3750 Salema caught in the 14 years of gill net sampling, only seven exceeded 200 mm SL. The largest fish recorded in the power plant monitoring was 199 mm SL. Salema up to 190 mm SL were included in the age and growth sample. Therefore, the age and growth sample encompassed most of the Salema documented size range.

Spawning occurred during the summer months, as may be expected in a southern distributed species at the northern extent of its range (Love et al. 2005). In Salema, the GSI was a significant predictor of spawning condition in both sexes with significantly higher levels of gametogenesis during the summer months as compared to the fall. Unfortunately, no adults for the life history analysis were successfully collected during the winter. The high GSI values observed in both sexes was surprising. Typically, in gonochoric species from southern California the female GSI far exceeds their male counterparts (Love et al. 1990; Allen et al. 1995; Miller et al. 2008). Salema mean male GSI was equivalent to the female GSI. This is commonly seen in species with high sperm competition (Stockley et al. 1997). While sperm competition has been identified in a variety of temperate fishes, especially those associated with reefs (Fischer and Petersen 1987), it has not been previously identified in fishes of the family Haemulidae. Unfortunately, field observations of Salema spawning have not yet been reported. Therefore, while the GSI values were consistent with sperm competition, we can only speculate as to its relevance to the undocumented Salema mating system. Females being significantly more common also discount the need for sperm competition by males.

Salema migration is undocumented, but the seasonal and interannual patterns in post-juvenile abundance found in this study were highly suggestive of migration. There were indications that larger fish repeatedly visited the areas sampled by the power plants on a seasonal cycle, but at intermittent annual frequencies. This was suggestive of an oceanographic cue, but none was identified here. Site-specific annual gill net CPUE were highest at gill net sampling sites centered near rocky reefs, consistent with Salema's known ecology. The negative correlations in site-specific annual gill net CPUE confirms that Salema was not uniformly distributed along the coast but exhibited high spatiotemporal variability. For instance, in 2006 Salema CPUE was well-above average in both June and October at Palos Verdes while the CPUE near Newport was well-below average. The same pattern emerged in October 1998. Each year was marked by anomalously warm waters caused by delayed upwelling (Goericke et

al. 2007) or a strong El Niño (Lynn et al. 1998). Otherwise, the CPUE at Newport was relatively stable in both months while the CPUE at Palos Verdes was substantially more variable.

Once spawned, Salema appeared to readily settle out of the plankton in the Southern California Bight, although no information was available to discern if these settlers are of local or distant (e.g., Baja California) origin. Ichthyoplankton surveys between 1978 and 1980 offshore of SONGS sporadically caught Salema larvae with the most taken in September 1978 (Walker et al. 1987). Similar surveys between 1982 and 1984 collected only two Salema larvae (McGowan 1993), despite a strong El Niño affecting the Southern California Bight between 1982 and 1983 (Fiedler et al. 1986). Finally, surveys in 2003–04 resulted in Salema collections ranking sixth in the nearly weekly sampling conducted offshore of HBGS; with most larvae taken in August 2004 (MBC 2005).

Regardless of where the Salema larvae were spawned, the presence of small, YOY size classes in the Southern California Bight indicates local recruitment. Smaller size classes appear to remain in the nearshore Southern California Bight areas sampled by the power plant intakes year-round. Reduced availability to the power plant intakes apparently begins with 125 mm SL size class as individuals >125 mm SL become seasonal migrants. This corresponds to an approximately one-year residence and partially contributes to our understanding of the interannual variation as these strong year classes residing in the area raise the overall annual mean entrapment rates. Once departed, they may only contribute to the annual total entrapment during the summer spawning period.

Factors regulating the observed larval settlement and total abundance patterns were not obvious. No evidence of a response to the 1976–77 regime shift (Miller et al. 1994) was found, despite the substantial biological reorganization in California waters in response to the altered oceanographic climate (Holbrook et al. 1997; McGowan et al. 2003; Miller and McGowan 2013). Salema abundances in the Southern California Bight increased initially during 1982–83 ENSO, with a sustained rise beginning in 1989, a year previously characterized as a regime shift outside of the PDO+/PDO– pattern (Hare and Mantua 2000; Bond et al. 2003; Miller and McGowan 2013). The 1989 regime shift reportedly influenced current patterns and productivity elsewhere (Polovina et al. 1995; Polovina 2005), but no investigations have looked for these changes in coastal southern California. Reasons for the post-2006 Salema abundance decline were unknown. It was unlikely that any anthropogenic impacts resulted in the decline as no fishery targeted Salema, no substantive

habitat loss occurred, and no demonstrative changes in wastewater or stormwater discharge has occurred in the recent years. Just as oceanographic changes associated with the 1989 regime shift likely resulted in the establishment of elevated (compared to previous years) seasonally resident populations in southern California, it was likely changes in oceanographic conditions led to their local decline. This question warrants continued investigation.

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