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Faunal shift in southern California's coastal fishes: A new assemblage and trophic structure takes hold

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A B S T R A C T

Trends in coastal fish abundance indices were examined using a novel 39-year (1972–2010) time series recorded at southern California coastal power plants. Since 1972, the annual mean abundance index significantly declined ($r^2 = 0.45$, $p < 0.001$). The mean annual biomass index likewise declined but with a large interruption in 2005–2006 when an influx of large bodied, southern species increased the annual means. Ensemble mean abundance indices for fished and unfished species declined at similar rates. Two faunal shifts were identified, 1983–1984 and 1989–1990. The ensemble mean, annual entrapment rate abundance index during the current period (1990–2010) represents only 22% of that recorded during the first and most abundant period, 1972–1983. The mean biogeographic distribution of the assemblage was non-linear over time including a shift south during the 1980s through the 1990s before shifting north in recent years. The northern shift in recent years accompanied higher variability than previously recorded and was likely related to the overall low abundance. Since the early 1980s, the mean trophic level derived from abundance declined. The observed patterns were not correlated with commonly employed composite indices such as the Pacific Decadal Oscillation, but did show some sensitivity to changes in coastal seawater temperature and density over time. Timing of the observed faunal shifts in the fish assemblage was consistent with reported oceanographic shifts. These data suggested factors beyond fishing, such as oceanographic change, have substantially impacted the coastal fishes of southern California.

1. Introduction

Marine community composition, abundance, and distribution change in response to low-frequency oceanographic conditions (Barry et al., 1995; Roemmich and McGowan, 1995; Holbrook et al., 1997; Schwartzlose et al., 1999; Alheit and Niquen, 2004; Genner et al., 2004, 2010; Perry et al., 2005; Lehodey et al., 2006; Hsieh et al., 2009; Alheit and Bakun, 2010). Fishing pressure increases sensitivities to environmental perturbations (Coleman et al., 2004; Hsieh et al., 2006, 2008; Anderson et al., 2008; Brander, 2010; Genner et al., 2010; Hidalgo et al., 2011). Further, science increasingly recognizes the detrimental effects of fishing lower trophic level organisms (Anderson and Piatt, 1999; Cury et al., 2011; Smith et al., 2011). Advances in remote sensing and development of long time series resulted in increased recognition of the environment-fishing integrated effects as well as success at disentangling these effects (Beaugrand et al., 2003, 2008; Harley et al., 2006; Brander, 2007, 2010; Hsieh et al., 2008; Genner et al., 2010). For instance, prior work in southern California using larval assemblages identified faunal shifts related to climate (Hsieh et al., 2009) and increasing environmental sensitivity in fished species (Hsieh et al., 2006, 2008). Similarly, data recorded during demersal trawl sampling (outside of California) provided additional insights into fish community responses to environmental change (Perry et al., 2005; Collie et al., 2008). While useful, these studies fail to capture patterns of change in water column and/or rocky-reef associated fishes not adequately sampled by plankton nets or demersal trawls.

Recently, a time series constructed from data recorded during coastal southern California power plant environmental monitoring has proven uniquely suited to address some of the issues discussed above, namely patterns of change in coastal fishes that were otherwise undersampled (Miller et al., 2011). Set in the Southern California Bight, a transitional biogeographic zone (Horn et al., 2006), this 39-year (as of 2010) time series represents sampling at fixed locations across the Bight without the bias of traditional net sampling, e.g. targeted species, areas, diel periods, or weather conditions. Size and spatial bias occurred as few large, powerful

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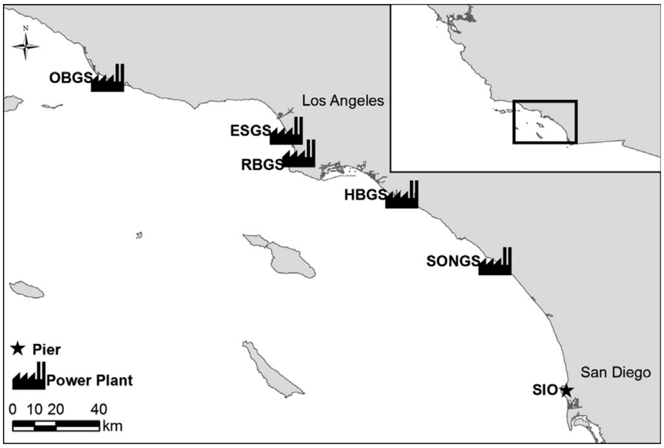

Fig. 1. Entrapment data were recorded at the five power plants depicted from 1972 to 2010, for most power plants. OBGS = Ormond Beach Generating Station, ESGS = El Segundo Generating Station, RBGS = Redondo Beach Generating Station, HBGS = Huntington Beach Generating Station, and SONGS = San Onofre Nuclear Generating Station. Sea surface temperature and salinity were recorded daily at the Scripps Institution of Oceanography Pier (SIO, 1916–2010).

swimming migratory species, e.g. *Thunnus* sp. or *Seriola lalandi*, have been taken while power plant monitoring has proven effective at sampling recently settled young-of-the-year rockfish (Field et al., 2010). These power plant data were further ground-truthed. Sciaenid abundance indices derived from the southern California power plant time series reflected offshore population densities as described by more conventional gill net sampling (Miller et al., 2011).

Utilizing the power plant time series, we examined patterns of change across a marine assemblage under a variety of fishing pressures (Leet et al., 2001) and environmental conditions. While fishing impacted some of these species, we hypothesize that environmental forcing contributed strongly to declines in the southern California coastal fish assemblage as a whole. Environmental forcing includes documented oceanographic regime shifts in the Northeast Pacific Ocean in 1976–1977 and, possibly, 1989 in addition to a long-term warming trend (Miller et al., 1994, 2011; Roemmich and McGowan, 1995; Hare and Mantua, 2000; Bograd and Lynn, 2003; Bond et al., 2003; McGowan et al., 2003). Assemblage responses following the regime shifts were reported for numerous marine populations across the Northeast Pacific (Hare and Mantua, 2000; Cloern et al., 2010), but few investigations of coastal Southern California Bight communities appear in the literature. The most prominent coastal study examined southern California rocky-reef communities (Holbrook et al., 1997). Therefore, a more directed and updated examination of fish assemblage abundance and composition patterns over time was warranted for this area where much of the marine community was structured by variable nearshore currents retaining (exporting) larvae out of the Bight (Selkoe et al., 2006, 2007, 2010; White et al., 2010).

2. Materials and methods

2.1. Data sources

Systematic monitoring of fishes entrapped in once-through-cooling water systems at five southern California coastal power plants (Fig. 1 and Table 1) resulted in a 39-year time series of littoral fish species abundance (1972–2010) and biomass (1980–2010). It recorded patterns of variability in a suite of mostly small (≈<500 mm SL; Love et al., 2005) coastal species that range from heavily harvested to minimally harvested. Few of these species, with exceptions, were rarely discussed in the scientific literature. Each power plant was unique in its design, intake placement, volume of cooling water circulated, and operational history (Table 1).

Seawater withdrawal was stopped and heat treatments discontinued at some intakes during the time series: one El Segundo Generating Station (ESGS) intake in 2003, one Redondo Beach Generating Station (RBGS) intake in 1988, and one San Onofre Nuclear Generating Station (SONGS) intake in 1993. Two new intakes at SONGS began operating in 1983 (Unit 2) and 1984 (Unit 3). The discontinued flows were minimal reductions in comparison to the additional flow at SONGS.

At each power plant, cooling water emptied into sedimentation basins at the terminus of the intake conduits. In the sedimentation basin, water intake velocities diminished to the point entrained fishes could take up residence, but not escape. All cooling water was filtered through 1-cm square mesh traveling screens where fish and other material were impinged. Heat treatments were conducted at variable intervals, commonly ranging once every 6–12 weeks at each intake to control biofouling. Exceptions include no heat treatments at Huntington Beach Generating Station (HBGS) in 1999–2000, Ormond Beach Generating Station (OBGS) in 2006–2010, and RBGS in 2009–2010. During each heat treatment, seawater temperatures in the sedimentation basin were raised to >38 °C, resulting in all accumulated fishes becoming impinged on the continuously rotating traveling screens. All impinged material (fish, macroinvertebrates, aquatic vegetation, trash, etc.) was washed off traveling screens into a collection area. Each heat treatment represented a single sampling event during which fishes were sorted from the total impinged sample. Exceptionally large samples required subsampling of the catch. Subsample decisions were made *in situ* based on the survey-specific conditions and

Table 1
The design, placement, and operational parameters for each generating station supplying data on fish entrapment. Parameters include the number (#) of offshore, submerged, cooling water intakes used. If more than one intake has been used by the station, then the parameters represent the mean description for all intakes for each station. Intake depth (m) is the isobath where the intake was located. Riser height (m) is the height above the seafloor the intake opening is situated. Distance offshore (m) is the distance from the shoreline the intake opening is placed. Habitats surrounding the intakes range from sand to kelp reef. All intakes have rocky rip-rap placed around the intake riser as protection against wave energy. The mean flow (10^6 m^3) represents the mean cooling water circulated (filtered) between heat treatments with standard error (SE).

Parameter	Ormond Beach	El Segundo	Redondo Beach	Huntington Beach	San Onofre
# of Intakes	1	2	2	1	3
Intake depth (m)	10.7	9.8	13.7	27.5	9.1
Riser height (m)	4.1	3.0	3.0	2.4	2.9
Distance offshore (m)	631	698	289	457	960
Habitat surrounding intake	Sand	Sand	Reef	Sand	Reef, Kelp
# of Surveys	196	350	394	278	480
Mean # of surveys/year (SE)	5 (0.5)	9 (0.9)	10 (1.0)	7 (0.5)	13 (0.8)
Mean flow (10^6 m^3) (SE)	97.0 (5.4)	52.1 (2.8)	70.3 (3.2)	53.3 (1.8)	292.1 (83.2)
Years surveyed	1975–2005	1972–2010	1974–2008	1972–1998, 2001–2010	1972–1974, 1976–2010