

THE ICHTHYOPLANKTON OF KING HARBOR, REDONDO BEACH, CALIFORNIA 1974–2009

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ABSTRACT

We report on twelve larval fish taxa, plankton volume, and total larvae caught in monthly ichthyoplankton tows in King Harbor, Redondo Beach from 1974–2009. Plankton volume, total larvae, and all but three taxa significantly declined throughout this study. Larval declines were primarily correlated with plankton volume and negatively correlated with a rise in sea surface temperature (SST). Taxa that did not decline were gobies and *Hypsypops rubicundus*. Localized processes, red tides, and other episodic events appeared to be associated with annual failures in larval production. With the exception of negative correlations with SST, oceanographic metrics (MEI, PDO, NPGO, NPI, and CUI) were not correlated with larval catch for individual taxa. Instead, SST, CUI, and MEI may be explanatory for the decline in plankton volume. Plankton volume was a potential major driver in the overall decline in ichthyoplankton observed during this study.

INTRODUCTION

While decades of research exist on the ichthyoplankton of the California Current and associated processes, by comparison, studies of the nearshore ichthyoplankton of the Southern California Bight are limited spatially, temporally, and taxonomically (Moser and Watson 2006) with some notable exceptions (Lavenberg et al. 1986; Moser and Watson 1990; McGowan 1993). Studies of the nearshore ichthyoplankton assemblages of the Southern California Bight have primarily focused on the effects of once-through-cooling associated with coastal generating stations and typically have been conducted over relatively short temporal scales and limited taxonomic categories (Schlotterbeck and Connally 1982; Barnett et al. 1984; Jahn and Lavenberg 1986; Walker et al. 1987; Watson 1992). These coastal generating station-funded surveys highlighted the importance of how this assemblage has changed since the 1970s.

The period between the initial studies in the 1970s and early 1980s and more recent times (2000s) has been punctuated by profound oceanographic variability (Bograd and Lynn 2003). Perturbations in the Southern California Bight oceanography include at least one

large oceanographic regime shift ca. 1976–77 (Miller et al. 1994), a globally significant El Niño ca. 1982–83 (Alheit and Bakun 2010), a dramatic fluctuation in the ENSO cycle 1997–99 (Schwing et al. 2000), delayed upwelling and anomalously warm waters without an El Niño signature in 2005 (Pierce et al. 2006; Schwing et al. 2006), and a recent period of remarkably cool waters in the Southern California Bight (Bjorkstedt et al. 2010). Many of these patterns were decoupled from the Pacific Decadal Oscillation (PDO). Di Lorenzo et al. (2008) found the PDO correlated only with sea surface temperature south of 38°N, while the North Pacific Gyre Oscillation (NPGO) significantly related to most productivity measures (e.g., nutrients, chlorophyll *a*) south of 38°N. While these oceanic climate indices are generally applicable to the California Current, most of the United States portion of the Southern California Bight inshore of the Channel Islands is largely dominated by the California Countercurrent (Hickey 1992; Hickey 1993; Bograd and Lynn 2003; Di Lorenzo 2003). The interannual variability in the strength of the California Countercurrent has been previously linked to recruitment strength in the area (Selkoe et al. 2006; Selkoe et al. 2007). Undoubtedly fish recruitment is linked to the larval pool.

The PDO, NPGO, and coastal indices (Di Lorenzo et al. 2008; Parnell et al. 2010) recorded a substantial shift in oceanographic conditions circa the mid-1970s that resulted in a transition to a predominantly warmer, nutrient-deficient regime in the SCB. Since this transition, the coastal fauna has witnessed substantial changes in abundance and composition that transcends taxonomic groups (Roemmich and McGowan 1995; Sydeman et al. 2001; McGowan et al. 2003; Sydeman et al. 2009; Parnell et al. 2010; Miller et al. 2011). Corresponding changes in the nearshore ichthyoplankton have yet to be described, although they are expected given the consistency across taxonomic groups in the juvenile and adult stages. Such analyses, however, are hampered by the triennial sampling frequency used by the California Cooperative Oceanic Fisheries Investigation during the 1970s, which limited its resolution to detect the mid-1970s shift in ichthyoplankton. Therefore, the

novelty of the King Harbor series (Stephens et al. 1994) becomes magnified as it stands as the only long-term record available to document a shift in the ichthyoplankton associated with the previously discussed regime shift. Considering this research, we hypothesize that there has been a long-term decline in nearshore ichthyoplankton productivity over the last four decades.

Santa Monica Bay is the most northern semi-enclosed bay in the Southern California Bight, featuring a complex physical oceanography. The major currents affecting the bay are the northwestern flow of the California Current from the Santa Barbara Channel and the Southern California Countercurrent from the southeast (Nezlin et al. 2004). Both of these currents are seasonal and influence the bay through complex cyclonic eddies as they move offshore past the Malibu and Palos Verdes headlands (DiGiacomo and Holt 2001). It features three submarine canyons that intersect a relatively long shelf, the most dramatic of which is the Redondo Submarine Canyon terminating in Redondo Beach proximate to King Harbor (Hickey 1993), the location of the Redondo Beach Generating Station which withdraws and discharges water near the mouth of the harbor with another independent intake located deeper within the harbor (Stephens et al. 1994) (fig. 1). As a result of the proximity of the canyon head to the shore, both King Harbor and the Redondo Pier have experienced devastating storm destruction from wave action since their construction. The heavy winter storms of 1983 and 1988 were the most recent examples of these episodic events. Following the 1988 storm events, the breakwaters were rebuilt and strengthened in 1989, after which the marina was dredged. King Harbor has been the location of red tides that occur in Santa Monica Bay (Somner and Clark 1946), which were absent from the early 1970s until 1995 (Gregorio and Pieper 2000). In the enclosed embayment, the red tides can cause anoxia and associated fish and benthic organism kills as were observed in 2005, when a red tide persisted along the southern California coastline for most of the summer and fall (Shipe et al. 2008).

The ichthyofauna of King Harbor, Redondo Beach has been studied intensively and continually since 1974 (Terry and Stephens 1976; Ellison et al. 1979; Stephens et al. 1994; Pondella et al. 2002). This study has been used to document regime shifts (Stephens et al. 1994; Holbrook et al. 1997), long-term trends in ecological and fishery species (Pondella et al. 2002), El Niño Southern Oscillation effects (Stephens et al. 1994) and has been cited as a time series indicating the effects of climate change (Hughes 2000). While global climate change is a specter that lurks over our nearshore environment, the timely nature of such nearshore ichthyofauna studies are critical for the understanding of the newly implemented marine

protected areas in the region as larval connectivity was a key component in the reserve network design and essential for its long-term success (Watson et al. 2010). It is within this context, monthly ichthyoplankton tows were conducted continually from 1974–2009 (Stephens et al. 1994; Stephens and Pondella 2002). We used this unique time series to examine how the nearshore larval fish assemblage has evolved over time, how these changes relate to oceanographic indices, and whether or not it is returning to its pre-1976–77 regime shift assemblage.

MATERIAL AND METHODS

From January 1974 through July 2009, monthly surface ichthyoplankton samples were conducted at two stations (1 and D) along and immediately proximate to the mouth of King Harbor, Redondo Beach (fig. 1) (Stephens et al. 1986; Stephens et al. 1994). From 1974 through 1977 only Station D was sampled. Station 1 was sampled from 1978–2009, while Station D was not sampled from 1978–80, but was sampled from 1981–2009.

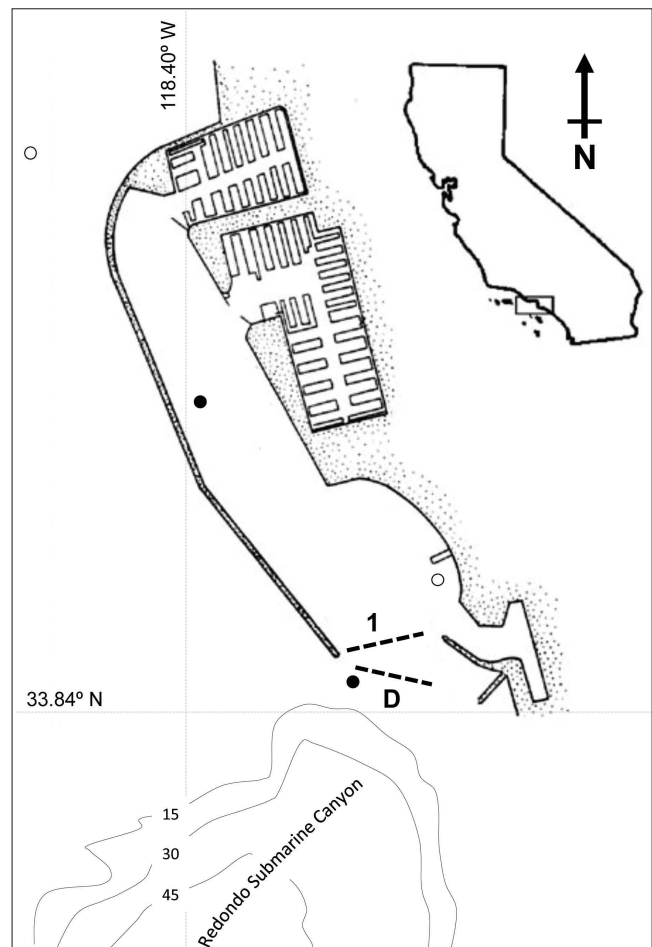


Figure 1. King Harbor, Redondo Beach, California. Location of stations 1 and D (hatched lines) where monthly nocturnal surface plankton tows were conducted from 1974–2009. Intake structures for the generating station are the solid circles, outfall structures are the open circles. Bathymetric contour intervals are shown in meters.

TABLE 1

Pearson's *r* correlation coefficients (with corresponding *p*-values; significant values are in bold text) for relationships between larval density, total plankton volume or specific larval taxon and various oceanographic indices including: Pacific Decadal Oscillation (PDO), multivariate ENSO index (MEI), North Pacific Gyre Oscillation (NPGO), North Pacific Index (NPI), Cumulative Upwelling Index at 33°N (CUI), and the sea surface temperature recorded at the Scripps Institution of Oceanography Pier in La Jolla, California (SST). Additionally, type of data transformation are provided for each variable.

	Catch Rank	MEI (p-value)	PDO (p-value)	NPGO (p-value)	NPI (p-value)	CUI (p-value)	SST (p-value)	Plankton Volume (p-value)	Transformation
Larvae density		-0.11 (0.53)	-0.10 (0.58)	0.09 (0.61)	0.19 (0.27)	0.35 (0.04)	-0.45 (0.01)	0.70 (<0.01)	none
Total plankton volume		-0.40 (0.02)	-0.18 (0.29)	0.20 (0.25)	0.22 (0.19)	0.46 (0.01)	-0.65 (<0.01)		none
<i>Hypsoblemmus</i> sp.	1	-0.13 (0.44)	0.02 (0.93)	0.02 (0.92)	0.04 (0.83)	0.33 (0.05)	-0.42 (0.01)	0.60 (<0.01)	sqrt
<i>Paralichthys/Xystreurus</i> sp.	2	0.13 (0.44)	0.22 (0.20)	-0.18 (0.28)	0.00 (1.00)	0.07 (0.68)	-0.24 (0.15)	0.46 (0.01)	Log (x+1)
<i>Hypsypops rubicundus</i>	3	0.18 (0.29)	0.00 (0.99)	0.02 (0.92)	0.06 (0.72)	0.09 (0.59)	0.26 (0.13)	-0.28 (0.09)	square root
<i>Genyonemus lineatus</i>	4	-0.08 (0.66)	0.05 (0.79)	-0.10 (0.58)	0.06 (0.74)	0.26 (0.13)	-0.60 (<0.01)	0.62 (<0.01)	third root
Gobiidae A/C complex	5	0.26 (0.12)	0.25 (0.14)	-0.19 (0.28)	-0.09 (0.59)	0.15 (0.38)	-0.23 (0.18)	0.37 (0.03)	square root
<i>Engraulis mordax</i>	6	0.05 (0.76)	0.08 (0.64)	-0.04 (0.80)	-0.01 (0.97)	0.13 (0.44)	-0.44 (0.01)	0.61 (<0.01)	Log (x+1)
<i>Lythrypnus</i> sp.	7	0.27 (0.11)	0.32 (0.06)	-0.27 (0.11)	-0.02 (0.92)	0.28 (0.10)	-0.01 (0.95)	0.09 (0.61)	Log (x+1)
<i>Seriplus politus</i>	8	-0.07 (0.68)	0.08 (0.63)	0.07 (0.70)	0.02 (0.92)	0.30 (0.08)	-0.57 <0.01	0.74 (<0.01)	fourth root
<i>Paraclinus integripinnis</i>	9	0.19 (0.28)	0.24 (0.16)	-0.24 (0.17)	0.05 (0.76)	0.08 (0.64)	-0.03 (0.89)	0.38 (0.02)	Log (x+1)
<i>Rhinogobios nicholsii</i>	10	-0.02 (0.90)	-0.08 (0.66)	0.18 (0.29)	0.04 (0.82)	0.33 (0.05)	-0.26 (0.13)	0.46 (0.01)	Log (x+1)

Considering the proximity of these stations and incomplete sampling over the entire time series, the surface night samples at Station 1 and Station D were combined to generate the 1974–2009 time series data set. Two minute plankton tows were conducted with a 333-µm mesh standard conical meter net. Samples were immediately preserved in a 5% formaldehyde-borate solution. The displacement volume of plankton was determined in the lab. All fish larvae were sorted, counted, and identified to the lowest possible taxon (Moser 1996) and recorded by larval stage (e.g., yolk sac, preflexion, flexion, post-flexion). To reduce the influence of the larval production of the harbor and associated localized processes, yolk sac and preflexion larvae were not used in these analyses; all other larval stages were combined. Larval catch (# of individuals) and plankton volume (ml) was standardized to filtered water volume (1000 m³) using a TSK flowmeter from January 1974–July 2008 and a General Oceanics Mechanical flowmeter (Model 2030R), thereafter. We also examined the following environmental conditions relevant to the study area, each represented by various indices including: Pacific Decadal Oscillation (PDO) (Mantua et al. 1997), multivariate ENSO index (MEI) (Parnell et al. 2010), North Pacific Gyre Oscillation (NPGO) (Di Lorenzo et al. 2008), North Pacific Index (NPI) (Trenberth and Hurrell 1994), Cumulative

Upwelling Index at 33°N (CUI) (Schwing et al. 1996), and the sea surface temperature recorded at the Scripps Institution of Oceanography Pier in La Jolla, California (SST) (Shore_Station_Program 2011).

For statistical analyses, we calculated annual mean densities and standard errors of late-stage larvae (#/1000 m³) and plankton volume (ml/1000 m³) by averaging across processed tows for each calendar year. In order to assess the relationship of the larval community among years, analyses were conducted in PRIMER (PRIMER-E Ltd. 2007) using the following routine. The annual mean density of larval taxa which comprised the top 99% of the overall cumulative catch were log (x+1) transformed and a Bray-Curtis similarity index was calculated. We ran a hierarchical cluster analysis with a SIMPROF test using 1000 permutations for the dendrogram to indicate significant group structure at a 0.05 significance level. We then used two-dimensional, non-metric multidimensional scaling (nMDS) to further examine segregation among years.

To describe the stationarity of the major component's annual means over time (years) within this data set we used the multiple regression package in STATISTICA (StatSoft 2007) on the top 10 larval taxa caught in the time series, the plankton volume, and total larval density. Prior to regression analyses data were tested for normal-

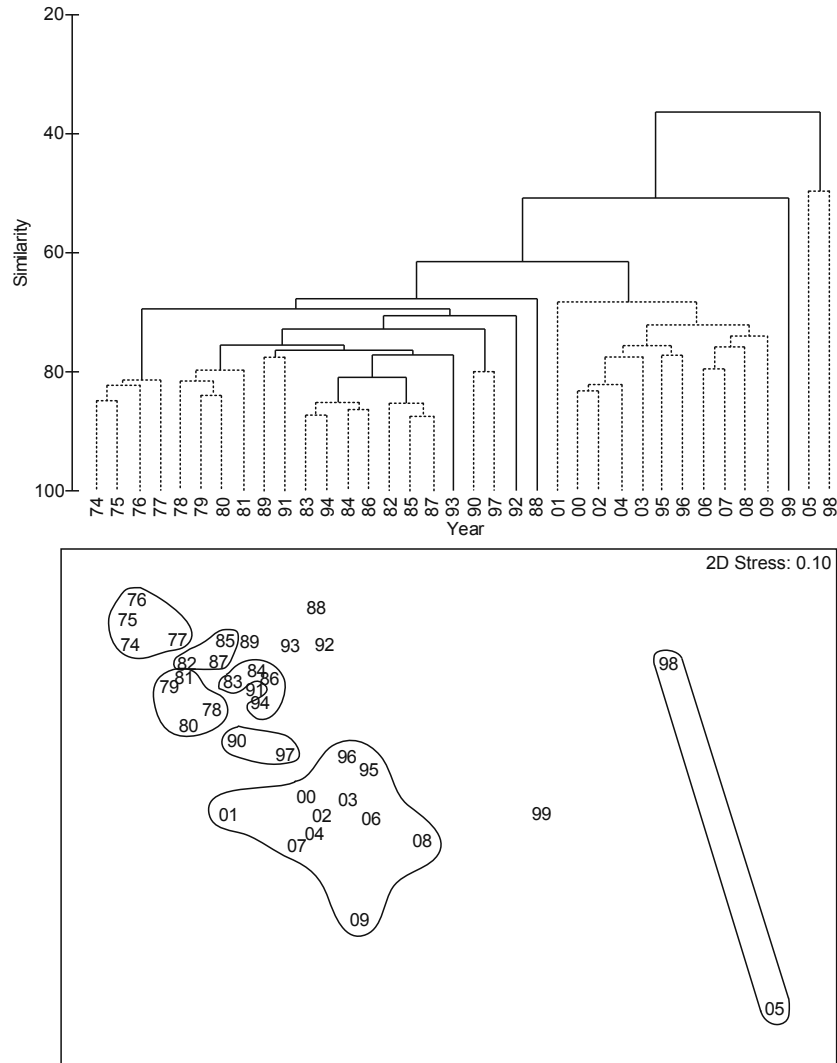


Figure 2. Bray-Curtis similarity matrix dendrogram of the annual larval community (above), dashed lines indicate groups of samples not separated (at significance level 0.05) by SIMPROF. nMDS two-dimensional ordination of the similarity matrix (below), significant clusters (as indicated by SIMPROF) are encircled with black lines. Years 89 and 91 together also form another significant cluster that was not encircled.

ity and autocorrelation. Departures from normality were tested using the Shapiro and Wilk W statistic in STATISTICA (StatSoft 2007), and data that were not normally distributed were transformed based upon their distribution (Legendre and Legendre 1998) (table 1). First order serial correlation was tested with the Durbin-Watson d statistic ($d_u \geq 1.52$) (Studenmund 2001) using residual analysis in R (R Development Core Team 2011). Where autocorrelation was detected, data were averaged over two-year periods, which successfully removed the serial correlation (Studenmund 2001). The normalized data were then tested for correlations with mean annual oceanic indices (MEI, PDO, NPGO, NPI, CUI and SST) and plankton volume using Pearson's r correlation coefficient in R (R Development Core Team 2011). Data that could not be transformed to a normal distribution were not further analyzed. To illustrate temporal (annual) pat-

terns, untransformed data are presented with trend lines fitted to them. Two important harvested taxa (*Paralabrax clathratus* and *Sardinops sagax*) were also included, however they were not treated in the correlation analyses due to model assumption violations.

RESULTS

From 1974–2009, 640 (annual mean = 17.77, median = 18) ichthyoplankton tows at Stations 1 and D (fig. 1) were completely processed and included in these analyses. Larvae ($N = 88,208$) comprised 99 taxa of which 31 represented 99% of the standardized catch. The larval community changed appreciably over the study period from the 1974–77 assemblages to the current condition. The cluster analysis with SIMPROF test identified 12 significant clusters of years (fig. 2). Clusters tended to form chronologically, demonstrating a general trend of larval

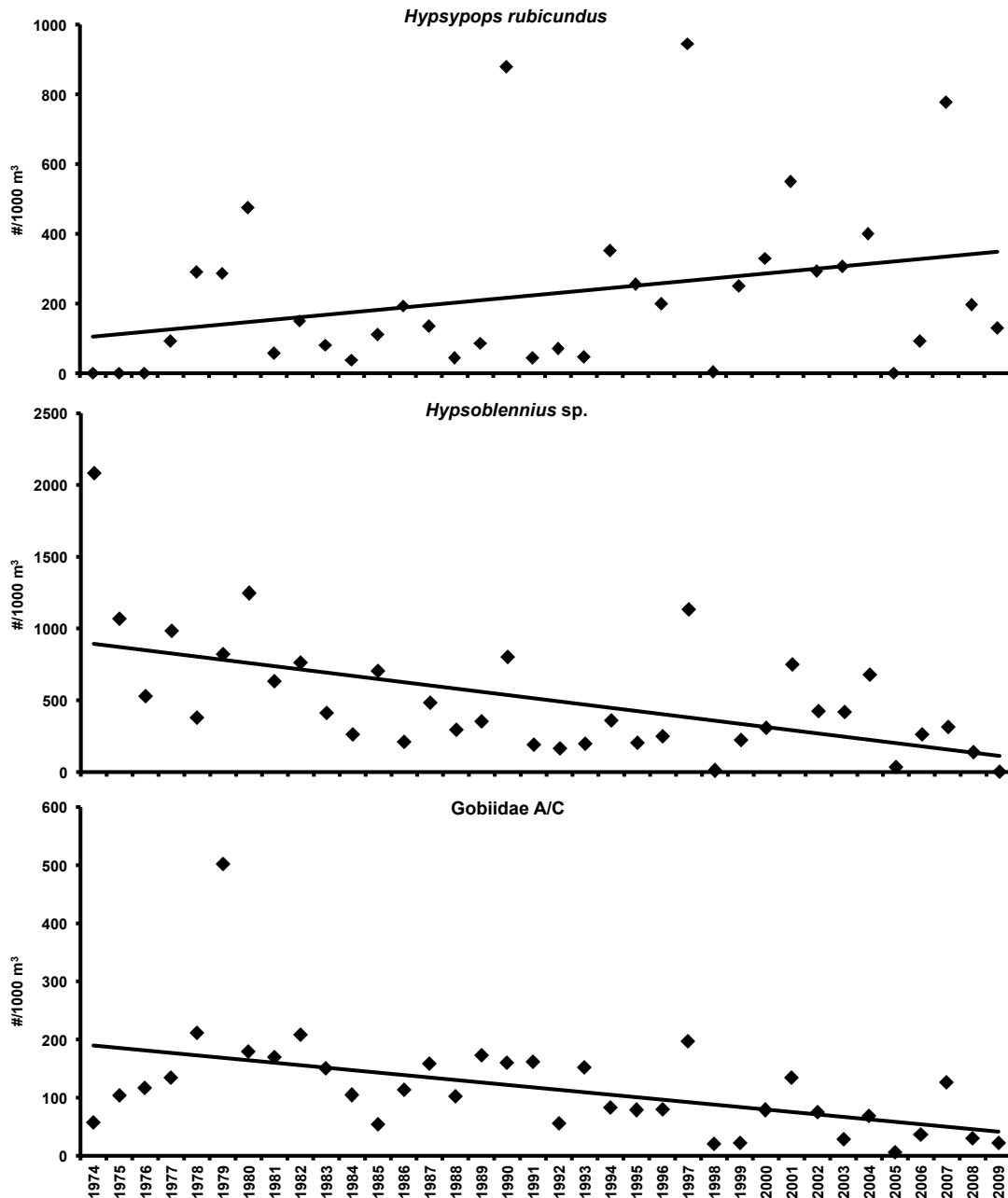


Figure 3. Larval density (# / 1000 m³) of *Hypsypops rubicundus*, *Hypsoblennius* sp. and Gobiidae A/C complex from 1974–2009.

community change from the 1974–77 cluster to the cluster containing the most recent years. Three years (1998, 1999, and 2005) lay outside this trend, being only approximately 50% or less similar to the rest of the time series.

Most taxonomic groups demonstrated a significant decline in abundance over the study and/or became virtually absent from the larval assemblage by the mid-1990s. The most abundant larval taxon, *Hypsoblennius* sp., started the time series at slightly above 2000 larvae / 1000 m³ in 1974 and had a long-term continual significant decline ($R = 0.560$, $F_{1,34} = 15.5$, $p < 0.001$), becoming rare (3.7 larvae per 1000 m³) by 2009. Low

Hypsoblennius catches were also observed in 1998 and 2005 (fig. 3; 12.2 and 38.3 larvae / 1000 m³). A significant decline was also observed in *Paralichthys integrispinnis* (fig. 4, $R = 0.428$, $F_{1,34} = 7.64$, $p = 0.009$) and in the Gobiidae A/C complex (*Clevelandia ios*, *Ilypnus gilberti* and *Quietula y-cauda*; fig. 3, $R = 0.576$, $F_{1,34} = 16.9$, $p < 0.001$). The *Paralichthys/Xystreurus* species complex also declined significantly ($R = 0.484$, $F_{1,34} = 10.4$, $p = 0.003$) with very few larvae captured from 1995–2009 (fig. 5). This second pattern was also observed in both sciaenid species, which declined precipitously (*Genyonemus lineatus*: $R = 0.869$, $F_{1,34} =$

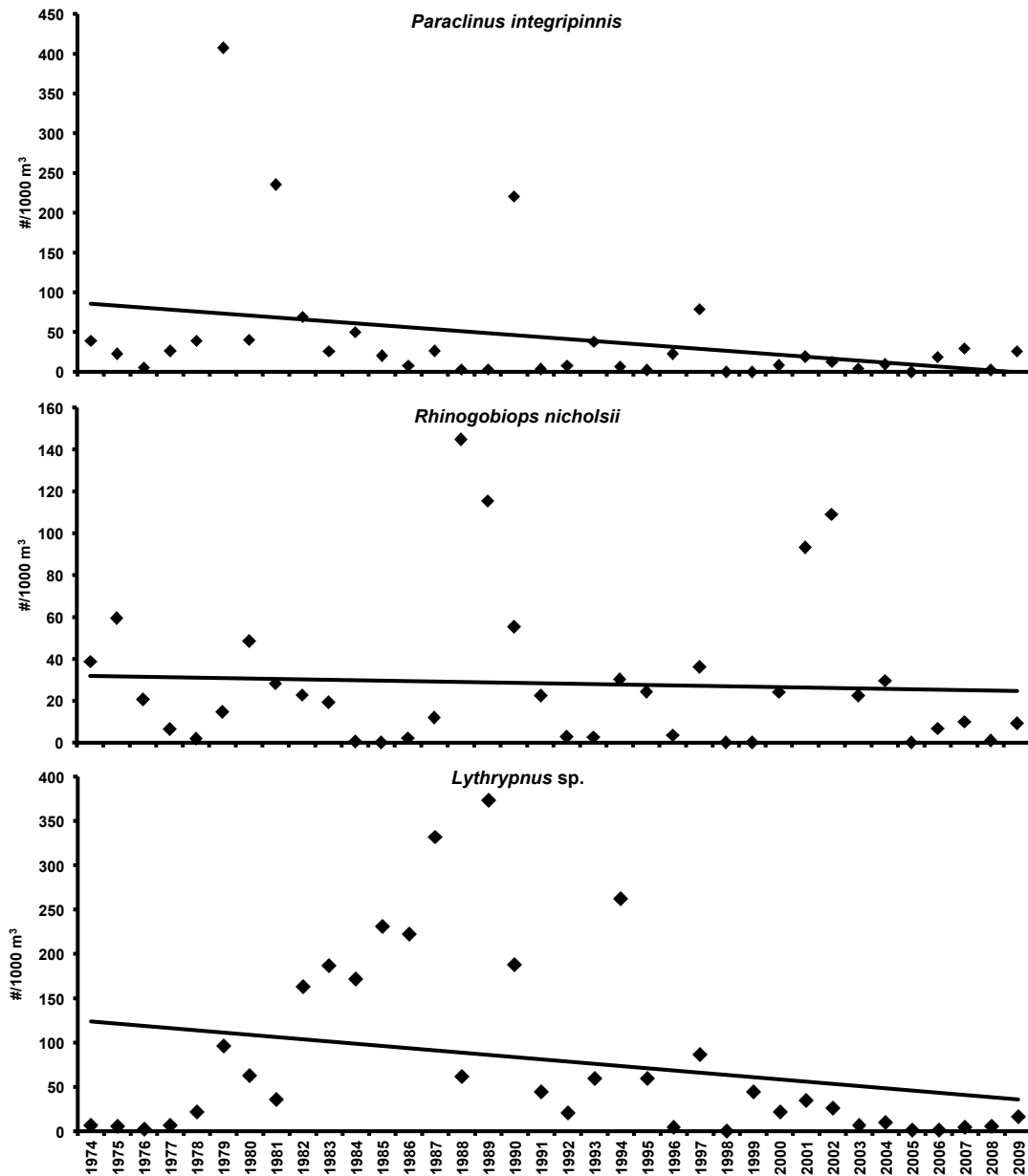


Figure 4. Larval density (# / 1000 m³) of *Paraclinus integripinnis*, *Rhinogobiops nicholsii* and *Lythrypnus sp.* from 1974–2009.

104.8, $p << 0.001$; *Seriphus politus*: 0.868, $F_{1,34} = 103.5$, $p << 0.001$). By 1995, *G. lineatus* were virtually absent from the larval assemblage and *S. politus* larvae all but disappeared in 1993 (fig. 5). This pattern of a significant decline and then near-absence by the mid-1990s was also observed in *Engraulis mordax* (fig. 6; $R = 0.867$, $F_{1,34} = 102.7$, $p << 0.001$), *Sardinops sagax* and *Paralabrax clathratus* (fig. 6).

A few taxa deviated from this general pattern of decline. The catch of *Hypsypops rubicundus* larvae was variable, did not exhibit first-order serial correlation ($d_u = 2.00$, $p = 0.904$), yet significantly increased (fig. 3; $R = 0.353$, $F_{1,34} = 4.8$, $p = 0.035$). No larvae were

caught from 1974–76 or in 2005, and only 2.8 larvae / 1000 m³ were caught in 1998. *Lythrypnus sp.* larvae also were absent in the early 1970s, but built to a peak in 1989 (373 larvae / 1000 m³) and then crashed by 2005 (fig. 4). A stationary, yet fluctuating time series was observed for *Rhinogobiops nicholsii* (fig. 4; $R = 0.101$, $F_{1,16} = 0.16$, $p = 0.691$). In fact, the annual catches of *R. nicholsii* exhibited first-order serial correlation ($d_u = 1.21$, $p = 0.002$).

Overall larval density (fig. 7; $R = 0.637$, $F_{1,34} = 23.3$, $p < 0.001$) and plankton volume (fig. 7; $R = 0.731$, $F_{1,16} = 23.3$, $p < 0.001$) significantly declined throughout the study period. Total larval density was correlated

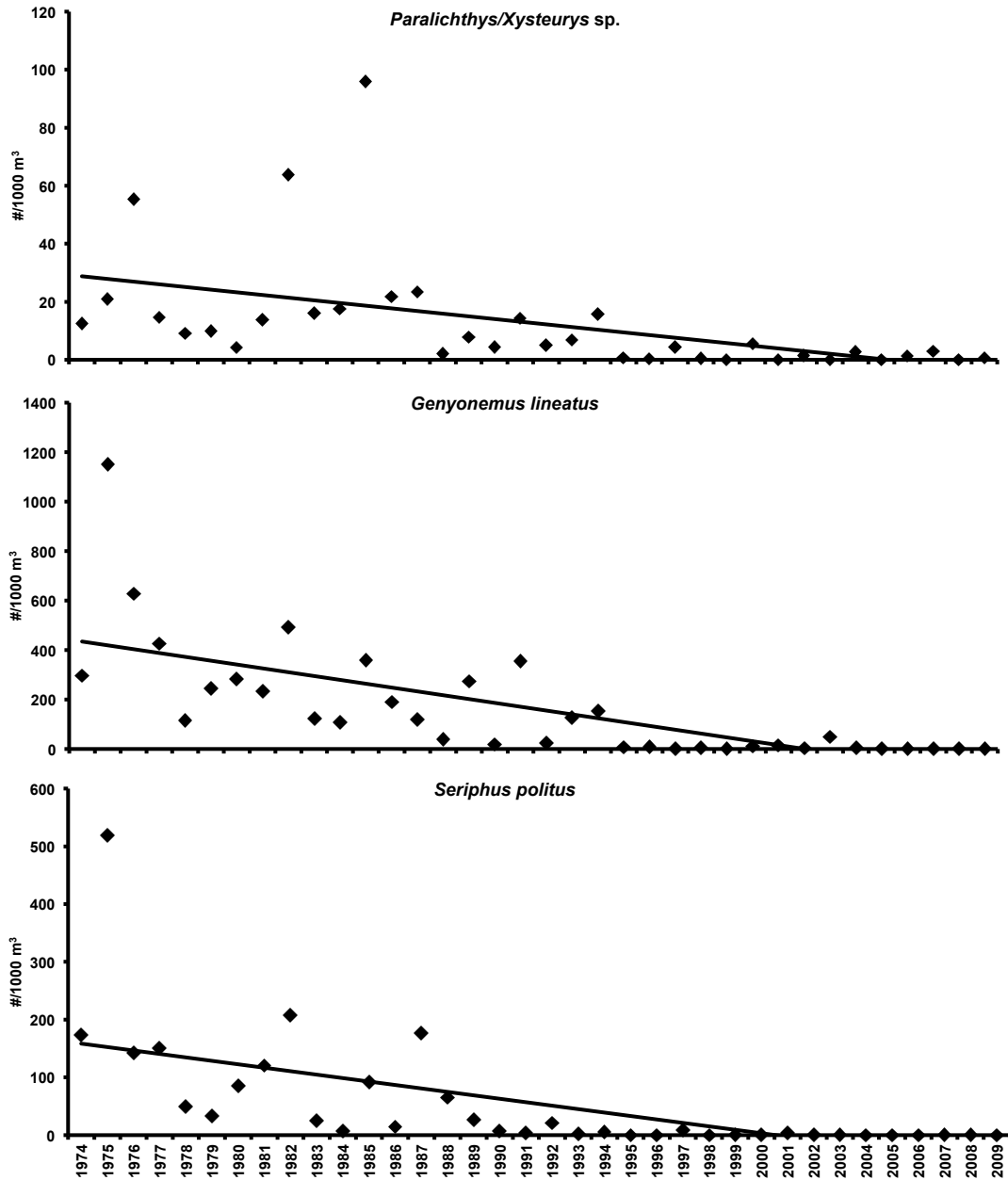


Figure 5. Larval density (# / 1000 m³) of *Paralichthys/Xysteurys* sp., *Genyonemus lineatus* and *Seriphus politus* from 1974–2009.

with the plankton volume ($R = 0.695, p < 0.001$). Larval catch peaked in 1975 (3579 larvae / 1000 m³) with a nadir in 2005 (84 larvae / 1000 m³). After the 1970s, the highest larval catch was in 1997 (2538 larvae / 1000 m³) followed by the second lowest catch in 1998 (59 larvae / 1000 m³). While the decline in plankton volume followed a cyclical pattern resulting in first-order serial correlation ($d_u = 1.23, p = 0.014$), the overall pattern may also be described by an inflection during the early 1990s. The lowest plankton volume reported was in 1993 (52 ml / 1000 m³) down from a high in 1975 (407 ml / 1000 m³). From 1991 through 2009, the time series

has some variation but is essentially stationary, remaining at approximately 25% of what was observed in 1974 (359 ml / 1000 m³) and 1975 (407 ml / 1000 m³) and approximately 50% of the plankton volume from 1976–90 (mean = 208 ml / 1000 m³). By 2009, we captured 15% (194 larvae / 1000 m³) of the larvae compared to the peak in 1975; similarly, there was a 70% decline in plankton volume between these years (407 ml / 1000 m³ and 122 ml / 1000 m³, respectively). Overall larval catch and plankton volume were positively correlated with the CUI (larvae: $r = 0.348, p = 0.037$; volume: $r = 0.460, p = 0.005$) and negatively correlated with SST

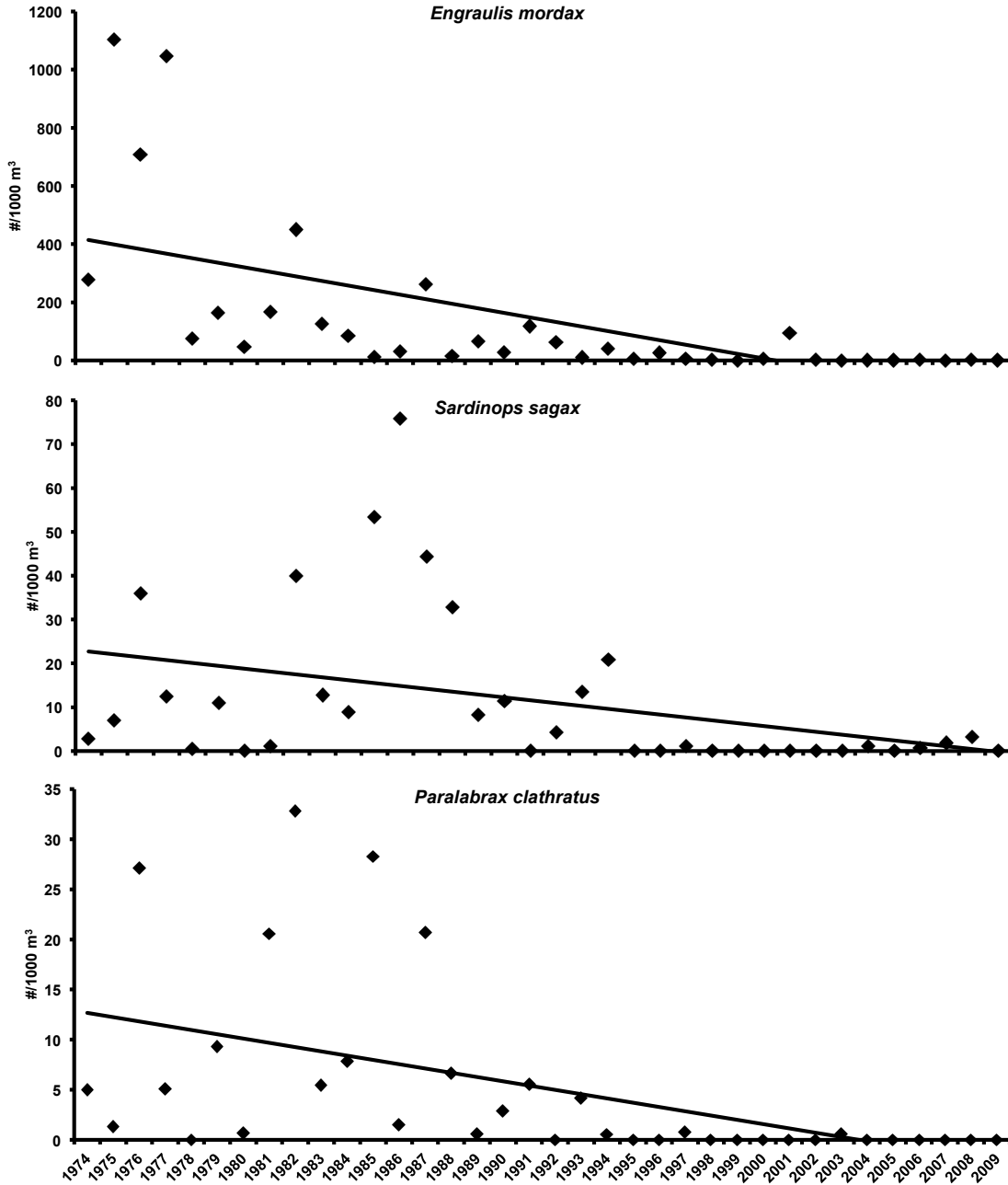


Figure 6. Larval density (# / 1000 m³) of *Engraulis mordax*, *Sardinops sagax* and *Paralabrax clathratus* from 1974–2009.

(larvae: $r = -0.453$, $p = 0.005$; volume: $r = -0.645$, $p < 0.001$). Plankton volume was also negatively correlated with the MEI ($r = -0.399$, $p = 0.016$), the only correlation with a climate index detected.

The response of various taxonomic groups to the oceanographic metrics varied appreciably, although with the exception of correlations with SST and CUI, oceanographic metrics (MEI, PDO, NPGO, and NPI) were not correlated with larval catch for individual taxa (table 1). *Hypsoblennius* catches were negatively correlated with SST (table 1; $r = -0.420$, $p = 0.011$). Sea

surface temperature was also negatively correlated with the annual larval density of the two sciaenids, *Genyonemus lineatus* ($r = -0.602$, $p < 0.001$) and *Seriphys politus* ($r = -0.569$, $p < 0.001$). *Paralichthys/Xystreureys*, *Hypsypops rubicundus*, Gobiidae A/C, *Lythrypnus* sp., and *Paralichthys integripinnis* larval catches did not correlate with the oceanographic metrics (table 1). Only *Rhinogobiops nicholsii* was correlated with the CUI ($r = 0.329$, $p = 0.050$). All taxonomic categories were correlated with plankton volume except for *Hypsypops rubicundus* and *Lythrypnus* sp.

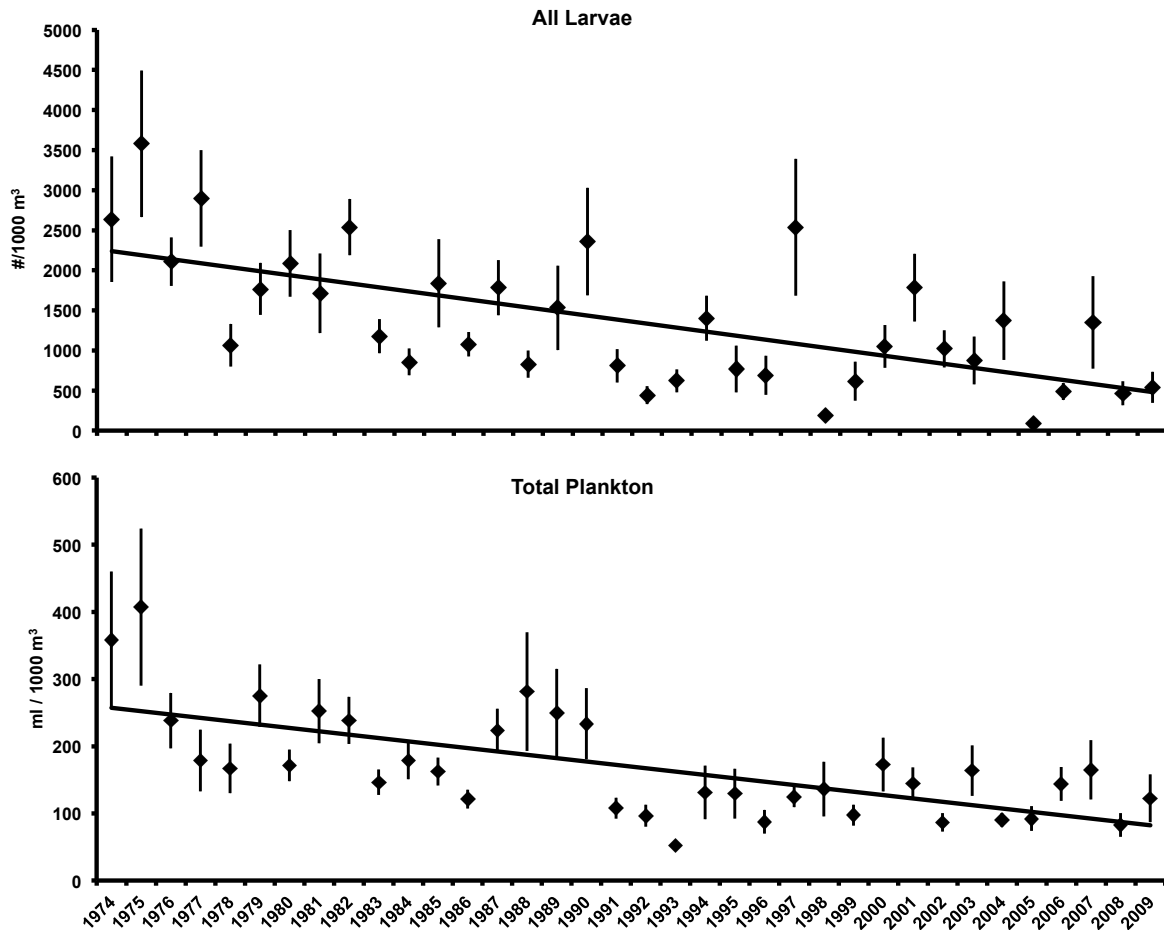


Figure 7. Total larval density (# / 1000 m³) and plankton volume (ml / 1000 m³) from 1974–2009. Error bars represent standard error.

DISCUSSION

The long-term trajectory of the ichthyoplankton assemblage of King Harbor is one of declining abundance with some aberrant annual assemblages (1998, 1999 and 2005), but no tendency toward returning to its pre-1976–77 condition (fig. 2). The 1998 and 1999 assemblages appeared to have been affected by the strength of 1997–99 ENSO, while previous ENSO effects were muted. The most unusual year was 2005, which was characterized by low larval densities and plankton volumes. We do not measure the volume of phytoplankton but, while not directly tested, we hypothesize that the unusually strong red tide that year (Shipe et al. 2008) resulted in low larval success. This poor larval year class may have been a result of larval mortality and/or reduced spawning success. One hint of the latter is the poor performance by nesting species (*Hypsypops rubicundus* and *Hypsoblennius* sp., fig. 3), whose larval catch was likely linked to nesting success.

Larval catch from these reef-nesting species (Clarke 1970; Stephens et al. 1970) was nearly synchronous after

Hypsypops rubicundus became established on the reef in 1977. For instance, both species had peaks in catch in 1980, 1990, and 1997; minor peaks in 1994, 2001, and 2004; and poor catches in 1984, 1988, 1991–93, 1998 and 2005. While yolk-sac and preflexion larvae were excluded from the analyses, reducing the influence of localized nests, these taxa still dominated the assemblage. Thus, these patterns were indicative of regional processes and/or they exhibited larval retention. *Hypsypops rubicundus* was the only taxon that catch increased over the study period. This was due to the rarity of adults and associated larval production on the reef from 1974–76 (Stephens et al. 1986). Excluding these years, the time series was stationary from 1977–2009 ($R = 0.158$, $F_{1,31} = 0.8$, $p = 0.381$). The appearance of *H. rubicundus* after 1976 clearly supports the hypothesis of a regime shift and the northern range shift of this subtropical species (Stephens et al. 1994). However, since our data set contains only three years in the cool phase prior to the regime shift, metrics such as the PDO or NPGO do not correlate with this change, as *H. rubicundus* was still

established and nesting in the harbor at the terminus of this study. In fact, *H. rubicundus* and *Lythrypnus* sp. are the only taxa we report on whose abundances are not correlated with one of the studied metrics (table 1). *Hypsoblennius* sp. declined significantly, and while this was negatively correlated with SST and positively correlated with plankton volume (table 1), we note that the harbor has not been dredged since 1989 and the inner reefs have been silting in, reducing blenny habitat (Pondella personal observation). Nonetheless, *Hypsoblennius* was declining prior to 1989. Thus, multiple factors affect the success of nesting species in King Harbor.

The reef gobies, *Lythrypnus* sp. and *Rhinogobiops nicholsii*, did not have a significant change over time, but followed very different trajectories. *Rhinogobiops nicholsii* catch correlated with upwelling and plankton volume, which were also correlated with each other (table 1). *Lythrypnus* sp. started the time series like *Hypsypops rubicundus*, another indication of a regime shift with the infusion of this southern group. The cause of its decline after the peak in 1989 seems more mysterious, but is likely rooted in a series of poor year classes of a relatively short-lived species. We also observed a decline in *Paralichthys integripinnis*, another small, cryptic reef species (fig. 4). With the exception of *R. nicholsii*, all the small reef associated fishes (*Hypsoblennius* sp., *Lythrypnus* sp., and *P. integripinnis*) declined.

All other taxa either significantly declined or became absent during this study. All of the commercial and recreational species (figs. 5 and 6) followed a similar pattern of variable but declining larval catches through the 1990s, with little or no catch through the remainder of the time series. All of these declines were correlated with plankton volume, with *Seriphys politus*, *Genyonemus lineatus*, *Engraulis mordax* and the *Paralichthys/Xystreurus* group also negatively correlated with SST (table 1). In the laboratory, both *G. lineatus* and *Paralichthys californicus* eggs exhibited poor hatching success at water temperatures > 20°C, so perhaps the increasing SST contributed to these declines (Gadomski and Caddell 1996). Recent reports for *S. politus*, *G. lineatus*, *Paralabrax clathratus*, and *P. nebulifer* have demonstrated a similar decline in the adult populations of these fishes (Erisman et al. 2011; Miller et al. 2011) suggesting that poor larval production was a factor in these declines. This pattern also appears to be occurring with one of the two primarily pelagic species in our study, *Engraulis mordax*. Commercial landings have declined since 2001 (CDFG 2011) along with rather steady declines in larval catches in the core CalCOFI region since 1987, with the exception of a large single year increase in 2005 (Fissel et al. 2011). For the other pelagic species, *Sardinops sagax*, commercial landings have remained steady near their allowable harvest levels (CDFG 2011), while annual larval den-

sities from CalCOFI sampling appear to be increasing or stable since the early 1980s (Moser et al. 2001; Moser et al. 2002). This pattern is in contradiction to the decline in larval densities we observed, however, *S. sagax* spawning has been largely occurring north of Point Conception and/or well offshore of southern California during this time period, potentially making larvae less available in our sampling area (NOAA Fisheries Resources Division: <http://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=16135>). Overall commercial or recreational species fared far worse than non-fished species during this study with larval catches going to zero by the mid-1990s.

The Redondo Beach Generating Station withdraws and discharges cooling water at multiple locations in and around the King Harbor (Stephens et al. 1994) (fig. 1), potentially concentrating or dispersing larvae at the sampling area. However, a previous study provided no indication that annual larval densities are influenced by annual variation in cooling water flow (Miller et al. 2009). While a significant positive correlation between annual flow rates and annual *S. politus* larval densities was observed over the entire period both data sets were available (1979–2006), this was a spurious statistical artifact of including all data (years) in the analysis. While cooling water volumes have tended to decline since their peak in 1980, with the lowest flow levels occurring after 2003 (see Miller et al. 2009; fig. 8a), if the years after *S. politus* densities declined to 0 (i.e., after 1994; fig. 5) are excluded from the correlation analysis, no relationship is observed with cooling water flow ($r = 0.028$, $p = 0.90$).

The most ubiquitous indicator for decline in the various larval taxa was the significant decline in plankton volume. It is curious that, while a significant decline in plankton volume can be described by a linear model, after its nadir in 1993, volumes remained stable, but this was concomitant with the disappearance of multiple larval taxa from our catches. Plankton volume was negatively correlated with an increase in SST over this time period, a finding consistent with the hypothesis that the warming waters of the Southern California Bight is associated with a reduced nutrient nearshore environment (Parnell et al. 2010). Macroscale oceanographic indices CUI and MEI also appear to be factors associated with plankton production (Stephens et al. 1994). Plankton volume and its correlates (SST and CUI) appeared to be informative in describing the significant decline in overall larval density from 1974–2009. While we did not explicitly test this hypothesis, it seems reasonable to assert that reduced plankton volume was a significant factor in the decline of late stage larvae in this nearshore environment due to reduced foraging opportunities.

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