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Evaluating stocking as an enhancement strategy for the red sea urchin, *Strongylocentrotus franciscanus*: Depth-specific recoveries

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ABSTRACT: Enhancement strategies for red sea urchin populations were evaluated by examining the recovery of laboratory-reared juvenile and wild adult sea urchins. Sea urchins (18mm) reared in the laboratory for one year were tagged and stocked (N=240) into shallow (5m) and deep (15m) subtidal sites in the Salt Point Sea Urchin Closure in northern California. Wild red sea urchins were also tagged (N=609) at these sites to examine spatial patterns in recovery. After one year, twice as many stocked juvenile sea urchins were recovered from the shallow (21%) compared with the deep (11%) site. Stocked juvenile sea urchins grew on average from 18 to 41mm during the year. Twice as many tagged wild urchins were also recovered from the shallow (38%) compared with the deep (16%) site. Relative measures of habitat quality indicated that the shallow site had higher abundances of adult conspecifics, less drift algae/urchin, less water motion, and more silt than the deep site. These results suggest that sea urchin mortality and/or movement rates may be lower in shallow habitats where adult sea urchins are abundant. Therefore, future enhancement and recovery strategies may be more successful in shallow habitats in northern California. Stocking studies such as this may also be used to assess habitat quality and essential habitat characteristics.

1 INTRODUCTION

Sea urchin fisheries are in decline worldwide (Keesing & Hall 1998). In California, landings of the red sea urchin, *Strongylocentrotus franciscanus*, have declined from a peak of 52 million pounds in 1989 to 14 million pounds in 1999. These declines highlight the need for research examining options for enhancement. Enhancement strategies can target several stages in sea urchin life history which appear to be limited; (1) fertilization (Levitan et al. 1992), (2) larval supply (Ebert et al. 1994), (3) juvenile survival (Tegner & Dayton 1977, Breen et al. 1985, Rogers-Bennett et al. 1998), and (4) availability of adult food for growth and gonad production (Tegner 1989). Stocking hatchery-reared juveniles is one approach that has been used to increase the abundance of juveniles during the vulnerable larval and juvenile life history stages.

The enhancement of shellfish resources through juvenile stocking has been attempted with varying success (Tegner & Butler 1989, McCormick et al. 1994, Kojima 1995, Iverson & Jory 1997). Recovery rates and estimates of survival appear to be spatially variable. Recovery rates of stocked juvenile abalone were site-specific varying from 1-72% in New Zealand (Schiel 1993). These results indicate a need to identify habitat features which enhance the survival of hatchery reared juveniles. One factor which has been hypothesized to enhance the recovery of hatchery reared juvenile sea urchins is the presence of adult conspecifics and their spine canopy. Fishing experiments support this hypothesis since wild juveniles are more abundant in sites where adults are present (Tegner & Dayton 1977, Breen et al. 1985, Rogers-Bennett et al. 1998). In addition, more stocked juvenile abalone were recovered from sites where adult red sea urchins (and their spine canopy) were present in northern California (Rogers-Bennett & Pearse 1998). If site-specific characteristics which enhance the survival of stocked juvenile sea urchins can be identified, then this information could be used to improve future enhancement efforts as well as increase our knowledge of essential shellfish habitats.

In this study, I investigate the recovery of stocked juvenile and tagged wild red sea urchins from sites with differing habitat characteristics; a shallow and a deep site. Hatchery-reared juvenile red sea urchins, averaging 18mm in test diameter, and wild red sea urchins were tagged and released in the Salt Point Urchin Closure, northern California. Recovery rates of both stocked juveniles and wild adults after one year are reported. Site-specific characteristics are quantified to examine the relationship between recapture rates and (1) adult sea urchin density, (2) the abundance of drift algae, (3) wave action, and (4) silt accumulation. The implications of these results are discussed for the development of sea urchin enhancement strategies as well as the identification of essential habitat features utilized by wild juvenile red sea urchins.

2 METHODS

2.1 *Sites*

Red sea urchins were tagged and recaptured one year later at two sites in the Salt Point Sea Urchin Closure (38°33'06"N,123°19'45"W) in northern California. Commercial sea urchin harvesting is prohibited within this closed area. One shallow and one deep site were selected within the closure. The shallow site ranged in depth from 3 to 5 m and was located at the southern border of the Gerstle Marine Life Refuge at the edge of the shore. The deep site, 15-17m, was located on the lee side of a large wash rock. Within each of the two sites adult red urchins were quantified inside a portion of a circle with a 12m radius. The shallow site occupied an area of 150m^2 with a large rock wall in two thirds of the circle. The deep site occupied an area of 226m^2 with a large rock wall in one half of the circle. Both sites were on hard rock substrate, with abundant adult red sea urchin populations, and seasonally dense kelp, *Nereocystis luetkeana*. A portion of the substrate of the deep site was dominated by worm tubes.

The abundance of silt at each of the sites was recorded from four collectors set out 12 days prior to stocking the juvenile red sea urchins. The abundance of drift algae was quantified along 30 x 2m transects at each of the sites on the day the adult sea urchins were tagged. A relative measure of wave action was examined by comparing the dissolution of plaster (Dieken Green®) discs. Each disc had an initial mean weight of 126.26g ($\pm$ 1.9). Differences in the final weight of the discs were compared between the shallow and the deep site after 12 days.

2.2 *Stocking*

Juvenile red sea urchins were cultured in the laboratory. Larvae were fed an algal diet of *Rhodomonoas lens*. At one year, juveniles averaged 18 mm in test diameter. Juvenile red sea urchins (N=240) were tagged by immersion in a solution of calcein (125mg/ liter sea water, pH adjusted to ambient seawater) for 24 hours. Calcein is a flourescent dye which binds to newly deposited Calcium and is clearly visible on the jaws and test plates.

Tagged juveniles were stocked into the ocean when wave conditions were calm on Aug. 31, 1992. Approximately, 240 juveniles were stocked into two sites. Juveniles were transported (2 hours) in six plastic 2 liter jars with wide diameter lids. Divers carried the jars to the sites and secured them in rock crevices. The lids were removed so that the juveniles could move out on their own. The majority of the juveniles moved out of the jars after one hour. Sea urchin predators such as the sun star, *Pycnopodia helianthoides,* and the leather star, *Dermasterias imbricata,* were removed from the sites on the day of stocking.

2.3 *Tagging*

Wild urchins at the two sites were tagged to examine spatial patterns in the recovery of adult sea urchins. On August 19, 1992 divers tagged a total of 609 wild red sea urchins *in situ* at the shallow and the deep site. Urchins were tagged internally by injecting a solution of 0.5-1.2 ml of a 1g tetracycline/ 100ml seawater solution (sensu Ebert & Russell 1992).

2.4 *Growth*

Final test size was measured at the time of recapture. To determine initial test size we examined the tagged jaws which indicate initial jaw size. Initial jaw size was converted to initial test size using Eq. 1.

$$\text{Test Diam.} = (3.31)\ \text{Jaw}^{1.15} \qquad \text{Eq. 1.}$$

Equation 1 was is the relationship between test size and jaw size (r^2= 0.989) developed from a large sample (N=383) of laboratory cultured juvenile sea urchins and wild sea urchins from Salt Point ranging in size from 3 to 180mm (Rogers-Bennett unpubl. data).

3 RESULTS

3.1 *Recapture Rates*

Sea urchin recaptured rates were twice as high in the shallow compared to the deep site for both stocked juveniles and tagged adults (Table 1). Sea urchins were harvested at both sites on September 18, 1993. In the shallow site, a total of 41 juvenile red urchins were harvested, ranging in size from 15-52mm in test diameter, of these 25 (60%) were tagged. In the deep site, a total 20 juveniles were harvested in the same size range and 13 (65%) of these were tagged. A total of 164 of the 609 (26.4%) wild adult sea urchins were recaptured, 116 from the shallow and 48 from the deep habitat (Table 1).

3.2 *Growth*

Stocked juveniles grew from an initial average test diameter of 17.6mm (SD 4.88mm) to a final test diameter of 40.95mm (SD 8.02mm). Final test diameters of tagged juveniles ranged from 23-52mm in the shallow and 29-55mm in the deep site. Juveniles in the shallow site grew an average of 22.95mm (SD 5.2mm) in one year while juveniles in the deep grew an average of 24.22mm (SD 4.6mm) during the year. There was individual variation in growth, but no significant differences in sea urchin growth between the sites. Adults grew less than juveniles.

Table 1. Numbers of juvenile and adult sea urchins tagged and recovered after one year from a shallow (5m) and a deep (15m) site in the sea urchin closure at Salt Point.

	Shallow	Deep	Total
No. Juvs. Stocked	120	120	240
No. Juvs. Harvested	41	20	61
No. Juvs. Recovered	25	13	38
No. Adults Tagged	309	300	609
No. Adults Harvested	374	352	726
No. Adults Recovered	116	48	164

3.3 *Sites*

The shallow site had a higher density of adult sea urchins ($4.2/m^2$) than the deep site ($0.75/m^2$) prior to stocking. The shallow site also had a more drift kelp, *Nereocystis,* $53.2g/60m^2$ compared to the deep site with $27.8g/60m^2$, however this resulted in less algae per sea urchin. The deep site had more wave flow since two of the three plaster discs had no plaster remaining and one weighted 2.6g averaging 0.86g ($\pm$ 1.5) after 12 days. The shallow site had less wave action with an average weight from four plaster discs of 13.4g ($\pm$ 4.2) after the 12 day period. Perhaps as a consequence of less water motion, the shallow site had more silt (mean 26.9mls sd =2.4) over the 12 day period examined, than the deep site (mean 5.6mls sd=1.5).

4 DISCUSSION

Fishery enhancement will ultimately depend on which life history stage limits fishable stocks (Tegner 1989). For sea urchins in California, larval sea urchin settlement intensity is temporally and spatially variable (Ebert et al. 1994) as is post-settlement survival (Rowley 1989). Theoretically, stocking juveniles could bypass these two bottlenecks. Stocking juveniles would enhance the population if it is not limited at another stage, such as adult food supply (Tegner 1989). Despite the interest in stocking, few sea urchin stocking studies have been conducted. One reason for the lack of studies is that sea urchin juveniles are difficult to obtain and track in the subtidal. Sea urchin harvest refugia are also lacking and so there are few areas protected from fishing that can be used for stocking experiments.

In this study, we cultured juvenile sea urchins then tagged and stocked them in a commercial sea urchin closure in northern California. We found good recovery rates of juvenile red sea urchins after one year of both stocked juveniles (16%) and tagged adults (27%). Recovery rates were twice as high in the shallow site compared with the deep site for both the stocked juveniles and the recaptured wild adult urchins (Table 1). Similarly, recovery of stocked juvenile abalone has also been shown to be spatially variable with recoveries ranging from 1-72% (Schiel 1993). The density of adult red sea urchins differed between the two sites. The shallow site had a higher abundance of adult red sea urchins and higher recoveries. This result supports the hypothesis that the presence of adult red sea urchins enhances juvenile survival (Tegner & Dayton 1977). Sites with adult red sea urchins also had better recoveries of stocked juvenile red abalone compared to sites without adult red sea urchins in northern California (Rogers-Bennett & Pearse 1998). The shallow site also had a higher abundance of drift algae, however with higher sea urchin abundances this translated into less algae per sea urchin. Therefore, it is unlikely that the differences in recovery were related to the abundance of drift algae. Higher amounts of silt at the shallow site did not appear to have a negative affect on juvenile recovery. One caveat for the algal, silt and wave action data is that these data were only collected once during the study and therefore may not reflect conditions throughout the year.

The timing of stocking also appears to influence recovery success. This study initiated in August had high juvenile recoveries (16%), however juvenile recoveries from a second experiment initiated in November at the start of the winter storms were poor (0-3%) (Rogers-Bennett, unpubl. data).

Differential sea urchin movement is a possible factor which could also explain differences in the recoveries between the two sites. Other studies have shown that sea urchins in shallow areas may be less mobile than sea urchins in deeper habitats. In northern California (Rogers-Bennett et al. 1995) and Alaska (Carney 1991), tagged sea urchins moved less in shallow nearshore habitats. Less movement would increase the chances of being recaptured. An alternative hypothesis is that mortality rates differed between the depths. This too would result in differential recovery rates. Further investigations could be designed to help distinguish between movement and mortality as mechanisms responsible for the recovery patterns observed. Regardless of the mechanism, knowledge of sites and site characteristics with high juvenile recoveries can be applied to improve future sea urchin stocking programs.

Sea urchin recoveries in California are an order of magnitude greater than juvenile abalone recoveries have been in both northern (<1%) (Rogers-Bennett & Pearse 1998) and southern California (<1%) (Tegner & Butler 1985). This suggests that sea urchin enhancement may be more promising than abalone enhancement efforts have been. Recovery rates from large-scale (N=40,000) stocking studies with juvenile sea urchins, *S intermedius*, in Japan have been high ranging from 23-39% after nearly two years (Omi 1987). In addition, recapture rates may be an underestimate of survival if sea urchins move away from stocking areas and survive but are not recovered. Assessing population enhancement, however will require tracking individuals for multiple years.

A second red sea urchin stocking study conducted in California using hatchery-reared juveniles also had variable recovery rates (1-22%) (Dixon et al.1992). Stocking was conducted in four sites, two in northern and two in southern California. Recoveries after one year suggested that there were no discernable spatial patterns in juvenile recoveries. Juvenile size, however did influence recovery. In that study, the largest juveniles (12-18mm) were recovered more than two smaller sizes (3-7mm and 8-12mm) at all sites (Dixon et al. 1992). Larger juvenile abalone have also been recovered in higher numbers than smaller abalone in Japan (Kojima 1981), but this pattern did not hold in southern California (Tegner & Butler 1989). Clearly, there is an economic trade-off between the cost of producing larger juveniles and the benefit of higher recoveries.

A number of factors both environmental and economic must be considered when designing enhancement strategies. Stocking programs must take into consideration possible problems arising from the spread of disease, introduction of exotics, and alteration of genetic composition. In northern California for example, one possible vector for the transmission of withering syndrome a lethal abalone wasting disease was the stocking of hatchery reared juvenile abalone (Friedman pers. comm.). Sea urchin stocking may not be profitable, in California despite high recoveries for two reasons. First, red sea urchins require at least three years until they are reproductively mature and 5-9 years to reach minimum legal size (Ebert & Russell 1992). Second, sea urchins are only worth $1-2 each at legal size.

Despite these considerations, experiments which track the survival of tagged juveniles are valuable not only in providing information on enhancement, but also as tools to assess habitat quality and learn more about populations dynamics. Identifying spatial patterns in juvenile survival, such as the location of high mortality "sink" habitats (sensu Pulliam 1988), will be important for gaining insights into sea urchin ecology.

The results from this enhancement experiment are consistent with the conclusion that shallow habitats with adult conspecifics are important nursery areas. Shallow habitats in northern California have previously been identified as nursery areas as well as areas with reproductively important broodstock (Rogers-Bennett et al. 1995). Knowledge of essential fish habitat (National Marine Fisheries Service 1997) will be key in the establishment of fishery management policies and in marine conservation efforts.

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