Fish production of a temperate artificial reef based on the density of embiotocids (Teleostei: Perciformes)

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The abundance of two embiotocids (*Embiotoca jacksoni* and *Rhacochilus vacca*) was surveyed continually from 1974 to 1998 on the breakwaters comprising King Harbor in Redondo Beach, California, and a nearby natural rocky-reef as a reference. Embiotocids provide an interesting model for reef-fish production because they are viviparous and their entire ontogeny can be observed on the reefs. We deduce that the two reef populations of both species were stable at their carrying capacity. This carrying capacity was greater in King Harbor throughout the study. We also report a linear decline in survival of juveniles of both species over the 25-year period. Overall regional processes were similar on the two reefs, yet temporal differences suggested that they were acting independently. The King Harbor reefs produced greater biomass for both species, which represents one factor explaining the higher density of kelp bass (*Paralabrax clathratus*), an important predator.

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Introduction

In developing reef designs, the general goal is to enhance yields of critical stocks, or offset losses from anthropogenic disturbances. Although a few studies have demonstrated an increase in yield for artificial reefs (e.g. Polovina and Sakai, 1989), the evaluation of fish production for artificial structures has proved difficult (Bohnsack, 1989; Polovina, 1991). The idea of equating fish production with the increase in the abundance of a stock per unit time is a much more difficult concept to demonstrate. Carr and Hixon (1997) have put forward that an adequate assessment of production of artificial and natural reefs should include a synthesis of birth rates, mortality, immigration/emigration and growth to interpret fluctuations in biomass overtime. For reef fishes, this evaluation has proven to be exceedingly difficult. Many of these life history parameters may not be known and most populations fluctuate appreciably through time. In such situations, suitable comparisons with natural reefs become difficult owing to high variance, stochasticity, and uncoupled trends between data sets.

Complicating such an effort is the fundamental separation between pelagic larval life stages characteristic of most marine fish species and the juvenile and adult populations associated with the reefs. Thus, part of the total production is associated with the pelagic larval stage where mortality is extreme (Laurence, 1990). Further, it may be argued that enhanced recruitment of larvae to artificial structures can be at the cost of reduced recruitment to natural reefs, even if the former survive to maturity. In such a limited larval pool, total production may not be increased at all.

The difficulties in associating recruitment success at distant reefs to egg production on an artificial reef further complicate the potential for demonstrating positive effects on total production. The connectivity between reef populations has in part fuelled interest in both metapopulation theory and non-linear modelling to explain complexity and variability observed in reef populations (Dixon *et al.*, 1999). Indeed, modelling such

processes appears exceedingly complex, further prohibiting adequate comparisons between natural and artificial reefs. Optimally, an artificial reef should produce fishes at a rate equal to or greater than a similar natural reef through time. Unfortunately, to show that this is the case is theoretically and experimentally exceedingly difficult.

We examine a mature temperate artificial reef, the breakwaters of King Harbor (Redondo Beach, California), on which fish populations have been monitored by SCUBA continually since 1974 (Terry and Stephens, 1976; Stephens and Zerba, 1981; Stephens et al., 1986, 1994). Concomitant with these surveys, the ichthyofauna at Palos Verdes Point (Rancho Palos Verdes, California) has been used as a reference (Stephens et al., 1984). Palos Verdes Point is a characteristic southern California rocky reef, supporting a vibrant giant kelp, *Macrocystis pyrifera*, fauna, and proximate to King Harbor.

Ideally, to properly address the question of fish production we would need to examine species that are well studied in terms of natural history. In the southern California bight, the relatively unique situation exists in which one of the more abundant groups of reef fishes, the surfperches (Perciformes: Embiotocidae) has the apomorphic character of being viviparous (Nelson, 1994). There are 24 species in this family of gibbous perch-like fishes that have an amphipacific distribution (Miller and Lea, 1972). We present data for the black surfperch (*Embiotoca jacksoni*) Agassizi 1853, and the pile surfperch (*Rhacochilus vacca*) (Girard) 1855, locally the two most common reef-associated surfperch species.

The black surfperch, a winnower, is a strict diurnal microcarnivore that eats small benthic animals, but prefers tubicolous gammarid amphipods (Quast, 1968; Ellison et al., 1979; Schmitt and Coyer, 1982). The pile surfperch is a picker specializing on hard-shelled molluscs and invertebrates inhabiting mollusc shells (Ellison et al., 1979). Both are year-round residents of jetties of King Harbor and the rocky reefs of Rancho Palos Verdes (Terry and Stephens, 1976; Stephens et al., 1984, 1994).

Black surfperch are relatively uncommon north of Point Conception and are found south along the Pacific Coast of Baja California (Quast, 1968; Miller and Lea, 1972; Hixon, 1981). Large males have been observed on natural reefs to be territorial protecting caves and associated reef areas primarily for reproduction and secondarily defending food resources (Hixon, 1981). We have not observed such territorial behaviour in King Harbor. Their restricted adult ranges, coupled with the lack of pelagic larvae, are the reasons for a distinct population structure (Hixon, 1981; Bernardi, 2000). The largest known barrier to gene flow is the sand habitat of Santa Monica Bay north of King Harbor (Bernardi, 2000). Similarly, the Redondo submarine canyon, which

lies between King Harbor and Palos Verdes (Stephens et al., 1994), is also considered a barrier to gene flow (Bernardi, 2000). The nearest rocky-reef habitat is at Palos Verdes, a distance of 9 km. Considering that there are two major barriers on either side of King Harbor and adult vagility is limited to chance migration events (Bernardi, 2000), the King Harbor population of black surfperch can be considered isolated.

Pile surfperch has been reported as far north as Alaska and is also a representative of the central California fauna (Miller and Lea, 1972; Laur and Ebeling, 1983). Maximum size for black surfperch and pile surfperch is 390 mm and 442 mm TL, respectively (Miller and Lea, 1972; Baltz, 1984). At parturition, juveniles are approximately 50 mm SL. With a maximum age of approximately 10 years, these fishes mature in their fourth year and we report data on three size classes: adults, sub-adults (corresponding to the mean size for second-year fishes) and juveniles (Baltz, 1984; Ebeling and Laur, 1985). Adults are not vulnerable to the primary predator on these reefs, the mesocarnivorous kelp bass (*Paralabrax clathratus*) (Girard) 1854 (Perciformes, Serranidae), but juveniles are (Laur and Ebeling, 1983). Large kelp bass immigrate each spring into the harbour at the time of the spring recruitment pulse of embiotocids. In fact, they actively defend the shallow reaches of the reefs, where these juveniles can be found.

Materials and methods

Fishes were censused quarterly in the period 1974–1998 following previously described protocols (Terry and Stephens, 1976). For King Harbor, 34 replicate rocky-reef transects are attempted per quarter and a total of 3648 transects (annual median and mode=136) were completed over 25 sampling periods. At Palos Verdes Point, 16 rocky-reef transects are attempted per quarterly sampling period and a total of 1041 transects were completed (annual median=42, mode=45). Surfperch were categorized into three size classes: adults (>150 mm SL), sub-adults (100–150 mm SL), and juveniles (<100 mm SL) following the classifications of Ebeling and Laur (1985). Data for juvenile and sub-adult fishes from 1974 were not included because the divers did not differentiate between these two size classes (Terry and Stephens, 1976). Quality control and initial data queries were completed in Borland's PARADOX 7.0. Data manipulations were completed in Microsoft's EXCEL 7.0. To reduce autocorrelation between temporally proximate data points and avoid violation of the assumption of independence in parametric models (Studemund, 1992; Sokal and Rohlf, 1995), annual mean densities were used for both study sites. Descriptive statistics, the Shapiro-Wilk W statistic for

tests of normality, analysis of variance, and linear regressions were also completed in STATISTICA (Release 5.1 Stat Soft, Inc.). Annual densities of adult kelp bass and pile surfperch and juvenile black surfperch were log-transformed, the latter after adding 1 because of zeros in the matrix, to ensure homoscedasticity and normality prior to analysis of variance (Legendre and Legendre, 1998). Because data for juvenile pile surfperch were not normally distributed, a Mann–Whitney U-test was used to test for differences between the means (Sokal and Rohlf, 1995).

The mean length of juvenile embiotocids was used with previously reported weight (w) versus standard length (SL) relationships to calculate weight (Quast, 1968): $\ln(w) = -5.08268 + 3.31179*\ln(SL)$ for black surfperch and $\ln(w) = -4.57282 + 3.03269*\ln(SL)$ for pile surfperch. The mean size (SL=105.4 mm) for juvenile black surfperch was calculated by averaging the size of juveniles (n=160) captured by gillnets in southern California between 1996 and 1998 (Pondella and Allen, 2000). The mean size for first-year pile surfperch (SL=87.0 mm) was taken from Baltz (1984). Biomass was then calculated as mean weight (juvenile black surfperch 41.4 g; juvenile pile perch 22.4 g) multiplied by overall mean density.

Results

The densities of black surfperch adults and juveniles at the two reef systems (Figure 1a,c) have a fairly constant mean and variance throughout the study period, indicating that the adult populations were stationary series (Studemund, 1992). Mean densities of adults and juveniles per 100 m^2 at King Harbor were 5.6 (s.e.= 0.22) and 1.3 (s.e.=0.19), respectively, and at Palos Verdes 3.1 (s.e.=0.20) and 0.1 (s.e.=0.03) fish, respectively. Both adults (ANOVA $F_{(1,48)}$=842, p<0.0001) and juveniles (ANOVA $F_{(1,46)}$=124, p<0.0001) significantly more abundant at King Harbor. In contrast, there was a significant linear decline in the density of sub-adults at both King Harbor (r=0.86, p<0.0001; Figure 1b) and Palos Verdes (r=0.79, p<0.0001; Figure 1d).

For pile surfperch (Figure 3), trends were similar to black surfperch but at lower densities. Adult densities were 2.4 (s.e.=0.20) and 0.13 (s.e.=0.03) per 100 m^2 for King Harbor and Palos Verdes, juvenile densities 0.39 (s.e.=0.09) and 0.08 per 100 m^2 (s.e.=0.05), respectively. Densities of both adults (ANOVA $F_{(1,48)}$=44.7, p<0.0001) and juveniles (U=51, p<0.0001) were also significantly higher at King Harbor. Sub-adult abundance again showed a linear decrease in King Harbor (r=0.73, p<0.0001; Figure 3b). At Palos Verdes, density of sub-adults fluctuated but still declined in a linear fashion (r=0.50, p=0.013; Figure 3d).
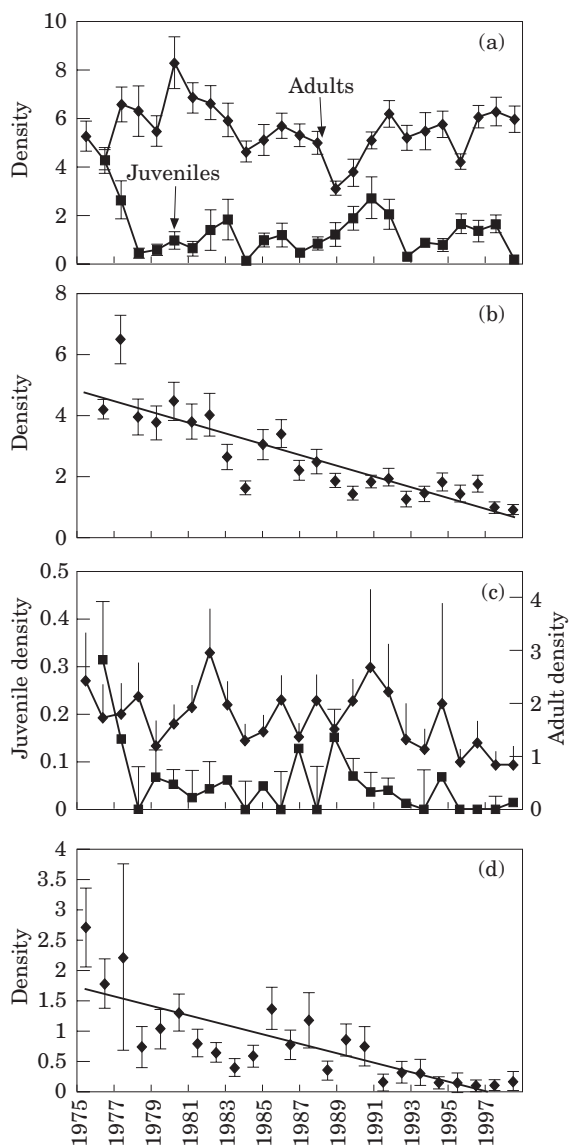

Figure 1. Densities (per 100 m^2; error bars: 1 s.e.) of black surfperch, 1974–1998. a. Adults and juveniles at King Harbor; b. sub-adults at King Harbor; c. adults (right-hand scale) and juveniles at Rancho Palos Verdes; d. sub-adults at Rancho Palos Verdes.

Annual biomass estimates (g per 100 m^2) for juvenile black surfperch were 53.8 (King Harbor) and 4.1 (Palos Verdes), and for pile surfperch 11.4 and 1.8, respectively.

The abundance of the predatory adult kelp bass peaked in the early 1980s, but has remained fairly constant throughout most of the study period (Figure 2). Its mean density for King Harbor was 3.6 (s.e.=0.41) and for Palos Verdes 2.87 per 100 m^2 (s.e.=0.31). King Harbor had a statistically higher density (ANOVA $F_{(1,48)}$=202, p<0.0001).
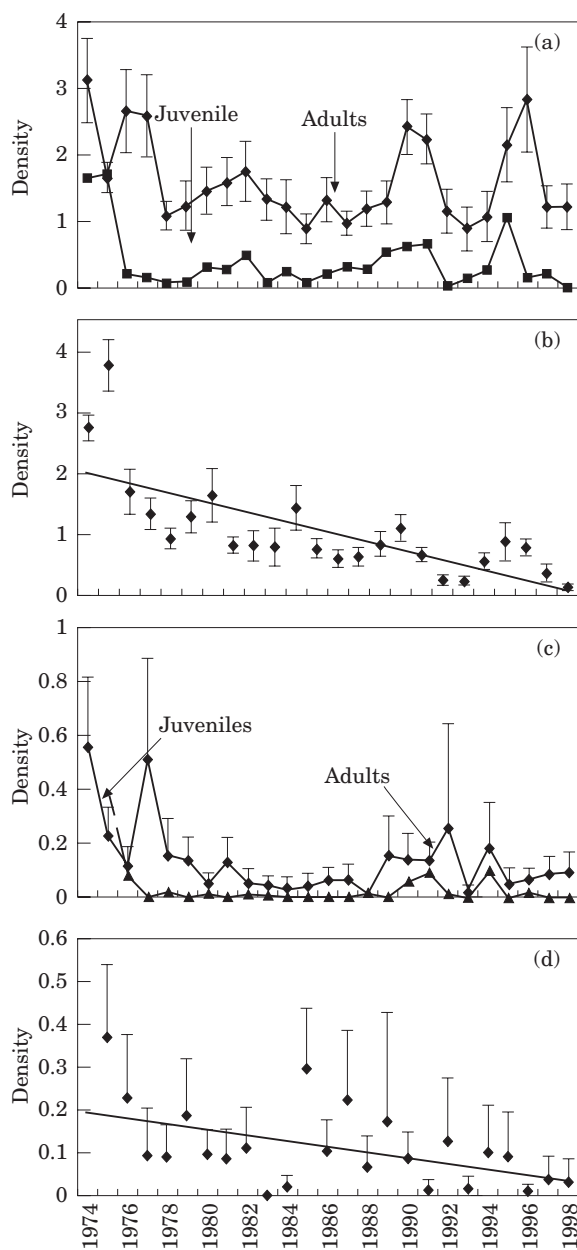
Figure 2. Densities (per 100 m²; error bars: 1 s.e.) of pile surperch, 1974–1998. a. Adults and juveniles at King Harbor; b. sub-adults at King Harbor; c. adults and juveniles at Rancho Palos Verdes; d. sub-adults at Rancho Palos Verdes.

Figure 3. Densities (per 100 m²; error bars: 1 s.e.) of adult kelp bass at King Harbor and Rancho Palos Verdes.

Discussion

For both species, population densities of adults have remained approximately constant for 25 years. Because the reef system at King Harbor was nearly 50 years old, this stability is an indication of reef maturity. We inte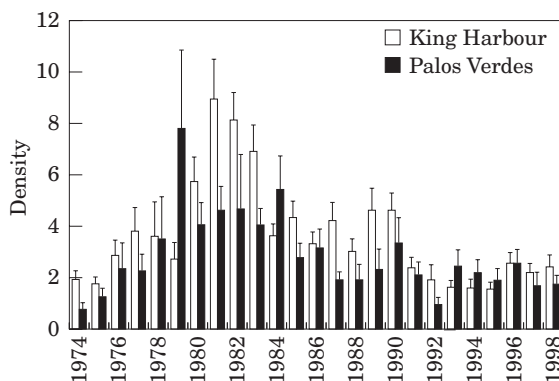rpret the mean density for adult and juvenile embiotocids as reflecting differences in the carrying capacity, which was significantly higher for King Harbor than for Palos Verdes. Apparently, the higher densities of adults at the former produced a larger number, and even a disproportionately larger biomass, of juveniles. Density of kelp bass, the main predator, fluctuated to some extent at the two reefs, but followed the same pattern with a peak in the early 1980s. However, the higher population densities of kelp bass at King Harbor cannot explain the higher number of juveniles. This leaves only the reef resources as the explanation for the higher carrying capacity at King Harbor. For black surfperch, the classic quarry rock breakwater increases the amount of caves that could be utilized for shelter and reproductive territories (Hixon, 1981). However, we did not observe territoriality at King Harbor, indicating that this resource was not limiting even though population densities were higher than at the natural reef. Although we did not test this, food resources may also be greater than those found on the natural reef. The reefs at Palos Verdes are primarily low-relief structures separated by sand and cobble (Stephens *et al.*, 1984). Laur and Ebeling (1983) found a greater volume of surfperch food items on reef slope and crest as opposed to cobble or flats. In King Harbor, reefs were primarily slope and crest structures perhaps facilitating higher densities.

The intriguing finding is the linear decrease in density of sub-adult fish for both species on both reefs. This suggests a regional and non-species specific trend, although the decrease of black surfperch bottoms out earlier at Palos Verdes (Figure 1d) while continuing to decline in King Harbor (Figure 1b). Because juvenile density was relatively constant, especially for black surfperch (Figure 1a and c), we interpret this decrease as an increase in mortality after the end of the first year of growth. At Palos Verdes, there may be a lagged effect on the adult population, which appeared to be declining since 1990. Since these fish are vulnerable to predation primarily during their first year (Ebeling and Laur, 1985;

Schmitt and Holbrook, 1985), a simple explanation of sub-adult decline would be an increase in predator density. However, density of kelp bass did not increase, suggesting that the linear decrease in survival to sub-adults may be due to a reduction of reef resources.

Based on the unique life history of these two embiotocids, the artificial reef system at King Harbor is inhabited by self-maintaining populations. Indeed, the differences in timing of the declines and the lack of coherence in the annual abundance estimates of adults among the populations suggest that their dynamics are temporally independent consistent with their spatial independence. Because concerns associated with pelagic larval stages can be eliminated, population dynamics must be coupled to reef resources. The constant adult density and linear decline of second-year fish found at both systems indicate that the four independent fish populations have attributes consistent among each other. The carrying capacity of the artificial reef is clearly higher than the natural reef. The lack of connectivity is important in this context because this alleviates concerns of attraction: we found no evidence for King Harbor negatively affecting natural reefs by acting as a refuge.

While these jetties were not designed to enhance the abundance of surfperches, we can try to understand why this has happened. The increased complexity associated with large quarry rock reefs has many favourable attributes. First, the boulders increased the shelter needed by these species for survival during nocturnal periods and as refuge from predation (Ebeling and Laur, 1985). The availability of a large number of caves per surface area also has the potential of increasing the number of reproductive territories (Hixon, 1981) perhaps affording a higher density of adults. Further, these quarry rock reefs are characterized by high relief and have a greater three-dimensional component than the natural reef serving as reference. This higher structural complexity increases the absolute surface area where these fishes can forage when compared to natural reefs of similar size. The combined effects of higher complexity and a potentially greater food resource on slope and crest aspects of the reef (Ebeling and Laur, 1986) appear to have had a positive effect on surfperch biomass.

Previous authors have estimated both somatic and gonadal production of black surfperch and pile surfperch at Torrey Pines Artificial Reef, a small quarry rock reef in La Jolla, California (De Martini *et al.*, 1994). We present evidence that artificial reefs maintained standing stocks over a 25-year period that were at least 50% greater than those on natural reefs. The higher abundance accompanied a larger number of first-year fishes, despite higher predator densities.

Mean biomass of juvenile fish was higher in King Harbor than in the kelp bed of Palos Verdes. Overall, we deduce that the surfperch production of the artificial reef has been higher than of the natural reference reef. This higher production may be one of many variables that have contributed to higher predator densities. In conclusion, well-designed artificial reefs can enhance fish production without reducing fish production of nearby natural reefs caused by attraction.

Acknowledgements

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