Sea Urchin Recruitment Patterns and Implications of Commercial Fishing

Abstract. *Coexisting sea urchins* Strongylocentrotus purpuratus *and* S. franciscanus *exhibit different recruitment patterns. Juveniles of the former species are found in a variety of habitats, whereas juveniles of the latter occur almost exclusively under the spine canopy of conspecific adults. The commercial harvest of* S. franciscanus *thus seems to affect nursery grounds as well as the reproductive potential of exploited populations.*

The recruitment of pelagic larvae of benthic marine organisms is fundamentally important to the dynamics of their populations and to the structure of the communities in which they live (*1*). We have studied the settlement and survival of postmetamorphic sea urchins to determine the effects of commercial harvesting, begun in 1970, on local populations (*2*). Our results indicate that the harvesting may not only decrease the reproductive potential of exploited populations but may affect the nursery grounds of young urchins and abalones as well.

Sea urchins are herbivores that profoundly affect the structure of benthic algal communities (*3–6*). The two most important urchins in southern California kelp beds are *Strongylocentrotus franciscanus* and *S. purpuratus*, species that have overlapping depth distributions and similar food preferences (*4*). The commercial fishery currently exploits the larger *S. franciscanus* but may in the future take *S. purpuratus*, which is currently utilized extensively by teachers and developmental biologists. These educational and scientific uses are in conflict with any future *S. purpuratus* fishery and the potential range extension of the urchin-eating sea otters (*5*) and should be considered in the management of nearshore resources in southern California.

To determine whether commercial fishing affects recruitment, we asked whether small urchins are recruited into a variety of microhabitats or whether there exist specific nursery grounds such as those reported for several other species (*7*). Although small *S. purpuratus* have been reported from a variety of microhabitats (*6, 8, 9*) (juvenile *S. franciscanus* have apparently not been studied), little was known about the relative ecological importance of these microhabitats. To locate newly settled urchins, we sampled coralline algae (low, turf-forming plants), cobble, kelp holdfasts, the undersides of rocks, and the substrate under adult urchins. These microhabitats are probably the only places offering enough protection for postmetamorphic urchins to survive. Sampling was conducted between November 1974 and May 1976. The study areas were located approximately 1.5 and 2 km offshore of Pt. Loma, San Diego, California (32°42′N, 117°16′W), at depths of 15 to 20 m in a large stand of giant kelp, *Macrocystis pyrifera*. The heterogeneous bottom consists of siltstone pavement rocks, rocky outcrops, boulder patches, and occasional sand channels. The holdfasts of *M. pyrifera* or lower standing kelp, such as *Pterygophra californica*, *Eisenia arborea*, and *Laminaria farlowii*, occupy much of the hard substrate. Both species of urchins are abundant in the rocky areas.

Foliose coralline algae (*Corallina officinalis* var. *chilensis*, *Calliarthron cheilosporoides*, *Bosiella orbigniana*, and *B. gardneri*) and cobble were collected both near and away from adult urchins and brought to the laboratory in fine mesh bags. Approximately ¼ m^2 of bottom area of these two microhabitats was sampled at a time; *M. pyrifera* holdfasts were pried off the substrate, bagged, and recovered for analysis. Surface area was computed by assuming holdfasts represent elliptical cones. To sample the substrate under adult urchins, the urchin was pried off the bottom and juveniles were collected from the undersides of the adult and from the bottom. Rocks were turned and measured and urchins were removed before each rock was replaced.

The results indicate that *S. purpuratus* juveniles are flexible in their recruitment behavior and that *S. franciscanus* are quite restricted (Table 1). Small *S. purpuratus* were abundant under rocks, in kelp holdfasts, and under adult urchins of both species. Cobble beds and coralline algae appear to be insignificant nursery grounds in this area, harboring less than 5 percent of the juvenile *S. purpuratus* and no *S. franciscanus*.

The most important site for juvenile *S. franciscanus* recruitment appears to be under the spine canopy of conspecific adults (Table 1). The tests of adult *S. franciscanus* are situated approximately 1 to 2 cm above the bottom, resting on the short spines of the oral surface; small urchins are located among these spines (Fig. 1). However, some juvenile *S. franciscanus* were found in other microhabitats; these exceptions were often informative. To sample the underside of rocks as a microhabitat, we haphazardly overturned rocks and removed all juvenile urchins. Many of these rocks had larger urchins of both species attached. After realizing that juvenile *S. franciscanus* are closely associated with adults, we returned and collected juvenile urchins from rocks that had no *S. franciscanus* individuals larger than 30 mm. Only one juvenile *S. franciscanus* was found in a total of 7.8 m^2 rock area searched, which suggests that the higher numbers of juvenile *S. franciscanus* found in the original haphazard rock search resulted from the presence of adult *S. franciscanus*. When the results are tabulated in terms of this second rock search, more than 80 percent of all the juvenile *S. franciscanus* found were under the spine canopies of conspecific adults. Of the 33 *M. pyrifera* holdfasts collected, 23 contained juvenile *S. purpuratus*, only 2 had both *S. purpuratus* and *S. franciscanus*, and 10 had no juveniles. The two holdfasts that contained *S. franciscanus* were both collected from the outer edge of the kelp bed in areas in which adult *S. franciscanus* are rare.

Juvenile *S. franciscanus* may seek out the adults of their own species. In August, 1975, a small reef was cleared of all *S. franciscanus*; 208 *S. purpuratus* remained. Four months later, after substantial recruitment had taken place in the general area, nine of the ten juvenile *S. franciscanus* found on this reef were under the single adult *S. franciscanus* that had migrated onto the reef. The tenth was associated with the spine canopy of an *S. purpuratus*. Furthermore, we have observed recently collected small *S. franciscanus* to cluster rapidly under larger conspecifics in aquariums. To test the hypothesis that recruitment of juvenile *S. franciscanus* is not random with respect to the presence or absence of adults, we sampled three small reefs that were of approximately equal area and close to each other. The first reef was densely populated (*10*) with *S. franciscanus*; under 49 adult *S. franciscanus* were 66 juveniles of the same species. There were 8 adults and 11 juveniles on the second reef. And on a third reef, which had been cleared of all urchins 6 months before sampling, we found no juvenile *S. franciscanus*. These differences between the areas significantly (one-tailed χ^2 test, $P < .005$) negate the null hypotheses (i) that recruitment of juvenile *S. franciscanus* is random with respect to the presence or absence of adults of the same species, or (ii) that recruitment is equal in equal areas. Since the ratios of adults to juveniles were approximately equal on the two reefs inhabited by urchins, there is probably no threshold effect of adult density on *S. franciscanus* settlement.

The association of juvenile *S. franciscanus* with adults of the same species raises the possibility that the commercial fishery may have a substantial effect on recruitment. To further test the hypothesis that the settlement or survival (or both) of juvenile *S. franciscanus* depend on the presence of adult *S. franciscanus*, we conducted small-scale fishing experiments designed to simulate commercial fishing practices. Numerous small rock reefs or pinnacles found at our 15-m study area are isolated from each other by rather homogeneous sandy siltstone covered with the canopies of lower-standing kelp. Adult *S. franciscanus* will only occasionally traverse these sandy siltstone areas. On three reefs, we removed *S. franciscanus* of the size classes exploited by the commercial fishery [95 to 130 mm (*11*)] leaving smaller *S. franciscanus* and all *S. purpuratus*. A nearby reef was designated as a control and left untouched. The fishing took place in summer before the time of heaviest settlement, and the experiment was concluded in late September after considerable settlement had taken place in surrounding areas. There was some migration of adult *S. franciscanus* onto each fished reef, and the larger the number of migrants, the larger the number of juvenile *S. franciscanus* at the end of the experiment. These migrants were not removed because their movements reflect the natural situation. Nevertheless, the number of juvenile *S. franciscanus* in the 0- to 10-mm size range (which would include animals that settled during the course of the experiment) from the fished reef was significantly lower than that on the control reef (one-tailed *t*-test, $P < .01$). The number of juveniles in the 10- to 20-mm size range (animals that probably settled before the start of the experiment) was also significantly lower (one-tailed *t*-test, $P < .05$). We have not determined the threshold size of adults for this nursery association, but the results of this experiment suggest that it may be close to the minimum size taken by the commercial fishery. If *S. franciscanus* individuals of the intermediate size class could have assumed the nursery function, it might have alleviated the effects of fishing the adults. However, in this experiment, there were more *S. franciscanus* of intermediate size (20 to 95 mm) on the experimental reefs than on the control (one-tailed *t*-test, $P < .05$).

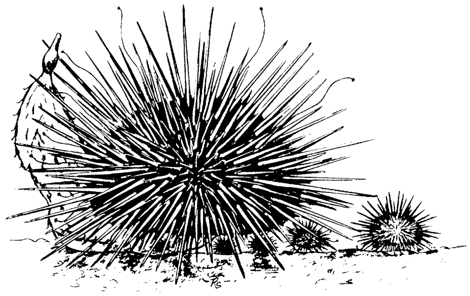

Fig. 1. Juvenile urchins recruit under the spine canopy of adult *S. franciscanus* and share the kelp caught by the bigger urchin. As juveniles get larger, they move toward the periphery of the spine canopy. [Drawn by R. Sturtz]

This nursery association of adult and juvenile urchins offers two probable advantages to the smaller animals, a food source and protection from predators. We often observed juveniles feeding on the drift kelp snared and anchored by the adult urchin (Fig. 1). Thus the small urchins get to feed on macroalgae probably too large for them to procure for themselves. However, the presence of numerous motile organisms in addition to the small urchins under the spine canopy of large *S. franciscanus*, including abalones, gastropods, shrimps, crabs, asteroids, ophiuroids, and fishes, suggests that all of these animals have simply sought the protection of the spine canopy. Although there is less room under the canopy of the short-spined *S. purpuratus*, small abalones and ophiuroids are found in this habitat along with the juvenile urchins.

The potential refuge of juvenile urchins from predators offered by the spine canopy may be the most important aspect of this association. Newly settled urchins, less than 1 mm in diameter (*12*), are probably susceptible to most predators that find them. We have observed eight species of asteroids (*13*) to prey upon juvenile urchins in the laboratory or field. Urchins are important to the diet of the spiny lobster, *Panulirus interruptus* (*14*), and the senorita (*Oxyjulis californica*), a common wrasse, has been observed picking juvenile urchins out of coralline algae and having small urchins in its gut contents (*15*). We have observed the sheephead (*Pimelometopon pulchrum*) pick small urchins of both species off the undersides of overturned rocks.

In this nursery association, the smallest urchins are found directly under the test of the adult (Fig. 1). As the juveniles grow larger, they progress toward the periphery of the spine canopy. Once too large to fit among the spines, the juveniles still cluster close to the adult. We attempted to determine the size at which juveniles are no longer protected by the adult by collecting the smallest individuals of *S. franciscanus* in an area we thought accessible to sheephead, the major fish predator. The mean size of these juveniles was 44 mm (N = 95; range, 22 to 76 mm). Although this is a subjective measure, the population size structure of *S. franciscanus* (N = 892) in our study areas is bimodal, and 44 mm is in the interval between the two major modes. We propose that *S. franciscanus* juveniles are protected from predation pressure by this nursery association until they reach a size of 30 to 40 mm, when they begin to move away from the adults. Juveniles then face intensive predation pressure until they achieve the partial refuge of size. Populations of *S. purpuratus*, which do not rely so heavily on a nursery

Table 1. Recruitment of sea urchins in different microhabitats. The location is given of all juvenile (≤ 20 mm) sea urchins (437 *Strongylocentrotus purpuratus* and 343 *S. franciscanus*) found in the 19-month sampling period. A total of 87 m^2 was searched. Habitat preference was determined by normalizing the number of urchins found in each microhabitat to a standard area searched.

Habitat	Density (No./m^2)		Habitat preference (%)	
	S. purpuratus	*S. franciscanus*	*S. purpuratus**	*S. franciscanus*†
Cobble	0.2	0	0.6	0
Coralline algae	1.12	0	3.7	0
Rocks‡	10.46	2.99	35.0	
Rocks§	¶	.13		1.1
Holdfasts	5.83	.79	20.0	6.9
Adult *S. purpuratus*	6.69	1.25	22.3	10.7
Adult *S. franciscanus*	5.63	9.49	18.9	81.2

*Calculated on the basis of haphazardly chosen rocks. †Calculated on the basis of rocks without associated adult *S. franciscanus*. ‡Haphazardly chosen rocks. §Rocks without associated adult *S. franciscanus*. ¶Not sampled.

association for recruitment, are not bimodal (in size) in our study area.

In this general pattern of recruitment, we cannot distinguish between success of settlement of newly metamorphosed urchins and the survival of somewhat larger animals. For example, our failure to detect substantial recruitment in coralline algae or cobble, as has previously been reported by others (*8*), may reflect good settlement in these microhabitats followed by high susceptibility to predation. Although these distinctions may be important, the main criterion for reproductive success is recruitment of adult size classes. The effects of commercial fishing on recruitment of *S. franciscanus* will probably be determined by the number of adults left behind or the number that migrate into an area after fishing takes place. It is not yet known whether harvesting of *S. franciscanus* will shift the ratios of *S. purpuratus* to *S. franciscanus* as might be expected from the different recruitment patterns of these coexisting species.

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Antischizophrenic Drugs: Chronic Treatment Elevates Dopamine Receptor Binding in Brain

Abstract. *Chronic treatment of rats with the neuroleptic drugs haloperidol, fluphenazine, and reserpine elicits a 20 to 25 percent increase in striatal dopamine receptor binding assayed with $[^3H]$haloperidol. This increase in receptor sites may account for behavioral supersensitivity to dopamine receptor stimulants in such animals and for tardive dyskinesia in patients treated with these drugs.*

Chronic treatment with antischizophrenic neuroleptic drugs produces motor abnormalities that appear related to the dopamine neuronal systems in the brain in both man and animals. Tardive dyskinesia, characterized by abnormal movements of facial muscles and extremities, is a major complication of long-term treatment with neuroleptic drugs (*1*). Lowering the dose or terminating the drugs frequently worsens these symptoms, while increasing the dose may alleviate symptoms. Since a major action of neuroleptics is blockade of dopamine receptors in the brain, speculations have linked tardive dyskinesia with a supersensitivity of dopamine receptors after prolonged blockade by chronic drug administration. This would explain why a reduction of dose worsens symptoms while a dose increase temporarily reverses motor abnormalities. Studies in animal models of tardive dyskinesia support the notion that the increased motor activity reflects supersensitivity of dopamine receptors. Rats or mice treated chronically with neuroleptic drugs display an enhanced sensitivity to the motor stimulant effects of apomorphine, a direct dopamine receptor agonist, after the neuroleptic treatment is terminated (*2–4*). A similar motor supersensitivity to dopamine receptor stimulants is apparent when dopamine synaptic activity is reduced by inhibiting synthesis of dopamine with α-methyltyrosine (*2, 4*), depleting dopamine storage with reserpine (*2, 5*), or making lesions in the nigrostriatal dopamine pathway (*5, 6*).

Table 1. Effect of chronic drug treatments on $[^3H]$haloperidol binding in the rat. Rats were injected subcutaneously with haloperidol (Haldol, 0.5 mg/kg), reserpine (Serpasil, 0.25 mg/kg), fluphenazine (Prolixin, 0.5 mg/kg), promethazine (Phenergan, 2.5 mg/kg), or *d*-amphetamine sulfate (5 mg/kg) daily for 3 weeks and killed 5 to 7 days later. Freshly removed corpora striata were assayed for binding with three concentrations of $[^3H]$haloperidol (0.2 to 1.4 n*M*). Results for the three concentrations were averaged for each rat. Data for each treated rat were expressed as the percentage difference in specifically bound radioactivity relative to that in a matched uninjected control rat assayed in parallel. Means and standard errors of the mean are given; probability values were computed by the one-tailed *t*-test; N.S., not significant. Control values for $[^3H]$haloperidol binding are as given for Table 2.

Injected drug	Number of treated animals	Difference relative to control (%)	*P*
Haloperidol	21	19 ± 4	< .0005
Reserpine	10	23 ± 7	< .005
Fluphenazine	6	27 ± 12	< .05
Promethazine	12	3 ± 7	N.S.
Amphetamine	5	−2 ± 4	N.S.

Dopamine receptors in the brain can be labeled by direct binding of $[^3H]$haloperidol (*7*). Binding sites occur only in brain regions rich in dopamine synapses, and the relative potencies of numerous neuroleptic drugs for the binding sites parallel their behavioral activities in animals and man (*8*). We now report enhanced dopamine receptor binding of $[^3H]$haloperidol in the corpus striatum of rats treated chronically with neuroleptic drugs.

Binding assays were performed as described (*8*). Homogenates (Brinkmann Polytron) of fresh rat corpus striatum (40 mg per side) in cold tris (hydroxymethyl) aminomethane (tris) buffer were washed twice by centrifugation. The final resuspension (in cold 50 m*M* tris buffer containing 0.1 percent ascorbic acid, 10 μM pargyline, 120 m*M* NaCl, 5 m*M* KCl, 2 m*M* $CaCl_2$, and 1 m*M* $MgCl_2$; final *p*H of 7.1 at 37°C) was warmed to 37°C for 5 minutes and returned to 4°C. Each tube received 1 ml of tissue suspension (8 mg of wet tissue) and contained 0.2 to 6 n*M* $[^3H]$haloperidol (9.6 c/mmole, Janssen Pharmaceutica). Tubes were incubated at 37°C for 10 minutes, and triplicate 0.3-ml portions were rapidly filtered under vacuum through Whatman GF/B filters with two 5-ml rinses of cold buffer. The filters were counted by liquid scintillation spectrometry. Specific binding of $[^3H]$haloperidol, measured as the excess over blank tubes containing 100 μM dopamine in addition to the above incubation mixture, represented about half of the total binding.

Treatment of rats for 3 weeks (Table 1) with the potent butyrophenone neuroleptic haloperidol produces about a 20 percent increase in specific $[^3H]$haloperidol binding ($P < .0005$). Fluphenazine, one of the most potent phenothiazine neuro-