# Recovery of red sea urchin beds following experimental harvest

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ABSTRACT: Adaptive management techniques using harvest experiments were employed to determine how red sea urchins recovered from three harvest strategies. We found that recovery from harvesting was highly variable spatially. Intermediate depth sites (11m) recovered quickly (<1 month) due to immigration of adults from nearby areas, regardless of harvest treatment. Recovery rates for urchins in shallow depths (5m) were slow, and harvest treatment influenced both population recovery from immigration and recruitment of juvenile urchins. The lower size-limit treatment, mimicking current regulations, resulted in a decline in urchin density and no successful recruitment for six years. Both harvest treatments which protected large adults, upper size-limits and harvest refugia allowed for high recruitment in shallow habitats. Our results support the protection of large adult urchins in shallow harvest refugia. These results suggest alternative management strategies proposed for northern California's urchin fishery may yield better recovery rates than current policies.

## 1 INTRODUCTION

Sea urchins are being fished worldwide (Conand & Sloan 1989) and in some cases overtaking more traditional finfish fisheries. Currently, red sea urchins, *Strongylocentrotus franciscanus*, are California's most valuable fishery, grossing more than salmon and dungeness crab fisheries. In northern California however, red urchin landings have declined dramatically from a peak of 13.8 x $10^6$ kg in 1988 to 2.2 x $10^6$ kg in 1995. This decline in urchin landings suggests that current management strategies may not be effective at sustaining yields and has prompted research examining alternative fishery management strategies. Current management policy for the red urchin fishery in California includes 1) limited entry of fishers, 2) limited number of fishing days, and 3) lower size limits (P. Kalvass pers. comm.). Several alternative management options have been proposed and are now being discussed (Ebert 1995); these include upper and lower size-limits (A. Bradbury pers. comm), individual transferrable quotas (ITQs) (Boyd & Dewees 1992, Ackroyd & Beattie 1996), area rotations (Bradbury 1991, Botsford et al. 1993, Pfister & Bradbury 1996), and shallow harvest refugia (Rogers-Bennett et al. 1995).

Adaptive management, taking the form of harvest experiments which simulate fishery management strategies, has been recommended as a valuable tool to assess the impact of proposed regulations (Holling 1978, Walters 1986). We experimentally manipulated beds of red sea urchins in northern California to mimic three harvest strategies: (1) the current policy of a lower size-limit (harvest all adults), (2) proposed upper and lower size-limits (selective harvest), and (3) proposed harvest refugia (no harvest areas). In 1988, six beds of red urchins were harvested at two depths following these three harvest treatments, and urchin density was re-examined periodically until 1995.

## 2 METHODS

Six beds of red sea urchins were selected, three at shallow (5 m) and three at intermediate (11 m) depths in the Bodega Marine Life Refuge, northern California, USA (38°19'03" N, 123°04'12" W). No commercial or recreational fishing is permitted in

the refuge and this area supports dense aggregations of red sea urchins. Urchin beds used in fishery manipulations consisted of discrete aggregations of urchins at densities greater than 100, but not more than 750 individuals. Natural beds were selected to maximize substrate uniformity and urchin abundance. Urchin beds were surrounded by rocky or sandy substrate devoid of red sea urchins.

The experimental harvest manipulations were initiated in September, 1988. Standardized 8m x 8m (64 m$^2$) areas were selected in the center of each of the six urchin beds. Three harvest treatments were implemented in the three shallow (5m) and the three intermediate (11m) depth urchin beds. Harvest treatments consisted of (1) harvesting all urchins greater than a lower size limit of 89mm test diameter (all adult harvest), (2) harvesting urchins between the lower size limit of 89mm and an upper size limit of 125mm (selective harvest), and (3) excluding all urchins from harvest (harvest refugia). Due to a redistribution of urchins from within the larger bed a second harvest manipulation was conducted in 1989 encompassing the entire bed, roughly 16m x 16m (256 m$^2$) using the same

Table 1. Density of red sea urchins within an 8 x 8 m (64/m$^2$) area before, after, and at 1 month post-harvest. Urchins were experimentally harvested using one of three strategies; (1) all adult urchins >89mm test diameter harvested, (2) selected urchins between 89 and 125 mm harvested, (3) no urchins harvested (refugia). Harvesting occurred in three shallow (5m) and three intermediate (11m) depth urchin beds on Sept. 28 and 29, 1988 in the Bodega Marine Life Refuge.

| Depth | All | Selective | Refuge |
|---|---|---|---|
| Shallow | | | |
| Before | 431 | 345 | 103 |
| After | 39 | 230 | 103 |
| <1Month | 40 | 229 | 106 |
| Intermediate | | | |
| Before | 151 | 108 | 155 |
| After | 3 | 19 | 155 |
| <1Month | 49 | 93 | 132 |

Table 2. The density urchins remaining after the 1989 and the final 1991 harvest. Harvesting in 1989 and 1991 occurred within three large sites (256 m$^2$) in the shallow depth (5m) only. Densities of urchins were monitored <1 month and again four years after the final harvest pulse.

| | All | Selective | Refuge |
|---|---|---|---|
| 1989 Harvest | | | |
| Before | 157 | 597 | 103 |
| After | 16 | 347 | 103 |
| 1989 Monitor | 16 | 347 | 115 |
| 1991 Harvest | | | |
| Before | | 230 | |
| After | | 169 | |
| 1995 Monitor | 8 | 210 | 81 |

harvest treatments. In 1991, the last pulse of the harvest manipulation was conducted at the selective harvest site at the shallow depth. Urchin densities were monitored at 1 month, and 4 years following the 1991 harvest.

Recruitment of juvenile urchins was monitored at the shallow sites. The presence of juvenile urchins (5-50 mm test diameter) was quantified within 1 m$^2$ quadrats placed randomly within the shallow sites. Each quadrat was searched invasively by examining cryptic microhabitats (e.g. rock crevices, coralline algae) as well as removing adult red sea urchins to search for juveniles under the adults' spines and test.

## 3 RESULTS

Recovery of experimentally harvested beds was highly dependent on the depth of the site. Beds at the intermediate depth (11 m) began to recover from harvest manipulations within weeks of the harvest; by 9 days post-harvest, the selective harvest site had regained 86% of its original density while the harvest all adults site had regained 32% (Table 1). We observed *in situ* that urchins at this

Table 3. The number of juvenile urchins (5-50 mm) found in 1 m² quadrats randomly placed within the three harvest treatment sites at the shallow depth in the Bodega Marine Life Refuge. The number of juvenile urchins found is followed by the number of quadrats searched in parentheses. (*) indicates that the central 64 m² area was searched invasively for juvenile urchins.

|      | All   | Selective | Refuge |
| ---- | ----- | --------- | ------ |
| 1989 | 1 (3) | 18 (6)    | 25 (5) |
| 1990 | 0 (5) | 6 (9)     | 0 (9)  |
| 1992 | 2 (6) | 58 (9)    | 45 (9) |
| 1995 | 0(*)  | 11(*)     | 12(*)  |

depth were highly mobile moving 1-10 m./ hour.

In contrast, urchin beds at shallow depths recovered slowly or did not recover from harvest. At 1 month post-harvest, urchin densities were identical to those immediately following the harvest, indicating no immediate immigration of shallow urchins into the experimental sites as was observed at the intermediate depths (Table 1). However, monitoring conducted after 1 year (1988-1989) showed these centralized areas (64 m²) experienced limited immigration from within the larger bed. Following the second larger (256 m²) harvest in 1989 (see methods), the shallow beds showed no signs of large-scale immigration of urchins from neighboring areas from 1989 to 1995 (Table 2). Some recovery of urchin density at the selective harvest shallow site was observed from 1991 to 1995 (169 to 210 urchins). However, at the shallow all adult harvest site, urchin density never recovered but decreased from 32 to 16 and then 8 urchins from 1989 to 1995. In addition, macroalgae began to overgrow the substrate at this site.

Juveniles were rare at the intermediate-depth sites compared with the shallow sites. Recruitment of juveniles (<50 mm), in the shallow sites was significantly greater ($X^2 = 110$, d.f.= 2, p<.001) in the two sites where adult urchins had been protected, the selective and the no harvest site compared with the all adult harvest site (Table 3).

## 4 DISCUSSION

### 4.1 Recovery and Immigration

Recovery of red urchin beds from experimental harvesting was spatially variable. Beds of urchins at shallow depths were highly susceptible to harvest with urchin densities recovering slowly in selectively harvested sites or not recovering following intense harvest, even after six years. In contrast, densities of urchins in the intermediate depths quickly (1 month) recovered to pre-harvest densities. Urchins at the intermediate depth were mobile, and routinely moved into experimental beds from neighboring areas. Previous tagging studies at these sites support our observations demonstrating that urchins at intermediate depths are highly mobile while urchins in shallow sites are sedentary, remaining encrypted within scoured depressions in the rock substrate (Rogers-Bennett et al. 1995). No evidence of wide-spread immigration into the shallow harvested sites was found. Therefore, we propose that the primary mechanism of population recovery in the intermediate depths was immigration of adults from nearby areas and that population recovery in the shallow sites resulted from the recruitment of juveniles and their growth into the fishery.

### 4.2 Recruitment

A second mechanism for recovery from harvest is the addition of individuals through juvenile recruitment. We found almost no recruitment of juveniles over the six year period in the shallow all adult harvest site. In contrast, we found good recruitment in both the shallow selective harvest and no harvest sites (Table 3). The recruitment of urchins Strongylocentrotus spp. was greater on average for shallow compared with intermediate depth habitats and shallow juveniles resided in cryptic microhabitats. In these sites juveniles were observed sheltering under the spines and test of adult urchins. Adult urchins in the shallow habitats also harbored a variety of other organisms, including flat fuzzy crabs, Hapalogaster cavicauda, and snails, Amphissa variegata.

We do not know at this time whether urchins are settling differentially between the shallow sites or if the differences we observe in

recruitment are due to differential post-settlement survival. Urchins could be settling in equal numbers within the three shallow sites but not surviving to be quantified by divers (approx. 5mm test diam.). Alternatively, settlement could be depressed due to the absence of adult conspecifics. Previous laboratory experiments indicate settlement is not dependent on the presence of adults conspecifics (Cameron & Schroeter 1980). The absence of adults in the shallow all adult harvest site allowed a dense algal cover to develop, potentially rendering the site unsuitable for urchin settlement or negatively impacting post-settlement survival.

In a similar fishing experiment conducted in southern California over one settlement season, significantly more juvenile red urchins recruited to an unfished control reef compared with three experimentally fished reefs (Tegner & Dayton 1977). While there were some recruits at the fished reefs this is thought to have been due to the presence of a small number of adults urchins which migrated onto the fished reefs and the number of juveniles appeared proportional to the number of adult migrants (Tegner & Dayton 1977).

These results support the canopy sheltering hypothesis which suggests that the recruitment of juvenile urchins is enhanced by the presence of adult conspecifics (Tegner & Dayton 1977, Breen et al. 1985, Rogers-Bennett et al. 1995). The benefits this association may provide juveniles has not been determined but the adult spine canopy may protect juveniles from predation or enhance juvenile feeding on drift algae (Tegner & Dayton 1977). In British Columbia, the threat of predation appears to be an important factor for this association (Breen et al. 1985). At our study sites strong waves may also threaten exposed juveniles.

### 4.3 Implications for Fishery Management

Our results suggest that urchin populations in shallow habitats are particularly vulnerable to harvest. Regardless of the mechanisms impacting recovery, the shallow all adult harvest site shows no indication of recovering six years post-harvest and no juveniles have been observed. Even in the shallow selective harvest site recovery has been very slow compared with intermediate depths.

Upper size-limits effectively promoted recruitment in the shallow selective harvest site. This site has also had high recruitment while the shallow all adult harvest site actually decreased in density and showed no recruitment. The benefit of an upper size limit in the intermediate depth sites

was less clear because of the immigration of adults from nearby areas. However, we caution that intensive harvesting of urchins on a large scale (e.g. northern California fishery) even exclusively at intermediate depths, could eventually deplete urchins available for migration and hinder recovery overall.

Our results support the proposal to establish shallow harvest refugia (Rogers-Bennett et al. 1995) because of the vulnerability of these populations to harvest. Harvest refugia may be preferable to alternative spatial management strategies such as area rotations, since we have shown that the duration of rotation cycles could be exceedingly long, >6 years and some shallow populations may never recover. Protecting shallow high density populations may also benefit the fishery since these populations may be acting as brood stock. Urchins in shallow beds were found at high pre-harvest densities, ($> 4/m^2$) and fertilization success has been shown to be greater than 80% for urchins at these high densities (Levitan et al. 1992). Other studies have shown that urchins in these shallow habitats have high gonad indices and access to abundant drift algae resources (Rogers-Bennett et al. 1995) all of which suggest they may be spawning successfully.

High urchin density may enhance juvenile recruitment as well as spawning success. Previous work has shown that sedentary adults in these shallow habitats are 6 times more likely to shelter juveniles under their test and spines than conspecifics residing in deeper habitats (Rogers-Bennett et al. 1995). Ideally, harvest refugia could be designed to protect spawners and juveniles, thereby promoting the production of larvae, juveniles, and adults which may then disperse into harvested habitats. Dispersal from protected areas into harvested sites has been demonstrated for other exploited invertebrate species including pink shrimp (Gitschlag 1986) and snow crabs (Yamasaki & Kuwahara 1990) Furthermore, the harvest of reproductively important patches could be detrimental to the population as a whole if these patches function as sources (*sensu* Pulliam 1988) for the larger metapopulation.

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