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ECOLOGY AND HABITAT USE OF JUVENILE ROCKFISHES (*SEBASTES* SPP.) ASSOCIATED WITH ARTIFICIAL REEFS IN PUGET SOUND, WASHINGTON

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ABSTRACT

We investigated the efficacy of small-size (15 cm diameter) quarry rock deployed in a low-relief (<0.5 m) substrate configuration as shelter-habitat for young-of-the-year (YOY) rockfish (*Sebastes* spp.) in Puget Sound, Washington. Two thousand eight hundred tons of rock were used to construct eight reefs. Four Integrated Reefs were constructed by augmenting existing high-relief artificial reefs with low-relief quarry rock, and four Isolated Nursery Reefs were constructed well away from the Integrated Reefs using only low-relief quarry rock. We compare distributions of YOY and adult rockfish from one Integrated Reef and its paired Isolated Nursery Reef during the first recruitment season after reef construction. Preliminary results show higher densities of YOY rockfish on an Isolated Nursery Reef than its nearby paired Integrated Reef. Adult and YOY rockfish tended to associate with high-relief and low-relief substrate, respectively, on the Integrated Reef. On low-relief substrate, we found YOY rockfish primarily on the most complex areas of the reefs, where the substrate was three or four rocks in thickness. Five factors which may contribute to these distributions are considered.

Typically, artificial reefs are constructed specifically to enhance production of fishes important to recreational and commercial fisheries. As a result, they provide habitat primarily for large, mostly adult forms. In Washington, these efforts have succeeded, with reefs whose standing stocks of adult rockfish exceed those of natural habitats (Buckley and Hueckel, 1985; Hueckel and Buckley, 1989). Integrated approaches to fishery management using artificial reefs include assessments of the efficacy of reef designs in meeting life history requirements of target species (Bohnsack and Sutherland, 1985; Seaman et al., 1989; Wilson and Krenn, 1989). This suggests a need for thorough evaluation of, and provisions for, requirements of the juvenile phase of species targeted for enhancement.

Since many species targeted for enhancement are carnivorous, artificial reefs present a potential for high predation-mortality on juveniles recruiting to these habitats. If suitable refuge-habitat is lacking for juvenile fishes on artificial reefs, juveniles recruiting to these habitats may suffer abnormally high mortality.

The effects of availability of suitable shelter or habitat on populations (the "limited shelter hypothesis"—Shulman, 1985; Hixon and Beets, 1989) were tested on communities of tropical reef fishes using artificial reefs. In these studies, potential shelter or refuge habitat (i.e., the number and size of available crevices) were manipulated, demonstrating that availability of suitable shelter can have a strong effect on recruitment success and early survivorship of fish on a reef. In particular, Hixon and Beets (1989) showed that increasing the number of holes or crevices on a reef increases the number of fish the reef can shelter, and more importantly for the present study, that a reef with small holes supports more small fish than a reef with the same number of large holes. Concurrently, they demonstrated that the presence of piscivores poses limits on the number of small fish a reef supports.

Availability of shelter and its effect on the degree to which piscivory impacts reef fish communities were also tested experimentally in a community of reef fishes (Shulman, 1984, 1985) and in the rocky reef goby *Lythrypnus dalli* (Beh-

rents, 1987). In these studies, predation on small fish was shown to increase with a reduction in available shelter for potential prey. Thus, habitat and predation are linked, each affecting the prospects of survival for newly settled or recruited juvenile fish.

In a survey of an existing quarry-rock artificial reef in a temperate (California) nearshore marine system, Anderson et al. (1989) documented ontogenetic changes in habitat requirements of eight of nine species examined, presumably based to a degree on the association of body size with shelter (hole) size. The authors concluded that this association was an important determinant of the fish fauna that characterizes a particular habitat. They further suggested that, as a result of their greater need for shelter, juveniles and small-bodied fishes have more specialized habitat requirements than adults or larger bodied fishes.

Some attempts have been made to enhance survival of juvenile marine fishes using artificial reefs or modifications to existing "adult" reefs. Materials tested include rock (Lindeman, 1989), polypropylene rope streamers (Gorham and Alevizon, 1989), and quarry rock/concrete (Wilson and Krenn, 1989; Wilson and Schlotterbeck, 1989) with mixed results. Ogden and Ebersole (1981) discussed the efficacy of a large, concrete block reef as a source of shelter for recruiting juvenile fishes in the Virgin Islands. Although documentation is limited, it appears that some Japanese artificial reef developers incorporate habitat designed for juveniles in their programs (Mottet, 1981).

The Washington Department of Fisheries (WDF) has been active in the development of artificial reef technology and has used artificial reefs to enhance recreational fishery harvests from the early 1970s. Since that time, the WDF has constructed 13 reefs in the state, covering a total of over 42,000 m^2. These reefs were built using large quarry rock boulders and scrap industrial concrete, and were designed to enhance stocks of bottomfish such as rockfish (*Sebastes* spp.) and lingcod (*Ophiodon elongatus*). Of the rockfishes, three demersal species dominate biomass on these reefs—copper (*S. caurinus*), quillback (*S. maliger*) and brown (*S. auriculatus*) rockfish. The parameters that characterize these reefs include siting relatively close to shore (within 500 m) in shallow (less than 30 m) depths, large overall size (>3,000 m^2), high vertical relief, materials selected to maximize numbers of crevices and caves, and separated modular piles placed to reduce impacts on existing benthic habitats.

Our study was designed to investigate the efficacy of artificial reef materials designed specifically to provide shelter-habitat for juvenile rockfish. The focus of the study was to provide information concerning how we can best increase efficiency of production of these species by modifying existing artificial reef structures or systems. This approach is predicated on the assumptions that (1) shelter-habitat is important for survival of juvenile rockfish and (2) increasing survival of juveniles that recruit to artificial reefs will increase future production of that species.

Additionally, the following experimental design incorporates and exploits what is currently known about rockfish settlement and their settlement habitat. Young-of-the-year (YOY) of the three species in this study appear to initially settle at a size of approximately 18 to 25 mm TL, to shallow, vegetated habitats such as beds of kelp (*Nereocystis luetkeana* and *Macrocystis integrifolia*) and eelgrass (*Zostera marina*) (WDF, unpubl. data; Haldorson and Richards, 1987; Carr, 1990; Love et al., 1991). The mechanisms whereby YOY rockfish move from these shallow, vegetated habitats to deeper, rocky habitats are unknown. However, one function of the nursery habitat designed for this study is to physically connect these habitats.

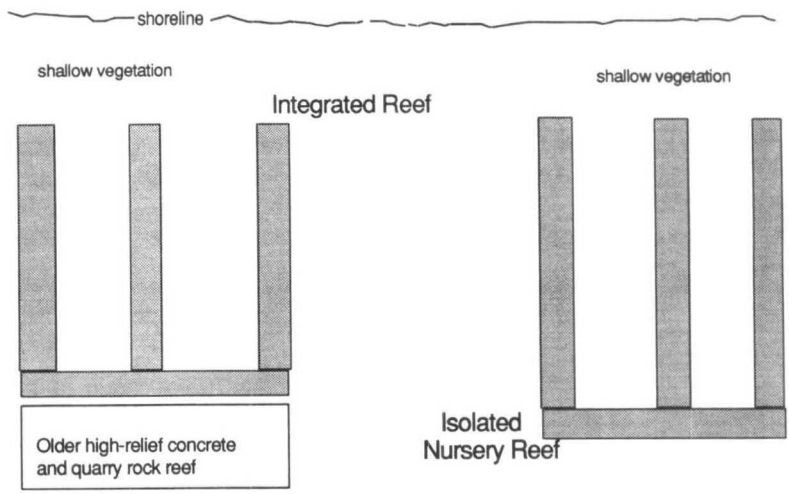

Figure 1. Plan diagram of Integrated Reef and Isolated Nursery Reef (low-relief quarry rock shown in stipple pattern).

The results presented here are preliminary, encompassing only the first few weeks after initial recruitment of YOY rockfish to these structures. Of the four locations used for the study, results from one are analyzed.

METHODS

In the fall of 1990, efforts were directed to investigate the associations of juvenile rockfish with existing artificial reefs. When observed in association with an existing high-relief reef, newly recruited YOY rockfish (<80 mm total length [TL]) usually hid in low-relief rubble, on the shallower inshore edge, away from the main body of the reef. The extent of this habitat is minimal, the result of a few small rocks rolling off the main reef during its construction. Crevice sizes used by juvenile rockfish in such low-relief rubble were measured, and a material was selected to best replicate this habitat for the present study (WDF, unpubl. data).

In the spring of 1991, we constructed four experimental nursery reefs for juvenile rockfish, in conjunction with existing artificial reefs. Each of the four sites received 700 tons of crushed quarry rock graded to a diameter of 8 to 20 cm. The rock was placed in a specific array designed to satisfy a number of criteria: (1) low vertical relief to discourage large, nearby, potential predators from establishing residence (of the potential predators of juvenile rockfish, adult rockfish are the most abundant), (2) refuge-habitat to provide crevices large enough for juveniles, but too small for predators, and (3) nursery habitat to provide shelter for YOY rockfish moving across the open-sand habitat from their primary settlement habitat to the rocky reefs.

At each of the four reef sites, roughly half the material (350 tons) was placed with the existing, older, high-relief reef. At the high-relief reef, a band of new rock was placed along the inshore edge of the reef, augmenting the existing low-relief rubble habitat described above (Fig. 1). Two or three bands of material were placed across the inshore zone of sandy substrate, towards shallow kelp (*N. luetkeana*) and eelgrass beds. This "Integrated Reef" thus incorporates two types of habitat (older, high-relief rock and new, low-relief rock), targeting two different life-stages of rockfish (adult and juvenile). The low-relief array was then repeated using 350 tons of new material some distance away (40 to 500 m), isolated from any high-relief substrate, creating an "Isolated Nursery Reef."

We began qualitative monitoring of immigration and recruitment of rockfish to the reefs in April 1990. Quantitative sampling began in October 1991 (approximately 210 days after construction), when we first observed newly settled rockfish on the reefs. Samples consisted of paired visual census strip transects, run from deep to shallow, covering various depth and habitat situations on the reefs. Transects were oriented perpendicular to shore along the habitat bands, each covering 250 to 350 m^2. Number and size of each species of rockfish were recorded in 5-m intervals by each diver in a 2-m wide strip along the transect line. Habitat (e.g., vertical relief and type of substrate) and depth information were also recorded within each of the 5-m by 2-m cells. Depth was recorded using diver-held

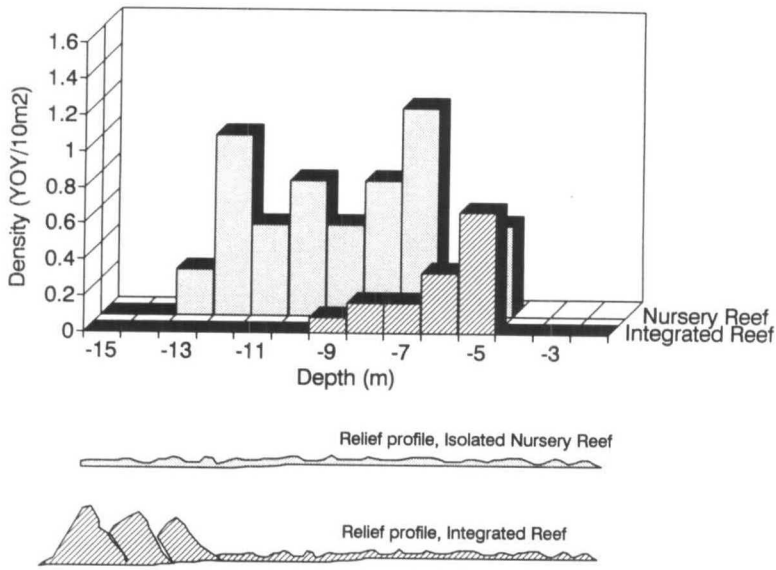

Figure 2. Distribution of YOY rockfish on Integrated Reef and Isolated Nursery Reef.

gauges and later standardized to height below Mean Lower Low Water. All transects were conducted during daylight hours as close to slack water as possible to minimize diurnal and tidal effects.

During the daylight hours when transects were conducted, rockfish remained close to the reefs. They were rarely encountered over the open, sandy bottom which surrounds the reefs. Counts included all individuals observed above and inside the reef, within the boundaries of the transect. Divers first counted fish in the water column before inspecting crevices (using lights) for hidden fish in each cell. The time spent by divers in each cell was variable, depending on the complexity of the substrate.

Visual identification of small rockfish (50 to 80 mm TL) is difficult in the field, hence, YOY presented in this analysis are an aggregate of copper, quillback and brown rockfish. To provide an appropriate comparison with YOY, adults of these species were pooled as well. All rockfish large enough to potentially consume YOY (>about 18 cm) are termed "adult," and assumed to be the primary potential predators of YOY, in this analysis.

The following analysis is based on a set of six transects taken over a 4-day period in October 1991; three were conducted at an Integrated Reef and three at its adjacent Isolated Nursery Reef. Numbers of rockfish were summed for paired 5-m by 2-m cells within 1-m isobaths, which provided density estimates (fish·10 m^{-2}·$isobath^{-1}$). Approximately 74% of the area covered by transects conducted on the Integrated Reef was comprised of new, low-relief material.

RESULTS

Within a few weeks of recruiting to this location, the mean density of YOY on the Isolated Nursery Reef was significantly greater than on the Integrated Reef (0.60 fish·10 m^{-2} and 0.13 fish·10 m^{-2}, respectively; t-test, $P < 0.05$). On the Integrated Reef, YOY rockfish were found associated only with the low-relief habitat, well away from the high-relief portion of the reef (Fig. 2). YOY were most abundant along the −5-m isobath, with densities decreasing to zero by the −10-m isobath. On the Isolated Nursery Reef, YOY rockfish were found throughout almost the full range of depths of the reef, from −13 m to −5 m (Fig. 2).

Adult rockfish on the Integrated Reef were primarily associated with the high-relief substrate (Fig. 3). The difference in densities of adult rockfish between the Integrated Reef and Isolated Nursery Reef was not statistically significant (t-test, $P > 0.05$). Certain areas of the Isolated Nursery Reef contained moderate densities of adults (especially the −14-m isobath). Adult rockfish seemed to aggregate in

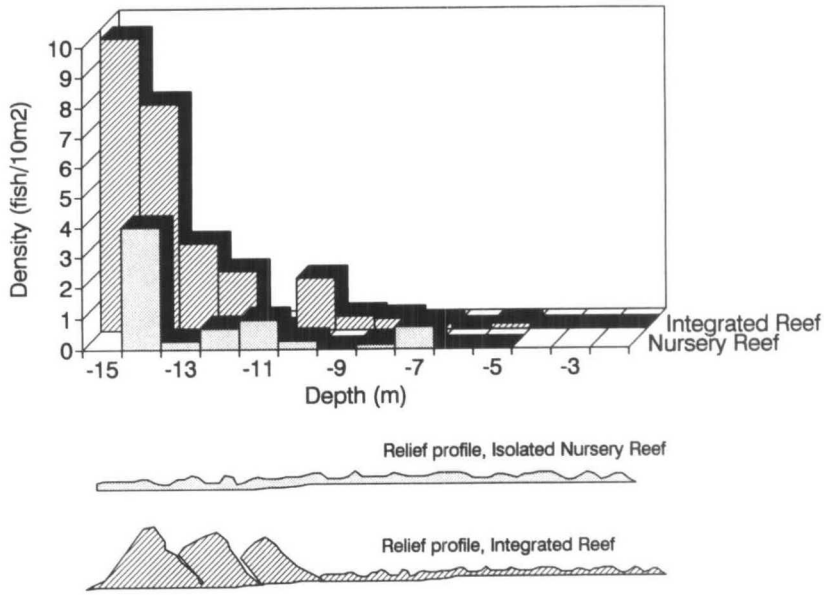

Figure 3. Distribution of adult rockfish on Integrated Reef and Isolated Nursery Reef.

areas where the relative vertical relief of the rock was greatest, and where the new rock was placed adjacent to steeply sloping natural substrate, especially in the deeper range of the reef. No juveniles were found in the cell (−14-m isobath) where the greatest concentration of adult rockfish on the Isolated Nursery Reef occurred.

Comparing the distribution of adult and YOY rockfish on the Integrated Reef

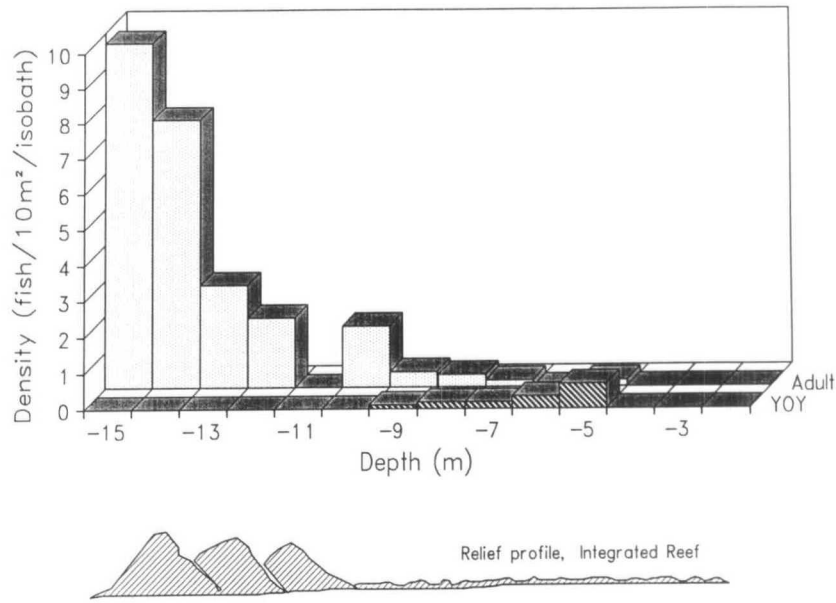

Figure 4. Segregation of rockfish by size on Integrated Reef.

shows a distinct segregation in size of rockfish based on type of habitat. When presented with two habitats of greatly differing relief (as on the Integrated Reef), adult rockfish occupied the high-relief portions and YOY rockfish occupied the low-relief portions of the reef (Fig. 4). We also observed trends in use of habitat by YOY rockfish on a smaller scale. The low-relief habitat appears homogeneous on a large scale (e.g., that of the entire Integrated Reef). However, smaller-scale heterogeneity within the low-relief habitat appears to affect distribution of YOY rockfish. YOY rockfish typically aggregated in the areas of the low-relief habitat that provided a large number of crevices. This occurs with a substrate relief of four or five layers of rock (total vertical relief approximately 50 cm). These areas seem to provide a complex refuge; when startled by divers or chased by predators (e.g., adult rockfish), YOY have been observed to immediately take cover deep within the crevices provided by the reef.

Discussion

The early trends we observed on these reefs suggest that the low-relief artificial habitat attracts juvenile rockfish. However, the results are represented by a small sample size (6 transects over 4 days), and conclusions must therefore be considered carefully. Trends observed in the first year on the newly constructed habitat may change as benthic communities develop. The distribution patterns we observed, however, are particularly important because they identify how YOY rockfish respond to a new habitat designed specifically to attract them and to provide refuge. Perhaps the most important result from this research so far is that YOY rockfish found the habitat quickly, in the first settlement period after construction of the habitat.

The analysis of distribution of adults and YOY on the Integrated Reef demonstrated that a segregation of rockfish based on size and habitat existed during our surveys. If viewed alone, a simple explanation of this segregation may be based on depth. Strong depth-distribution patterns have been observed in YOY Puget Sound rockfish (*S. emphaeus*) in natural habitats in Puget Sound and the San Juan Islands (WDF, unpubl. data). However, when distributions of YOY from the Integrated Reef are compared with distribution of YOY on the Isolated Nursery Reef, depth (in the range presented by these reefs) appears not to affect distributions of YOY.

Other factors may contribute to the distribution patterns we observed, including (1) avoidance by YOY of the high-relief portions of the Integrated Reef, (2) selection by YOY of low-relief habitat, (3) differential predation of YOY between habitats, (4) migration of YOY between these habitats and (5) sampling error. It is possible that each of these factors contributes, to a degree, to the distributions we have seen.

The preliminary results presented in this manuscript suggest that juvenile rockfish respond to characteristics of habitat structure similarly to adult rockfish, but on a much smaller scale. Increasing survival of juvenile rockfish recruiting to artificial reefs depends on how we recognize, quantify and manipulate these responses. By understanding the relationship of predation-mortality and the mitigating effects of habitat as a refuge from predation for YOY, we may be able to develop artificial reef systems that produce greater potential yields of target species.

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