

Abstract.—We used data from fish-impingement studies of the coastal electric generating stations of Southern California Edison Company to examine patterns of nearshore rockfish abundance in the southern California Bight. The impingement data spanned 17 years (1977–93), comprised a minimum of several surveys per month and included power plants from throughout much of the Bight. Sixteen rockfish species were taken and six (olive rockfish, *Sebastes serranoides*; brown rockfish, *S. auriculatus*; bocaccio, *S. paucispinis*; blue rockfish, *S. mystinus*; treefish, *S. serriceps*; and grass rockfish, *S. rastreliger*) accounted for 99% of all rockfish caught. Most of these fishes were between 0 and 2 years old. Catch rates for all six of these species have dropped substantially since the inception of the survey in 1977. Catch rates peaked in the early 1980s, dropped by a factor of over 100 to a low in 1984, and have generally remained low through 1993. One species, blue rockfish, has not been taken since 1984. We compared our rockfish impingement data from one power station in King Harbor, Redondo Beach, with data from scuba transects conducted during the same period within King Harbor. The results of the two surveys strongly suggest that the catch rates of rockfishes by power plants reflect the abundance of these fishes surrounding the plants. We suggest that the reduction in the abundance of nearshore rockfishes in the southern California Bight is due to both decreased recruitment success, reflecting long-term adverse oceanographic conditions, and to overfishing.

Declines in nearshore rockfish recruitment and populations in the southern California Bight as measured by impingement rates in coastal electrical power generating stations

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The oceanographic regime off southern California is extremely dynamic, undergoing decadal changes in temperature, upwelling, and offshore transport (Roemmich and McGowan, 1995; MacCall, 1996). Beginning in 1976, the waters of the southern California Bight (SCB) began to warm and temperatures have generally remained warmer than those of the previous four decades (MacCall, 1996), characterizing part of a process of fluctuating water temperatures that has occurred for thousands of years (Soutar, 1967; Soutar and Isaacs, 1974; Baumgartner et al., 1992).

This warming trend is associated with a decline in upwelling and subsequent decreased zooplankton biomass (Roemmich and McGowan, 1995; Hayward et al., 1996). In addition, several studies in the SCB indicate that this change in the physical regime has led to changes in reef fish population size, community structure, and recruitment (Stephens et al., 1986; Holbrook and Schmitt, 1996). An ongoing 20-year survey at King Harbor, Redondo Beach, as well as one of 13 years duration at Santa Cruz Island, north-

ern Channel Islands, has documented population declines in many fish species (Stephens et al., 1994; Holbrook and Schmitt, 1996). In particular, the King Harbor study shows a severe decline in the abundances of rockfishes (genus *Sebastes*). Some species, such as the blue rockfish, *S. mystinus*, that were very common in the mid-1970s, virtually disappeared by the mid-1980s and have remained absent (Stephens et al., 1986, 1994).

Despite widespread recognition that long-term data are essential for understanding population fluctuations and for correlating changes in population size with environmental events, most studies of reef fishes are limited in both temporal and spatial scales. The few cases where populations have been tracked for many years are limited in spatial scale. Both the Santa Cruz Island and the King Harbor studies, although of relatively long duration, have tracked fish populations at only a single site. A more accurate portrayal of fish abundances would come from multisite surveys, conducted over a number of years. Data from the fish-impingement studies

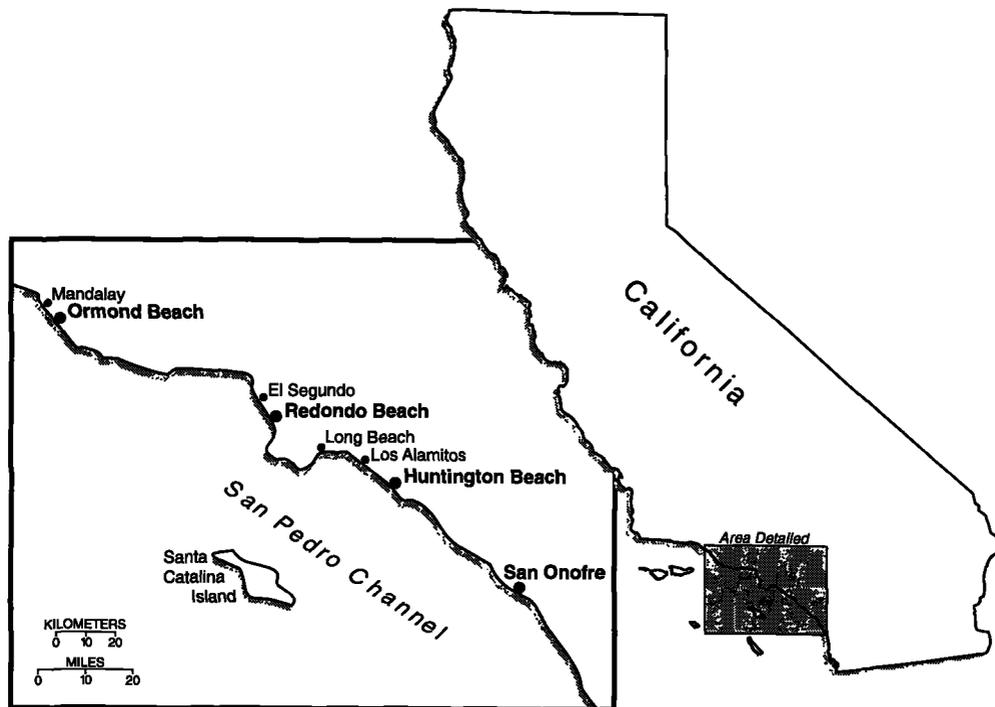


Figure 1

Location of the eight Southern California Edison coastal electric generating stations. For this survey, we used fish-impingement data from the four stations indicated in bold.

of the Southern California Edison Company (SCE) provide a unique long-term look at fish populations in the SCB. The impingement data are relatively long-term (17 years), are collected at fine temporal resolution (at minimum several surveys per month), and encompass much of the broad spatial distribution of the SCB.

This paper is the first in a series investigating changes in fish abundances over the past 17 years in the SCB using the extensive data set collected by SCE. Here, we report on patterns of rockfish (genus *Sebastes*) impingement from 1977 to 1993. Although rockfish made up slightly less than 1% of all species impinged in the SCE stations, as a group they are extremely important in both recreational and commercial fisheries in southern California (Wine¹; Ally et al.²; Barsky³). In addition to documenting changes in abundance of common species, we discuss patterns

of change in abundance in relation to changes in sea surface temperature over the same time period.

Materials and methods

Data on fish impingement were obtained from the biological monitoring program conducted by Southern California Edison at coastal electric generating stations throughout much of the SCB. Although fish impingement was monitored at all eight stations, we chose to analyze data from the four stations that had the most continuous sampling effort over the period 1977–93 (Fig. 1). Three of the plants, Ormond Beach, Redondo Beach, and Huntington Beach, are fossil fuel fired; San Onofre is a nuclear generating station. Although the timing of sampling among the stations was haphazard, samples were taken at least once and up to 11 days per month. The number of samples taken per year at each station are shown in Table 1.

All power plant intakes are situated on sandy bottom and all are surrounded by varying amounts of rock rubble. Intake openings are at approximately equal depths (8–10 m) with the exception of Redondo Beach station where intakes are situated in slightly deeper water (14 m). The intake openings vary in their distance to the shoreline from 285 m at Redondo Beach to 965 m at San Onofre.

¹ Wine, V. 1979. Southern California independent sport fishing survey. Annual report. 3. Calif. Dep. Fish Game, Mar. Res., Admin. Rep. 79-3.

² Ally, J. R. R., D. S. Ono, R. B. Read, and M. Wallace. 1991. Status of major southern California marine sport fish species with management, based on analyses of catch and size composition data collected on board commercial passenger fishing vessels from 1985 through 1987. Calif. Dep. Fish and Game, Mar. Res. Div., Admin. Rep. 90-2, 376 p.

³ Barsky, K. 1996. California Department of Fish and Game, 530 E. Montecito St., Santa Barbara, CA, 93103. Personal commun.

Table 1

Number of fish-impingement samples taken during normal operations at four coastal electrical power generating stations from 1977 to 93.

Year	Huntington Beach	Ormond	Redondo (units 7-8)	San Onofre 1	San Onofre 2	San Onofre 3
1977	0	0	87	76	0	0
1978	13	13	67	90	0	0
1979	55	68	73	93	0	0
1980	98	100	103	34	0	0
1981	60	58	52	42	0	0
1982	47	43	35	19	27	0
1983	57	55	48	23	61	8
1984	57	50	58	28	65	70
1985	56	54	55	63	84	67
1986	53	57	49	28	69	101
1987	45	57	43	51	57	60
1988	41	47	25	42	57	47
1989	38	46	47	40	46	58
1990	26	37	30	36	55	43
1991	16	43	50	48	46	57
1992	37	44	38	58	78	68
1993	67	40	31	24	65	69
Total	753	799	737	629	710	648

All data presented were obtained during "normal" power plant operations. During normal operation, fishes are entrained in the cooling water and flow through conduits to the station where they are impinged on traveling screens in the forebay of the power plant. "Normal" fish-impingement surveys consist of counting all fishes impinged during a 24-h period of routine plant operations (e.g. on full flow days). Impinged fishes are separated from incidental debris, sorted by species, identified, counted, and measured to standard length (mm).

Because flow rates differed slightly among stations and years, all abundance data are presented as the number of fishes per million gallons of water passing through the intake. Flow rates also varied within each station from month to month but remained constant during any given month. Thus, it was necessary to calculate monthly mean catch rates for each site. Annual mean catch rates are presented in this paper. For most analyses, annual catch is the grand mean of all monthly means across all sites for that year. For one comparison, mean annual catch rates are calculated for the Redondo station only.

Results

During this survey, 27,546 rockfishes, representing 16 identifiable species, were caught (Table 2). Olive rockfish (*Sebastes serranoides*) were the most com-

Table 2

Number of rockfish impinged during normal operations at four coastal electrical power generating stations from 1977 to 93.

Species	Common name	Number
<i>Sebastes serranoides</i>	Olive rockfish	14,571
<i>S. auriculatus</i>	Brown rockfish	5586
<i>S. paucispinis</i>	Bocaccio	3262
<i>S. mystinus</i>	Blue rockfish	1640
<i>S. serriceps</i>	Treefish	1124
<i>S. rastrelliger</i>	Grass rockfish	1092
<i>Sebastes</i> spp.	Unidentified rockfish	129
<i>S. carnatus</i>	Gopher rockfish	65
<i>S. dalli</i>	Calico rockfish	44
<i>S. caurinus</i>	Copper rockfish	9
<i>S. miniatus</i>	Vermilion rockfish	8
<i>S. atrovirens</i>	Kelp rockfish	8
<i>S. goodei</i>	Chilipepper	5
<i>S. melanops</i>	Black rockfish	2
<i>S. ovalis</i>	Speckled rockfish	1
<i>S. maliger</i>	Quillback rockfish	1
<i>S. flavidus</i>	Yellowtail rockfish	1
	Total rockfish	27,546

monly taken, followed by brown rockfish (*S. auriculatus*), bocaccio (*S. paucispinis*), blue rockfish (*S. mystinus*), treefish (*S. serriceps*), and grass rockfish (*S. rastrelliger*). These six most abundant species represented 99% of all rockfish caught. From the lengths of the fishes sampled (Fig. 2), we determined

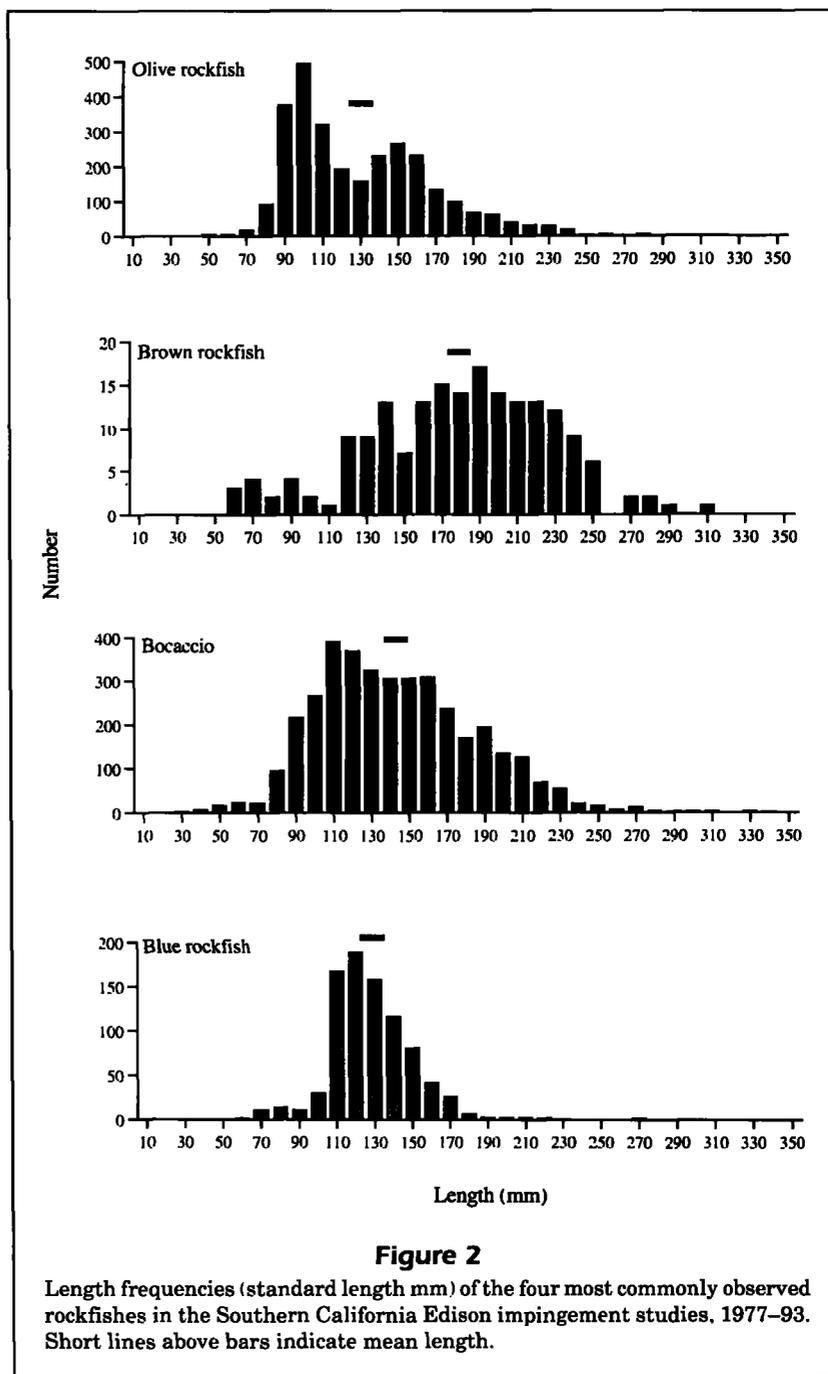
that most of the rockfishes impinged were between 0 and 2 years old (Love and Westphal, 1981; Love et al., 1990; Love and Johnson, in press).

The life histories of these six species encompass a range of habitat preferences and behaviors. Olive rockfish and blue rockfish are near-shore, midwater fishes. Grass rockfish and treefish are shallow-water benthic species, usually inhabiting high relief. Brown rockfish are found primarily along sand-rock interfaces or over low relief. Bocaccio are mid-water fish; the young are found in shallow water and they migrate into deeper water as subadults (Feder et al., 1974).

We analyzed abundance patterns over time for all rockfishes combined and separately for the six most common species. Since the inception of the survey in 1977, mean catch rates for all rockfishes combined have dropped substantially (Fig. 3). Catch rates peaked in the early 1980s, dropped precipitously (by a factor of over 100) to a low in 1984 and have generally remained low through 1993. The exception was a one-year, nearly tenfold rise between 1987 and 1988 which was due primarily to a large influx of young bocaccio, although olive, brown, and grass rockfish catches also increased slightly during this period (Fig. 4).

Despite very different life histories, the six most abundant species showed generally similar impingement patterns over time (Fig. 4). In all six species, peak impingement occurred in the late 1970s or early 1980s. Maximum catches occurred in 1977 (bocaccio), 1980 (grass, blue, and brown rockfish), or 1981 (olive rockfish and treefish). Between 1983 and 1993, with only one exception, impingement of these six species was either extremely low or nonexistent. The exception occurred in 1988, when relatively large numbers of bocaccio were impinged. The 1988 peak in bocaccio abundance was the result of catches at only two stations, Redondo and San Onofre, in May of that year.

Between the late 1970s and early 1990s, there was a sharp drop in the amount of rockfish impingement in the SCE coastal generating stations. We believe



that this pattern reflects the abundance of these fishes in nearshore waters at the time. To address this issue, we compared our impingement data for olive rockfish, blue rockfish, and bocaccio with that from visual diving surveys conducted on transects in King Harbor, Redondo Beach (Stephens⁴). The visual surveys primarily record juvenile abundance

⁴ Stephens, J. 1997. Department of Biology, Occidental College, 1600 Campus Rd., Los Angeles, CA, 90041. Unpubl. data.

because rockfish of the three target species tend not to remain in King Harbor as adults. For this comparison, we used only the yearly catch rates from the Redondo Beach electrical power generating station that is closest to the King Harbor transects. In the dive survey, all three species were common during the mid- to late-1970s (Fig. 5). However, by 1980, individuals of these species were rarely seen. Blue rockfish and bocaccio have not been observed since that time. Olive rockfish have remained scarce, although small population increases were noted in the late 1980s and early 1990s. The patterns of impingement for these three species at Redondo show similar trends to that from the diver surveys. During the late 1970s, olive rockfish were commonly impinged but catches declined markedly by 1980 (Fig. 5). Two of the slight increases noted in the diver survey in 1985 and 1991 were reflected in the impingement study, although the magnitude of the increase is greater in the SCE data in 1985 and in the diver surveys in 1991. In the impingement survey, blue rockfish catches were relatively high in the late 1970s and declined to zero in 1981 (Fig. 5). This pattern matches precisely the pattern observed in the diver surveys, with one exception. The exception was a one-day pulse of small blue rockfish caught in a single day at the Redondo station in 1982. Regarding blue rockfish, the two data sets are in general agreement; no blue rockfish have either been observed or captured since 1983. Changes in abundance of bocaccio are also similar between the impingement data and the diver surveys (Fig. 5), with the exception of a large pulse of young bocaccio impinged during a single collection in 1988.

Discussion

From at least the 1950s through the late 1970s, black-and-yellow, blue, gopher, and olive rockfishes, as well as young bocaccio, were important components of the inshore rocky reef community of the SCB (Limbaugh, 1955; Ebeling et al., 1980; Larson, 1980; Stephens et al., 1984, 1986; Patton et al., 1985). In particular, blue rockfish and olive rockfish were among the dominant species over many reefs (Carlisle et al., 1964; Ebeling et al., 1980). However, since the early 1980s, most species of rockfishes have nearly disappeared from the nearshore waters of the SCB (Stephens et al., 1994; Larson⁵; Schroeder⁶). On many of the reefs that once held substantial numbers of these species,

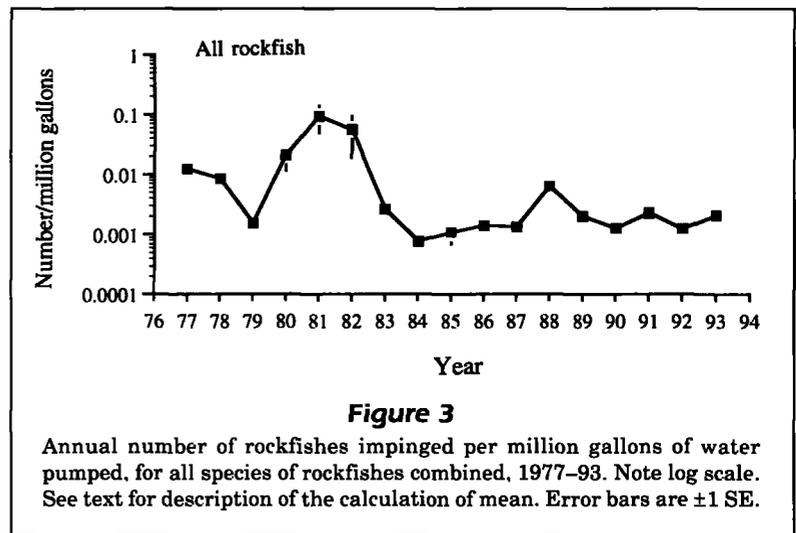


Figure 3

Annual number of rockfishes impinged per million gallons of water pumped, for all species of rockfishes combined, 1977–93. Note log scale. See text for description of the calculation of mean. Error bars are ± 1 SE.

very few rockfishes remain. Results of the fish-impingement surveys conducted since 1977 support the observation that several species of rockfish are less abundant now than in the late 70s and early 80s. We find it particularly compelling that for at least two species (blue rockfish and grass rockfish), not a single individual was collected in the past ten (blue rockfish) or three (grass rockfish) years.

We feel that the pattern of changing abundance in the impingement study is an accurate reflection of the pattern of change in the nearshore environment. Despite two very different survey methods, the patterns of rockfish abundance derived from the impingement data and the visual survey data from King Harbor were similar. On the gross level, the patterns for three species show amazing similarity; all have declined drastically since the late 70s and have remained low in the 80s and early 90s. On a finer scale, there were several large peaks in the impingement data that were not evident in the visual survey data (Fig. 5: blue rockfish in 1982, bocaccio in 1988). These differences may be due to differences in the ages of some of the fish recorded in the two surveys. Although the visual surveys mainly record juvenile blue rockfish, olive rockfish, and bocaccio, they may occasionally include older individuals, whose population levels may be buffered from the potentially large variations in recruitment by mortality. The impingement collections comprised mainly 0–2 year olds. Both of the large pulses seen in the impingement data were collections taken on a single day.

⁵ Larson, R. 1997. Department of Biological Sciences, San Francisco State University, San Francisco, CA 94132. Personal commun.

⁶ Schroeder, D. 1997. Marine Science Institute, University of California, Santa Barbara, CA 93106. Personal commun.

It is likely that the decline in rockfish abundance in the southern California Bight was well underway by 1977 when the current impingement surveys started. The King Harbor survey began in 1974 and results showed that the abundance of blue rockfish and bocaccio were at much higher levels from 1974 to 1977 than in later years. For example, blue rockfish were extremely abundant in King Harbor in 1974 but since 1983, not a single blue rockfish has been observed or impinged. There were also occasional impingement collections dating back to 1975 and these also indicate that pre-1977 rockfish catches were as high or higher than 1977 levels. These pre-1977 impingement surveys were too temporally sparse to be included in the complete data set, but they are suggestive. Thus, it appears that, despite larger variation in year to year rockfish impingement during the late 70s and early 80s, there has been an overall decrease since that time which probably reflects a decrease in nearshore populations of these species throughout the southern California Bight (Stephens⁴; Love et al., in press).

Although none of the previously mentioned nearshore studies conducted during the 1950s–1970s were designed to focus on rockfish year-class strength, it appears from these surveys that the widespread abundance of nearshore rockfishes before the early 1980s was generated by a series of strong year classes. During this same period, Southern California trawl studies of two other deeper-dwelling rockfish species implied a similar phenomenon (Mearns et al., 1980). It is likely that recent declines in abundance of these nearshore species were due to a decade-long series of very poor year classes.

What might be responsible for this poor rockfish recruitment? The succession of poor year classes off southern California is likely linked to decade-long changes in oceanographic conditions. Most rockfishes are primitively viviparous (Boehlert et al., 1987) and rockfish larvae are found primarily in the upper mixed layer (Ralston and Howard, 1995). After approximately one month, rockfish larvae metamor-

phose into pelagic juveniles that spend 3–6 months in the water column as plankton and micronekton

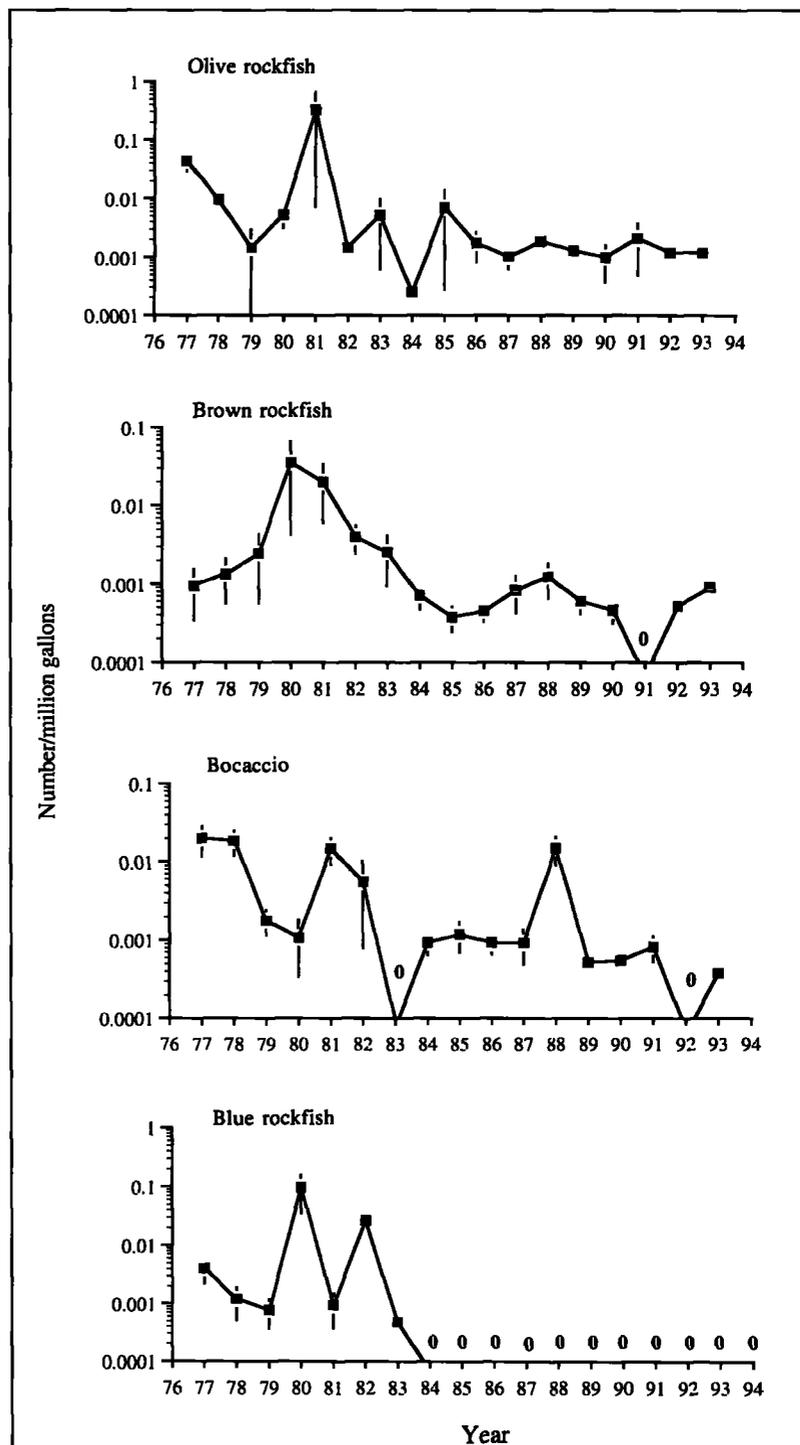
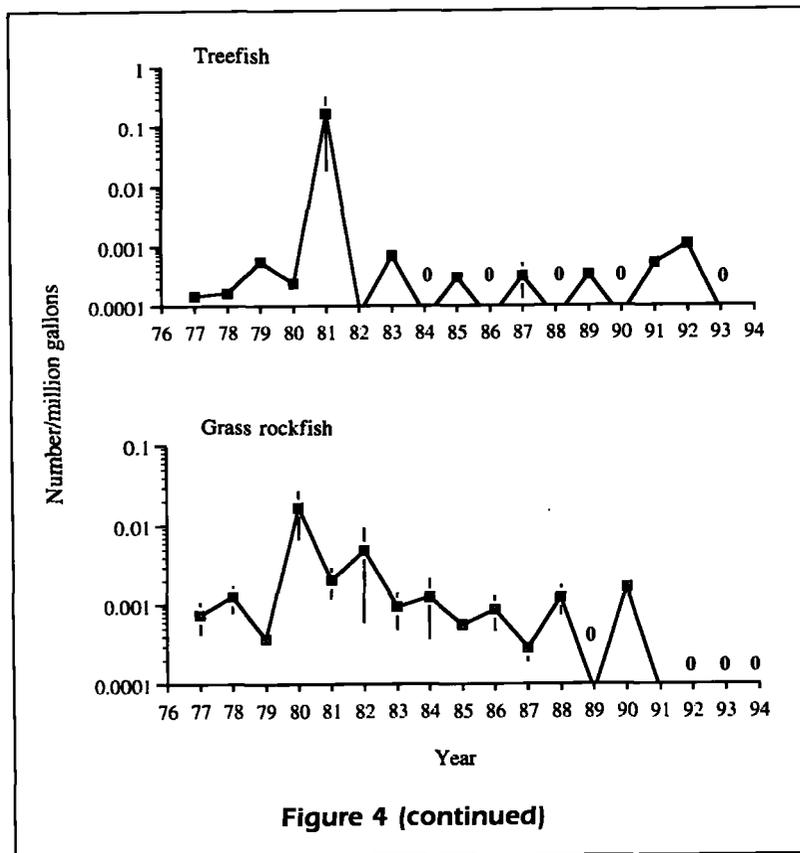


Figure 4

Annual number of rockfishes impinged per million gallons of water pumped for the six most commonly impinged species, 1977–93. Note log scale. See text for description of the calculation of mean. Error bars are ± 1 SE.



(Love et al., 1991). It is during the larval and pelagic juvenile stages that rockfish year-class strength is determined (Ralston and Howard, 1995) and upwelling appears to be a particularly important factor affecting survival during these stages. Years with intermediate levels of upwelling seem to correspond with strong year classes (Ainley et al., 1993).

Since the late 1970s, waters in the southern California Bight have warmed approximately 1.5°C and upwelling has declined to approximately one half of the levels observed in the late 70s and early 80s (Norton and Crooke, 1994). In turn, this has led to reduced zooplankton production (Roemmich and McGowan, 1995) and an apparent reduction in the larval and juvenile survivorship of many marine fish species (Holbrook and Schmitt, 1996). The current low-upwelling conditions are probably part of a long-term alternation of warm- and cold-water regimes that extend along much of the northeast Pacific (MacCall, 1996). Poor pelagic juvenile rockfish survivorship of many species also extends at least into central and northern California (Ralston⁷). Juvenile

bocaccio recruitment indices for central-northern California (Ralston et al., 1996) show a steady decline similar to the decline we observed for bocaccio in the impingement data.

There has also been a sharp decline in the numbers of both subadult and adult inshore rockfishes in southern California. These reductions are due both to natural mortality and heavy fishery exploitation. Unlike many deeper-water and more northerly species, the inshore rockfishes of California have relatively short life spans, often less than perhaps 25 years (Miller and Geibel, 1973; Love and Westphal, 1981; Love and Johnson, in press). Thus, even without fishing pressure, the number of adults of many of these species would tend to decrease relatively rapidly during extended periods of poor reproduction. In addition, these are also very heavily fished species. Until the early 1990s, most of the catch was made by recreational fishermen (Wine¹; Ally et al.²). Beginning in the early 1990s, a live-fish commercial fishery developed that targets shallow-water species (Barsky³).

The sharp decreases in inshore rockfish populations are also mirrored by similar declines in the populations of deeper-water species. Between 1980 and 1996, it appears that there was also a substantial decrease in the numbers of deeper-water rockfishes off southern California. An analysis of the recreational rockfish catch in southern California since 1980 shows steep declines in catches of most of the important species (Love et al., in press). As an example, catches of chilipepper rockfish (*S. goodei*) have declined to 0.5%, bocaccio to 1%, and widow rockfish (*S. entomelas*) to 1.25% of 1980 levels. These declines are almost certainly reflective of lowered abundances of many species rather than a shift in fishing emphasis by recreational vessels.

It is generally held that although reef fish populations exhibit large temporal variations, even undergoing local extinctions, external sources of new young will eventually provide new recruits. Referring specifically to the California coast, MacCall (1996) speculated on the establishment of southern marine species, such as the Pacific seahorse (*Hippocampus ingens*), at the northern ends of their ranges off California. He noted that these animals probably establish themselves during warm-water periods and, in the absence of fishing pressure, may survive colder

⁷ Ralston, S. 1996. National Marine Fisheries Service, Tiburon Laboratory, 3150 Paradise Dr., Tiburon, CA, 94920. Personal commun.

periods if the adults suffer low mortality. A similar phenomenon has been described for California sheephead (*Semicossyphus pulcher*) which exhibit episodic recruitment related to anomalous events in current flow (Cowen, 1985).

The reverse of this phenomena has occurred for at least some of the inshore rockfish species, particularly blue rockfish and olive rockfish. In the SCB, both species are near the southern end of their usual geographic ranges and large-scale recruitment may occur only during cold-water cycles, as occurred during the 1960s and early 1970s. During this current warm-water period, recruitment waned and the adult population was expected to decline slowly. However, the continuing fishing pressure on the populations accelerated this process.

On the basis of current flow in the SCB, it is likely that even during periods of successful recruitment, many of the rockfishes in southern California are generated from southern California adults (Reid et al., 1958; Schwartzlose, 1963; Browne, 1993). If true, the sharp drop in the adult populations of many rockfishes is particularly troubling and raises the issue of recruitment overfishing. This is a particularly strong possibility because there is little incentive for recreational anglers to decrease fishing activities on shallow reefs. These rockfishes are caught as part of a species assemblage that includes not only various rockfishes, but also such species as kelp bass (*Paralabrax clathratus*), Pacific barracuda (*Sphyraena argentea*), California sheephead (*Semicossyphus pulcher*), and ocean whitefish (*Caulolatilus princeps*). As long as even moderate numbers of any recreational reef species are taken, recreational vessels will continue to fish on rockfish-depleted reefs and continue to reduce already low numbers of rockfish. Because virtually all inshore reefs in southern California are heavily fished, successful recruitment will likely continue to be hazardous.

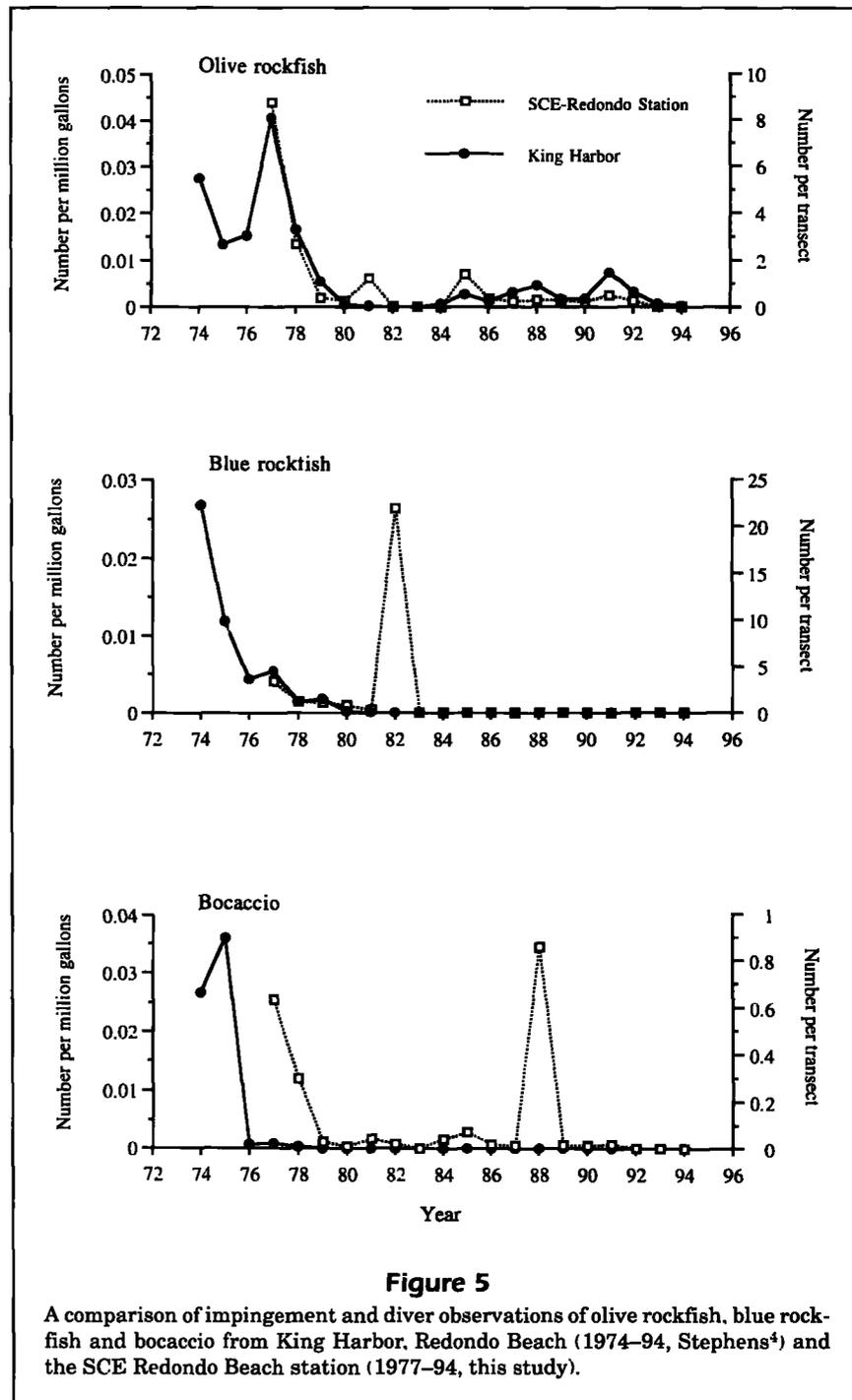


Figure 5

A comparison of impingement and diver observations of olive rockfish, blue rockfish and bocaccio from King Harbor, Redondo Beach (1974-94, Stephens⁴) and the SCE Redondo Beach station (1977-94, this study).

Acknowledgments

This work was conducted through a cooperative agreement with the Biological Resources Division, U.S. Geological Survey, contract number 1445-CA-0995-0386. As usual Lyman Thorsteinson was very supportive of our work. We would like to thank John Stephens for providing the King Harbor survey data.

We would like to thank Donna Schroeder and two anonymous reviewers for helpful comments on earlier versions of the manuscript.

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