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EXPERIMENTAL SEEDING OF HATCHERY-REARED JUVENILE RED ABALONE IN NORTHERN CALIFORNIA

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ABSTRACT The feasibility of enhancing populations of red abalone, *Haliotis rufescens,* by seeding juveniles was evaluated in Northern California. We seeded 50,000 hatchery-reared juvenile red abalone averaging 8 mm in length in October 1995 into six sites: Caspar, Van Damme, Salt Point, Bodega Marine Life Refuge north, BMLR south, and Half Moon Bay. Recovery of juveniles at 6 months, 1 year, and 2 years totaled less than 1% of the number seeded, however seed accounted for one-third of the 1995 cohort. Recovered juveniles with obvious hatchery markings grew 15 mm per year. Recapture rates were higher at three sites with urchin spine canopy microhabitat as compared to three sites without sea urchins. Although juvenile recoveries may not be good indicators of survival, poor recapture rates highlight the present importance of conservative fishery management strategies.

KEY WORDS: enhancement, *Haliotis rufescens,* stocking, seed survival, Northern California

INTRODUCTION

The red abalone, *Haliotis rufescens* (Swainson), is the largest abalone in the world and is harvested by both commercial and recreational divers in California. Commercial harvest rates have declined more than 80% from an average of 2,000 metric tons in the 1950s and 1960s to 330 mt in 1989 (California Dept. Fish and Game statistics, Karpov and Tegner 1992). Commercial abalone fisheries are in decline worldwide. In 1997 the commercial abalone fishery in California was closed. The north coast of California supports a large recreational free-diving fishery, with daily limits of four abalone, which seems to have stable landings, ranging from 1–3 million pounds per year in the late 1980s (Karpov 1991, Karpov and Tegner 1992). This region, however, has sporadic natural recruitment. Because of the economic importance of abalone coupled with irregular natural recruitment, there has been considerable interest in abalone enhancement.

Abalone enhancement by seeding hatchery-reared juveniles has been practiced in many parts of the world. Success rates however, have been mixed (Tegner and Butler 1989, McCormick et al. 1994). In Japan, a large-scale seeding effort has been underway with more than 10 million seed produced and distributed by fishing cooperatives in 1979 alone (Tegner and Butler 1989). Nevertheless, reports of juvenile survival vary widely, ranging from 1–80% (Saito 1984, Tegner and Butler 1989, Kojima 1995). Similarly, in New Zealand survival of juveniles varies spatially ranging from 1–72% (Schiel 1993). In Southern California, juvenile recapture rates have been low, averaging less than 1% for seeded red abalone (Tegner and Butler 1985, 1989); however, similar studies have not been conducted in Northern California. Despite low recapture rates in Southern California, recent genetic work indicates that adult abalone at previous seeding sites are genetically similar to hatchery abalone, suggesting high juvenile seed survival (Gaffney et al. 1996).

In this paper, we examine the results of a large-scale seeding experiment using juvenile red abalone in Northern California. In October 1995, 50,000 juvenile abalone averaging 8 mm in shell length were seeded in six sites ranging from Half Moon Bay to Fort Bragg. Because juvenile abalone have been observed under the spine canopy of adult urchins (Tegner and Dayton 1977, Kojima 1981, Tarr et al. 1996, Rogers-Bennett pers. comm.), three sites were selected with and three without red sea urchins, *Strongylocentrotus franciscanus* (Agassiz). We report on the number of seed recovered and their growth after 6 months, 1 year, and 2 years.

MATERIALS AND METHODS

Study Sites

Six sites were selected for the seeding experiment; Caspar Reserve, Van Damme, Salt Point, Bodega Marine Life Refuge (BMLR) north, BMLR south, and Half Moon Bay (Mavericks). Caspar, Salt Point, and BMLR north have red sea urchins at 2–3/m^2, and urchins are absent from the remaining three sites. The sites were all in shallow water (5–8 m) and were selected to maximize cobble and movable substrate while minimizing sand scour and silt. Potential abalone predators at these sites include Cabezon fish, *Scorpaenichthys marmoratus* (Ayers), red and rock crabs, *Cancer* spp., and the sea stars, *Pycnopodia helianthoides* (Brandt), *Dermasterias imbricata* (Grube), and *Pisaster* spp.

Experimental Seeding

Juvenile red abalone were cultured at Bodega Farms, Bodega, California. Seed from three spawnings in spring of 1995 were randomly mixed and used. Larvae settled 7–8 days after fertilization. Animals were given a complete health examination including inspection for the presence of polychaetes by Dr. C. Friedman (California Dept. Fish and Game) and assessed as healthy. Delivery of juveniles occurred in September when the animals were weaned from microalgae and feeding on macroalgae averaging 8.22 mm in length (SD 1.08, n = 100). Their shells were turquoise or pale green, indicative of their hatchery diet of diatoms and *Macrocystis pyrifera* (Linnaeus) (Tegner and Butler 1989). Juvenile abalone were placed in mesh bags (1-mm mesh) in groups of 500. One group of 500 was counted and weighed (45.8 g), and subsequent bags were stocked by weight. Fleshy red algae, *Cryptopleura* spp., were added to the bags to acclimate the juveniles to a wild diet. Animals seemed to clump actively onto the algae and feed, and no transfer mortalities were observed.

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Juveniles were seeded into the six sites during an 11-day period in October, 1995. Two seeding methods were used: hand planting and release from abalone modules. Red algae were used as seed substrate and divers hand placed the algae with attached juveniles into cryptic microhabitats, including rock crevices, under moveable cobble, and under adult red urchins (where available). Hand-planting juveniles on the algal substrate took approximately 6 hours per site. Abalone were also placed in seeding modules (see Ebert and Ebert 1988 for module design) for release. The modules are large cement boxes with doors closed by rubber straps (bungee) attached to magnesium links that dissolve after 18 hours, freeing the juveniles at midnight the following night.

At Caspar, Van Damme, and Half Moon Bay the two seeding methods were used. Half the abalone were hand planted and the other half were placed in three abalone modules at a density of approximately 1,700/module. At the other three sites, all juveniles were hand seeded. The seeding area encompassed roughly a 4 × 15 m core area within the larger 24 × 30 m site. Juvenile density after seeding was approximately 150–170 seed/m^2 within the smaller core area. Sea star predators were removed from the sites at seeding.

Surveys

At 6 months, 1 year, and 2 years, sites were searched invasively by lifting movable cobble, removing adult urchins, searching in coralline and other red algae, rock crevices, and under ledges. The 6-month survey was a 3-hour invasive search, but no identification of hatchery seed was attempted, because juveniles were not collected. At the 1 and 2 year surveys, all juvenile abalone found were collected and measured. These surveys were conducted along six parallel 4 × 30 m transects for a total area searched of 720 m^2 per site. This extensive search took approximately 8–10 hours depending on the habitat type and abalone density. We compared the number of seed recaptured from sites with and without urchin spine microhabitat in 1996 and 1997 using a chi-square test.

Growth

All juvenile abalone collected from the sites with obvious hatchery shells were measured in the laboratory to assess original and final size. Growth is reported as the difference between original size determined from the green shell, and final size (See Table 1). In addition, juvenile seed were maintained in the laboratory and their final size was assessed after 2 years.

RESULTS

Surveys

At 6 months, fewer than 20 juveniles between 6–16 mm were found at each site in February and March 1996 (Table 1). No dives were made at 6 months at Half Moon Bay because of rough ocean conditions. No shells indicating mortality were found at any of the sites.

One year after release, shells with obvious hatchery coloration (turquoise and pale green) ranged in size from 18.4–28.4 mm. Hatchery-reared seed accounted for one-third of all the juveniles found between 16–30 mm (Table 1). Seed recoveries ranged from 0–0.17% for the six sites. Juvenile density in the study sites (each 24 × 30 m) ranged from 0–0.07 juveniles/m^2 at one year. Caspar had the most seed in the target size range and the highest seed recovery of 17 animals; whereas, at Half Moon Bay, neither juvenile nor adult abalone were found. At 1 year, we recovered significantly more seed from the sites with urchins, as compared to the sites without urchins (χ^2 = 18.78, df = 1, p < .001).

Two years after release, shells with obvious hatchery-reared colors ranged in size from 28.4–51.0 mm. Again, hatchery-reared seed made up approximately one-third of all the juveniles found between 26–52 mm (Table 1). Recoveries from the sites ranged from 0–0.21% of the total number of juveniles seeded. Juvenile density in the study sites ranged from 0–0.08 juveniles/m^2 at 1 year. Again, Caspar had the most seed in the target size range and the highest seed recovery of 21 animals. In Half Moon Bay, no juvenile or adult abalone were found in the survey and none were found in a broad scale emergent survey conducted over an area 10 times the size of the study site. Again, we recovered significantly more seed from sites with urchin spine canopy microhabitat (χ^2 = 9.77, df = 1, p < .01).

Using the most liberal interpretation of the recovery data, so that all juveniles between 16–30 mm in the 1st year and all juveniles between 26–52 mm in the 2nd year are counted as seed, still yields less than 1% of the total 50,000 recovered after 2 years. Here, we use the more conservative estimate of seed recovered including only those seed with obvious hatchery coloration. Although seed recovery was exceedingly low (<1%), one-third of the 1995 cohort was hatchery-reared seed (Table 1).

TABLE 1.

Number of juvenile red abalone seeded (size 8.22 mm), number of juveniles recovered of potential recapture size, number of definite recaptures, and mean increase in shell size of the recaptured juveniles. Recaptures are from six field sites (each 720 m^2) in Northern California where sites 1–3 have red sea urchins and sites 4–6 do not have urchins.

	1995	1996 (6 mo)	1996 (1 Year)			1997 (2 Years)		
Site	# Seeded	# (6–16 mm)	# (16–30 mm)	# Seed	$\bar{x}$ Growth (SD)	# (26–52 mm)	# Seed	$\bar{x}$ Growth (SD)
With urchins								
1. Caspar	10,000	11	47	17	15.75 (SD 3.7)	59	21	28.49 (SD 6.0)
2. Salt Point	10,000	16	35	10	17.07 (SD 3.1)	11	5	30.64 (SD 9.0)
3. BML north	5,000	5	13	4	13.5 (SD 1.2)	4	2	27.9 (SD 3.7)
No urchins								
4. Van Damme	10,000	8	5	5	15.03 (SD 3.3)	23	9	30.57 (SD 7.6)
5. BML south	5,000	2	5	0	No data	2	0	No data
6. HMB	10,000	No data	0	0	No data	0	0	No data
Total	50,000	42	105	36		89	37	

Growth

Juveniles averaging 8 mm at the time of seeding grew a mean of 15 mm during the 1st year and 15 mm more in the 2nd year (Table 1). There were no significant differences in growth between sites or between years. Seed reared in the laboratory grew 19.48 mm (SD 1.63, n = 9) over 2 years.

DISCUSSION

The feasibility of seeding red abalone populations with small hatchery-reared juveniles was explored. We recovered fewer than 1% of 50,000 juvenile abalone (8 mm) after 2 years from six sites in Northern California. Recoveries seemed unrelated to local adult abalone density, and the recreational abalone fishery in Northern California did not seem to have an impact on the recovery of seeded juveniles. These recoveries contrast sharply with results from Japan and New Zealand, where some sites had greater than 50% juvenile survival (Saito 1984, Schiel 1993, Kojima 1995). Our results are more consistent with recoveries from the Palos Verdes Peninsula in Southern California, where fewer than 1% of the juveniles (45 and 71 mm) were recovered after 1 year (Tegner and Butler 1985). Growth of seeded juveniles was lower in Northern California, with juveniles growing 15 mm per year than in the Palos Verdes study, where juveniles grew 30 mm per year (Tegner and Butler 1985). Elsewhere in Southern California, recovery of seed abalone (41 mm) from inside artificial habitats in the Channel Islands was also low, ranging from 0–6% after the first year and 0–2% after the second year (Davis 1995).

Sites with adult red sea urchins had significantly higher juvenile abalone recoveries, as compared to sites without urchins. Many of the hatchery-reared juveniles were found under the spine canopy of red sea urchins. Juvenile abalone in Southern California (Tegner and Dayton 1977, Tegner and Butler 1989), Japan (Kojima 1981), and South Africa (Tarr et al. 1996) have been found in association with the spine canopy of sea urchins. Sites designed as commercial urchin harvest refugia enhanced the recovery of hatchery-reared juvenile abalone. This result supports an ecosystem-based fishery enhancement strategy.

Poor recoveries have been attributed to high predation mortality. There is evidence for differential mortality of hatchery-reared as compared with wild juveniles, because laboratory experiments indicate that wild juveniles are better able to find cryptic shelter and avoid predation (Schiel and Weldon 1987, Tegner and Butler 1989, but see Tegner and Butler 1985). In this study, we found few shells resulting from predation or other causes of mortality; however, wave action in this area may hinder shell recovery.

An alternative explanation is that juveniles not recovered survived but evaded recapture and that recoveries are a poor indicator of juvenile survival. In this study, recoveries did not decrease over time (Table 1). Surprisingly, the poorest recoveries occurred at the earliest time point (6 mo). This suggests juveniles were cryptic and difficult to relocate in the complex habitat. In addition, juvenile abalone are known to be highly mobile. For example, Tegner and Butler (1989) showed that 38% of the small abalone (13 mm) moved out of a study area in 1–2 days. Therefore, juvenile abalone in our study could have easily moved outside of the study areas between survey periods.

Genetic evidence also suggests that seed survival rates may be greater than recoveries indicate. Resident adult abalone from Tyler Bight on the south side of San Miguel Island in the Channel Islands, a site that was seeded repeatedly in the 1970s and 1980s, currently seem to have genotypic and allelic frequencies similar to hatchery animals (Gaffney et al. 1996). This is further evidence that, despite poor recoveries, many juveniles could have survived to become adults. Genetic markers such as these, although raising concerns about the genetic diversity of seeded juveniles, may prove useful in tracking their fate.

It seems clear that although juvenile recoveries in this study were low (<1%) more work is needed to determine long-term survival. With one-third of the juveniles in the 1995 cohort originating as hatchery seed (Table 1), it will be important to follow their survival over time. If the survival trend observed in 1996 and 1997 continues, hatchery seed have the potential to contribute to the local population, despite poor recoveries. At present, the future reproductive contribution of these hatchery juveniles is unknown. From an economic perspective, this approach does not seem cost effective; however, better information regarding survival to reproductive size and to minimum legal size (177 mm) is required for economic analyses. In the meantime, our poor recovery results (<1%) support careful conservation of red abalone resources and conservative stock management policies, because northern populations are the only healthy abalone stocks remaining in California today.

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LITERATURE CITED

Davis, G. E. 1995. Recruitment of juvenile abalone (*Haliotis* spp.) measured in artificial habitats. *Mar. Freshw. Res.* 46:549–554.

Ebert, T. B., & E. E. Ebert. 1988. An innovative technique for seeding abalone and preliminary results from laboratory and field trials. *Calif. Fish Game* 74:68–81.

Gaffney, P. M., V. Rubin, D. Hedgecock, D. A. Powers, G. Morris & L. Hereford. 1996. Genetic effects of artificial propagation: signals from wild and hatchery populations of red abalone in California. *Aquaculture* 143:257–266.

Karpov, K. A. 1991. A combined telephone and creel survey of the red abalone, *Haliotis rufescens* (Swainson), sport in California, from Monterey to the Oregon border, from April through November 1989. California Dept. of Fish and Game. Admin. Rept. 91–2.72.

Karpov, K. A. & M. J. Tegner. 1992. Abalone. pp. 33–36 *In:* W. S. Leet, C. M. Dewees, and C. W. Haugen (eds.). California's Living Marine Resources. California Sea Grant Ext. Publ. UCSGEP-92-12.

Kojima, H. 1981. Mortality of young Japanese black abalone *Haliotis discus discus* after transplantation. *Bull. Japan. Soc. Sci. Fish.* 47:151–159.

Kojima, H. 1995. Evaluation of abalone stock enhancement through the

release of hatchery-reared seeds. *Mar. Freshw. Res.* 46:689–695.
McCormick, T. B., K. Herbinson, T. S. Mill & J. Altick. 1994. A review of abalone seeding, possible significance, and a new seeding device. *Bull. Mar. Sci.* 55:680–693.
Saito, K. 1984. Ocean ranching of abalones and scallops in northern Japan. *Aquaculture* 39:361–373.
Schiel, D. R. 1993. Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. *Mar. Ecol. Prog. Ser.* 97:167–181.
Schiel, D. R. & B. C. Weldon. 1987. Responses to predators of cultured and wild red abalone *Haliotis rufescens,* in laboratory experiments. *Aquaculture* 60:173–188.
Tarr, R. J. Q., P. V. G. Williams & A. J. MacKenzie. 1996. Abalone, sea urchins, and rock lobster: a possible ecological shift that may affect traditional fisheries. *S. Af. J. Mar Sci.* 17:319–323.
Tegner, M. J. & P. K. Dayton. 1977. Sea urchin recruitment patterns and implications of commercial fishing. *Science* 196:324–326.
Tegner, M. J. & R. A. Butler. 1985. The survival and mortality of seeded and native red abalones *Haliotis rufescens,* on the Palos Verdes Peninsula. *Calif. Fish Game* 71:150–163.
Tegner, M. J. & R. A. Butler. 1989. Abalone seeding. pp. 157–182. *In:* Hahn, K. O. (ed.). Handbook of Culture of Abalone and Other Marine Gastropods. CRC Press, Boca Raton, Florida.