Relative Abundance and Size Composition of Subtidal Abalone, *Haliotis* spp., Sea Urchin, *Strongylocentrotus* spp., and Abundance of Sea Stars off Fitzgerald Marine Reserve, September 1993

by **Konstantin A. Karpov, John J. Geibel,** *and* **Philip M. Law**

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Relative Abundance and Size Composition of Subtidal Abalone, *Haliotis* spp., Sea Urchin, *Strongylocentrotus* spp., and Abundance of Sea Stars off Fitzgerald Marine Reserve, September 1993

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Abstract

Data were collected at twenty-six dive stations at seven discrete latitudes along Fitzgerald Marine Reserve (FMR). Dive stations were targeted at three stratified depth zones: shallow (6.1 m), medium (10.7 m), and deep (16.8 m) in six of the seven locations. Two types of line transects, emergent and invasive, were completed by separate dive teams at each dive station. The area surveyed totalled 1,510 m^2 for emergent and 560 m^2 for invasive transects.

Reef habitat dominated all depth zones, with moveable boulder and cobble increasing at medium and shallow depths. Encrusting coraline and surface algae dominated (49%), followed by turf (37%), sub-canopy (11.2%), and rare canopy (0.2%). Canopy was found only at shallow depths. Turf and sub-canopy decreased with depth.

Only two species of abalone, red, *Haliotis rufescens*, and flat, *H. walallensis*, were found. Flat abalone were extremely rare with only two found on invasive transects (0.004 abalone m^{-2}). Red abalone densities were low at both emergent (0.02 abalone m^{-2}, s.e.=0.01) and invasive (0.07 abalone m^{-2}, s.e.=0.03) transects. Red abalone concentrations differed significantly by depth and location. No abalone were found at deep depths and only one sport-legal (178 mm shell length) abalone was found at medium depth. One commercial-legal (198 mm shell length) abalone was found on the entire survey. Most sport-legal abalone were located in cryptic habitat in shallow invasive transects (38%), compared to 7% on emergent transects. The only evidence of recruitment was found on invasive transects where three young-of-the-year (<=31 mm shell length) red abalone were found. Evidence from our survey and other sources suggests that sport and commercial fisheries are not sustainable off the San Mateo coast.

Red urchin, *Strongylocentrotus franciscanus*, were more abundant than purple urchin, *S. purpuratus*, or red abalone. Red urchin densities were lower in emergent (1.08 urchin m^{-2}, s.e.=0.04) than invasive (1.52, s.e.=0.06 m^{-2}) transects. Densities of red urchin at deep stations in areas of lower algal abundance and potentially greater commercial fishing pressure were about one-half the densities at medium and shallow depths. ANOVA showed

significant differences by depth and location. Mean Test Diameter (MTD) increased from deep to medium to shallow depths, while juvenile (<=50 mm) MTD showed an inverse relationship with depth. Shallow-depth invasive transects revealed a missing mode of 83 mm red urchin. This size mode was not found in emergent transects, probably due to cryptic habitat.

Purple urchin were found at low densities at all three depth strata. Purple urchin densities were comparable in emergent (0.11 urchin m^{-2}, s.e.=0.02) and invasive (0.09 urchin m^{-2}, s.e.=0.03) transects. ANOVA showed densities varied significantly by location but not depth. 'Juvenile' purple urchin abundance showed an inverse relation to juvenile red urchin, increasing from deep to shallow depths. Purple urchin MTD of 84 mm (s.d.=23) was larger than reported for intertidal areas off FMR.

Sea stars were found in high abundance off FMR. Bat stars, *Asterina minata*, had the highest densities (0.79 sea stars m^{-2}, s.e.=0.03) followed by *Pisaster* sp. (0.47 sea stars m^{-2}, s.e.=0.03), and sunflower stars, *Pycnopodia helianthoides*, (0.11 sea stars m^{-2}, s.e.=0.04). *Pisaster sp.* was the only group of sea stars where differences in density were significant by depth or location.

Introduction

The San Mateo County coast has long been subject to sport and commercial abalone harvest, and more recently (since 1985) commercial urchin harvest (Miller et al. 1974; Karpov et al. 1993; Peter Kalvass, California Department of Fish and Game [CDFG] pers. comm.). The area between Pigeon Point (San Mateo County) and Point Lobos (San Francisco County) is the only mainland area in northern California where commercial abalone harvest is currently allowed. Commercial abalone divers typically use hooka (hose with surface-supplied compressed air). The commercial abalone fishery there has engendered controversy among local sport fishing groups who are restricted to free (breath-hold) diving, and who are concerned about declining fishing success. In 1991 Assembly Bill 3705 opened the area inside the 20-foot depth contour (6.1 m) to commercial harvest, exacerbating the controversy among sport fishing groups (Karpov et al. 1993).

Fishery-dependent assessments of the San Mateo County abalone fishery, including sport-creel surveys and commercial-landing receipt reviews, have been conducted since the 1960s (Miller et al. 1974; Karpov et al. 1993). However fishery-independent assessments, such as diver-based surveys in subtidal areas, are absent except at the Fitzgerald Marine Reserve (FMR) area (Ebert and Ebert 1986; Smith 1993). Diver-based surveys for abalone and urchin have been conducted in other areas of northern California since 1986 (Parker et al. 1988; Kalvass et al. 1991; Kalvass and Taniguchi 1993; K. Karpov unpublished). Such assessments are important in providing 1) estimates of current stock levels at index locations, and 2) resource inventory baselines for estimation of future impacts.

In 1993 we assessed subtidal abalone stocks off San Mateo County using Department of Fish and Game (CDFG) divers during the annual three-day diving recertification. We restricted the survey area to the FMR, an area of about two miles of coastline (Figure 1), for the following reasons: 1) given the patchiness of habitat, a larger area could not be adequately sampled with the available number of divers, while a smaller "index" area could; 2) FMR has good abalone habitat relative to other San Mateo coast locations, and is still fished by sport and commercial fisheries (Smith 1993); and 3) FMR has been studied in the past by both dive and creel surveys (Ebert and Ebert 1986; Smith 1993). We expanded the utility of the study by also assessing densities of sea urchin competitors and sea star predators of abalone.

Methods

Date and Site Selection

FMR is on an exposed coast that can only be surveyed at shallow depths (< 6 m) by divers during calm sea conditions. FMR extends along 2 nautical miles of coast to 304.8 meters offshore in San Mateo County (Figure 1). Most of the area in the reserve boundaries is shallow, with depths of less than six meters. Commercial take of abalone off FMR is restricted to waters deeper than 6.1 meters while sport take is allowed at all depths that can be reached using breath-holding techniques. Use of SCUBA or surface-supplied air is not allowed to be used by sport divers in central or northern California.

The survey was scheduled for 14-16 September, 1993. September is a period of relatively calm sea conditions along the San Mateo coast, and was also the time period of the CDFG annual diver recertification, which afforded access to a large pool of trainable research divers. In a presurvey reconnaissance, seven dive area latitudes were selected using a Global Position System (GPS) unit. Selection was based on several criteria: 1) rocky bottom in a depth range of 3.0 to 16.8 m; 2) areas with visually recognizable landmarks for participating boats without GPS; 3) areas spaced approximately 0.2 nautical miles apart that together would span most of the area off FMR; and 4) areas (Nye Rock, Monument, and Frenchman's Reef) that had been surveyed previously by others (Smith 1993). GPS coordinates were recorded at 10.7 m at each target latitude (Table 1; Figure 1).

Target Depths

Dives at each of four target depths were planned off each of the seven target latitudes A through G (Figure 1). Target depths were selected to allow data analysis by stratified depth zone for comparison to other northern California studies (Parker et al. 1988; K. Karpov unpublished). Target depths were 3.0 m (shallow-3 m), 6.1 m (shallow-6.1 m), 10.7 m (medium), and 16.8 m (deep). Depths recorded by divers were subsequently corrected to Mean Tide Level (MTL) using time of day and tide tables.

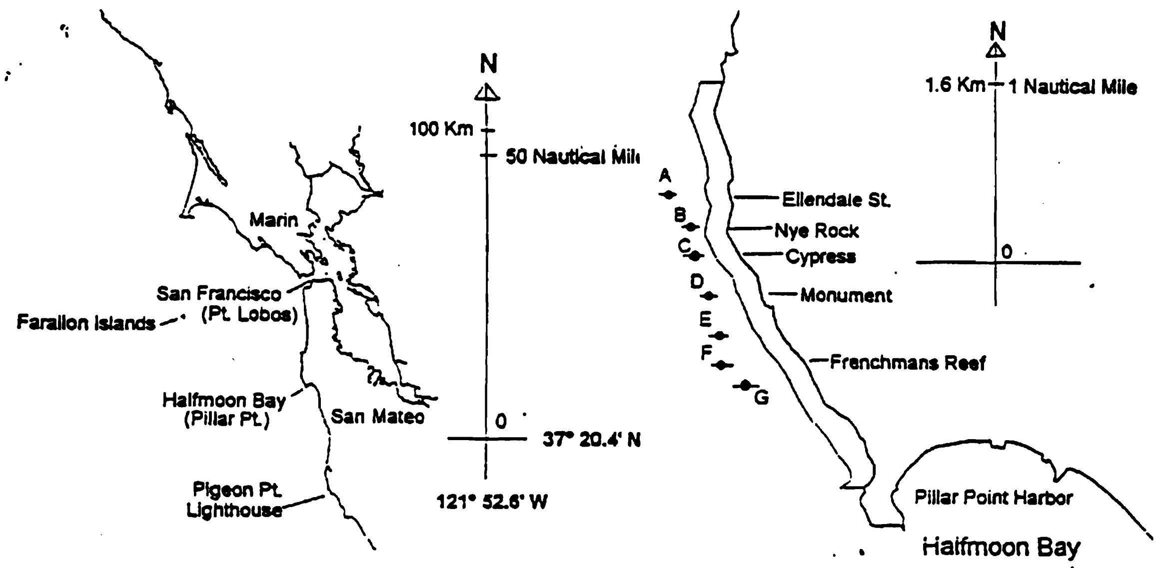

FIGURE 1. Location of Fitzgerald Marine Reserve and 10.7 m dive stations off Fitzgerald Marine Reserve, San Mateo County, California.

Abalone density data were also analyzed for two depth zones, <=6.1 m and >6.1 m, to allow comparison of shallow areas (which in FMR are excluded from commercial harvest) to the deeper commercially targeted areas (Table 2).

Diver Training and Participation

Thirty CDFG divers were trained by the senior author to participate in the survey. Divers were assigned to six groups, one per vessel. On each vessel, divers were assigned to 'invasive', 'emergent abalone', or 'emergent urchin' transect teams (described below). Segregating tasks among divers on the same team optimized efficiency underwater and simplified training requirements. Manuals were prepared (K. Karpov unpublished) and training groups formed for each type of diver. Plastic calipers designed by the author were used by each diver for measuring animals *in situ* and recording data. The calipers were also inscribed with the specific diver tasks to be accomplished. Data sheets customized by diver task were provided to the divers for transcribing data from the calipers after each dive.

Transect Layout

Each vessel was equipped with sonar, which helped in finding rocky bottoms at assigned target latitudes and depths prior to dropping anchor. The anchor was used as a starting point for deploying all transect lines to promote diver safety by minimizing surface swimming and separation from the boat. This protocol was considered necessary due to known white shark, *Carcharodon carcharias*, activity in the area. Transects were deployed along the target depth contour when possible but avoided large patches of sand. The protocol called for relocation of the anchor if the bottom area encountered was more than 50% sand. Emergent transects were patterned after methods developed in northern California (Kalvass and Taniguchi 1992; K. Karpov unpublished). Transects were run one meter on either side of the line. Emergent transects were run along a 30 m line, while invasive transects were run along a 5 m line. All divers used a meter stick to delimit a one-meter wide area off the transect line (Figure 2).

Emergent Transects

The main purpose of the emergent transects was to obtain densities and measurements of exposed (non-cryptic) abalone and urchin. Divers conducting emergent transects were designated as 'urchin' or 'abalone' specialists. The 'urchin' diver worked one side of the 30 m line (30 m^2) and had three groups of tasks to complete: 1) measure the first 25 red urchin,

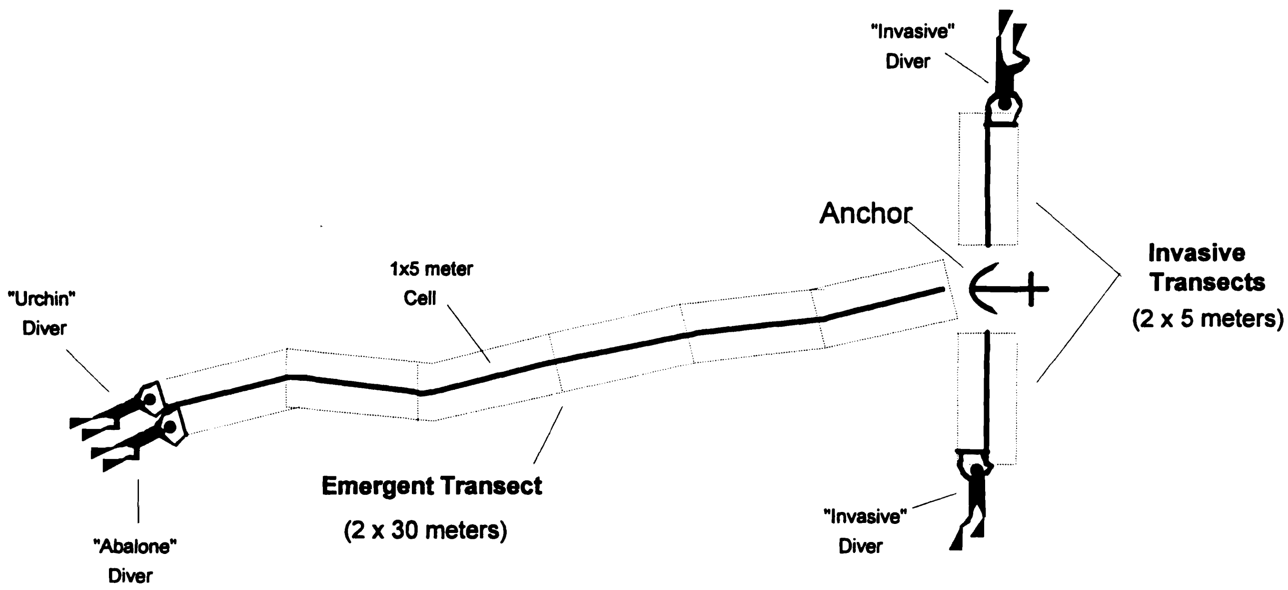

FIGURE 2. Orientation of emergent and invasive transects relative to boat anchor.

Strongylocentrotus franciscanus, and 10 purple urchin, *S. purpuratus*, encountered, segregating measurements for 'canopy' and 'sub-canopy' red urchin; 2) count red and purple urchin and red abalone, *Haliotis rufescens*, for six 1x5 m (5 m^2) cells; and 3) record depth at each 5 m interval along the transect line. Sub-canopy urchin were individuals <=50 mm that were under or whose spines under-lapped red urchin > 50 mm ('canopy' urchin) (Kalvass and Taniguchi 1993).

The 'abalone' diver covered the other side of the 30-m line (30 m^2) and also had three groups of tasks to complete: 1) measure the first 25 red abalone and 10 each of any flat abalone, *H. walallensis*, pinto abalone, *H. kamtschatkana,* or black abalone, *H. cracherodii*, encountered; 2) count each of those species for six 1x5 m (5 m^2) cells; and 3) record percent substrate type at each of six points at 5-m intervals on the transect line. The four substrate types were reef, moveable boulder, cobble, and sand. Reef was defined as hard substrate that could not be moved, moveable boulder was rocks larger than 0.5 m that could be moved by a diver; cobble was moveable rock less than 0.5 m; and sand was any substrate into which a hand could be pushed.

Thus emergent survey areas were 60 m^2 for red abalone and 30 m^2 for all other species of abalone and urchin. Emergent transects of similar design have long been utilized by other researchers and are useful for historical comparisons (Parker et al. 1988; Tegner et al. 1989; Davis et al. 1993; Kalvass and Taniguchi 1993; Karpov unpublished).

Invasive Transects

Animals were censused more thoroughly on invasive transects than on emergent transects. Invasive transects are useful in providing evidence of recruitment for red abalone which are cryptic at sizes below 10 to 12 cm (4 to 5 in) (Tegner et al. 1989; Karpov unpublished) especially in areas were moveable habitat is available. Flashlights were used and substrate and animals were moved to look for both cryptic pre-emergent and exposed animals. Divers conducting invasive transects were the most highly trained of the three diver types, and were expected to count and measure exposed and cryptic species of abalone and urchin as well as record counts of sea stars, substrate and algal cover. Each diver surveyed one or more 2x5 m (10 m^2) invasive transects on each dive along a 5-m line (Figure 2).

Divers were expected to complete six groups of tasks: 1) measure up to 25 each of red abalone and red urchin, and 10 each of the other species of abalone and purple urchin; 2) count all abalone and urchin by species; 3) record average depth; 4) estimate percent algal cover (canopy, sub-canopy, turf, and encrusting) over the entire transect; 5) estimate percent substrate (reef, boulder, cobble, or sand) at each meter mark; and 6) count numbers of Ocer stars, *Pisaster* sp., sunflower stars, *Pycnopodia helianthoides*, bat stars, *Asterina miniata*, and unidentified sea stars. Algae were typed by size and defined as: canopy (> 1.0 m); sub-canopy (0.3 to 1.0 m); turf (< 0.3 m); and encrusting (surface).

Juvenile Urchin and Abalone

Juvenile red urchin were defined as having test diameters of <=50 mm (Sloan et al. 1987; Kalvass and Taniguchi 1992). Purple urchin were described as juvenile at test diameters of <=30 mm (Ebert 1968). A one-year-old red urchin was defined by a test diameter <= 30 mm (Ebert et al. 1992; Kalvass and Taniguchi 1992). Young-of-the-year red abalone were defined by total lengths <=30 mm by Tegner et al. (1989) in southern California.

Statistical Analysis

Abalone and urchin were measured and recorded in 5-mm intervals. Size frequency histograms were standardized to density (count m^{-2}) to allow graphical comparison between urchin and abalone sizes and densities. Coefficients of Variation (CV=s.d./ mean x 100) were calculated for all size distributions. A large CV has been used to indicate frequent recruitment, based on the wide distributions of sizes relative to the mean (Ebert and Russell 1988).

Densities were compared by area (location) and depth using two-way ANOVA using procedure GLM from the statistical package SAS (SAS 1987). The model used was Density= Area | Depth; where Area and Depth were class variables. Prior to applying ANOVA the densities were transformed using the method of Pearce and Hines (1987) (Transformed Density = Log (Density+1)). Significance was assumed at P>0.05.

Results

Totals of 25.2 emergent abalone transects, 24.3 emergent urchin transects, and 56 invasive transects were completed in 26 dives at the seven target latitudes (Table 2). Because shallow depths extend well offshore, all 16.8 m and 10.7 m dive stations were outside the reserve boundaries (Figure 1). Swell and wave height were low and varied from 1.0 to 1.8 m during the survey period; the calmest conditions were on 15 September when most shallow water stations were completed. In spite of the relatively calm conditions, the safety protocol of initiating all transect lines immediately off the anchor line and the potential danger of shallow reefs to vessels prevented us from obtaining a sufficient number of shallow-3 m transects. Only one emergent and five invasive shallow-3 m transects were completed. We therefore pooled the shallow-3 m and shallow-6.1 m transects into a single 'shallow' group.

At shallow stations, the pooled emergent transects averaged 6.1 m deep and the pooled invasive transects averaged 6.2 m deep. At medium stations, seven emergent and 16 invasive transects were completed; average depths were 10.8 m and 10.5 m, respectively. At deep stations, four emergent and nine invasive transects were completed; average depths were 16.5 m and 17.0 m, respectively. At least one shallow, medium, and deep station was completed at target latitudes A, B, C, D, F, and G (Figure 1). Latitude E was sampled only at a medium depth station where one emergent and two invasive transects were completed.

Six emergent and 15 invasive transects were at depths of <=6.1 m or shallow depths where predominantly sport take occurs off FMR. Depths of those transects averaged 5.4 m (emergent) and 5.2 m (invasive). Depths of transects deeper than 6.1 m averaged 10.4 m for the 20 emergent and 10.6 m for the 41 invasive transects (Table 2).

Substrate

Preselection of sites, using sonar to identify rocky bottom and avoid excessively sandy areas, resulted in only 2.2% and 1.0% sand on emergent and invasive transects, respectively (Table 3). Both emergent and invasive transects were similarly dominated by reef (90.4% and 92.3%), followed by cobble (5.3% and 4.1%), and moveable boulder (2.1% and 2.6%). As depth increased, invasive transects showed a clear progression of decreasing boulder and cobble and increase in reef. The trend among emergent transects was less clear but the percentage of reef still increased by depth (89.6, 89.8, and 93.3%). Cobble was most prevalent at medium stations (7.1%), followed by shallow (5.0%), and deep (3.3%). Moveable boulders predominated at deep stations (2.7%), followed by shallow (2.1%) and medium (1.7%).

Algal Cover

Algal cover was recorded only on invasive transects. Encrusting coralline and surface algae dominated the surveyed areas (48.9%), followed by turf (36.8%), sub-canopy (11.2%), and canopy (0.2%) (Table 4). Percentages of canopy, sub-canopy, and turf abundance decreased with depth. Canopy of bull kelp, *Nereocystis* sp., was absent from FMR. Algae forming canopy underwater was found only at shallow stations (0.4%). Sub-canopy was found only at shallow (13.1%) and medium (13.9%) stations. Turf decreased in abundance from shallow to deep stations. Divers reported that turf was predominantly red algae. Encrusting algae were greatest at medium depths (55.9%), followed by deep (48.9%), and shallow (42.4%). Algal cover varied considerably by location, with Canopy found only at Nye Rock (B) and North Frenchman's Reef (F). Sub-canopy was identified only at Nye Rock (B), and North and South Frenchman's Reef (F and G).

Abalone

Of the four target species of abalone, only two (red abalone and flat abalone) were found (Table 5). The emergent transects yielded 37 red abalone and 0 flat abalone from 302 five-meter cells (1510 m^2) on 25.2 transects at 26 separate dive locations. The invasive transects yielded 38 red abalone and 2 flat abalone from 112 five-meter cells (560 m^2) on 56 transects at 26 dive locations. Red abalone were found at all target latitudes except the Monument (D). The two flat abalone were encountered at the medium depth station at Cypress Point (C). Red abalone density averaged 0.02 m^{-2} and 0.07 m^{-2} on emergent and invasive stations, respectively.

Abalone density decreased as depth increased at emergent and invasive stations (Table 5). The differences were significant by depth but not by area or interaction at both emergent and invasive transects (Table 6).

Emergent and invasive abalone densities averaged 0.07 m^{-2} and 0.11 m^{-2} at shallow depths (<=6.1 m), and 0.01 m^{-2} and 0.05 m^{-2} at deeper depths (Table 5). Differences were significant by depth, area, and interaction at emergent transects, and significant by area only at invasive transects (Table 6).

On emergent transects, 28 red abalone were measured for total length (Table 7). Of those, 27 were measured at shallow stations; they ranged from 55 to 200 mm and averaged 139 mm (Figure 3). Only one was smaller than 113 mm, only two were sport legal (> 178 mm), and only one was commercially legal (>198.5 mm).

On or near the 56 invasive transects, 44 red abalone were measured. Of those, 37 were from shallow stations and seven were from medium stations. The number measured exceeded the number counted because seven abalone were inadvertently measured but not counted outside transect boundaries. At shallow stations they averaged 139 mm and ranged from 33 to 193 mm (Figure 4). Of those, 14 (38%) were sport legal and none were commercially legal (Table 7). At medium stations they ranged from 23 to 178 mm, and only one was sport legal. Of the 44 measured abalone, 10 were smaller than 113 mm, and three (7%) were young of the year (<=31 mm). The CV for invasive transects (48) was almost double the value for emergent transects (25).

Competitors

On both emergent and invasive transects, large numbers of red urchin were found relative to purple urchin, red abalone, and flat abalone (Figures 3 and 4). On the emergent transects, 792 red urchin and 83 purple urchin were found in 146 five-meter cells (730 m^{-2}) on 24.3 transects at 25 dive locations. On the invasive transects, 849 red urchin and 50 purple urchin were found on 112 five-meter cells (560 m^2) on 56 transects at 26 dive locations (Table 8).

Red Urchin

Red urchin density averaged 1.08 m^{-2} and 1.52 m^{-2} at emergent and invasive stations, respectively (Table 8). Average density was lowest at the deep stations (0.78 m^{-2} emergent and 0.72 m^{-2} invasive). At medium stations, average densities of emergent transects (1.55 m^{-2}) and invasive transects (1.61 m^{-2}) were also similar. At shallow stations, densities were lower in emergent transects (0.93 m^{-2}) than in invasive transects (1.7 m^{-2}). In both emergent and invasive transects, the differences in density were significant by depth, area, and interaction (Table 6).

Totals of 538 and 758 red urchin were measured for test diameter in emergent and invasive transects, respectively (Table 9). In both emergent and invasive transects, Mean Test Diameter (MTD) of red urchin decreased as depth increased. The greatest drop (15 mm) was in the emergent transects between the shallow and medium depths. The decline between shallow and medium in invasive transects was 8 mm. The percentage of commercially-legal urchin (> 89 mm) also declined with depth, from 86% to 22% in the emergent transects and from 52% to 13% in the invasive transects.

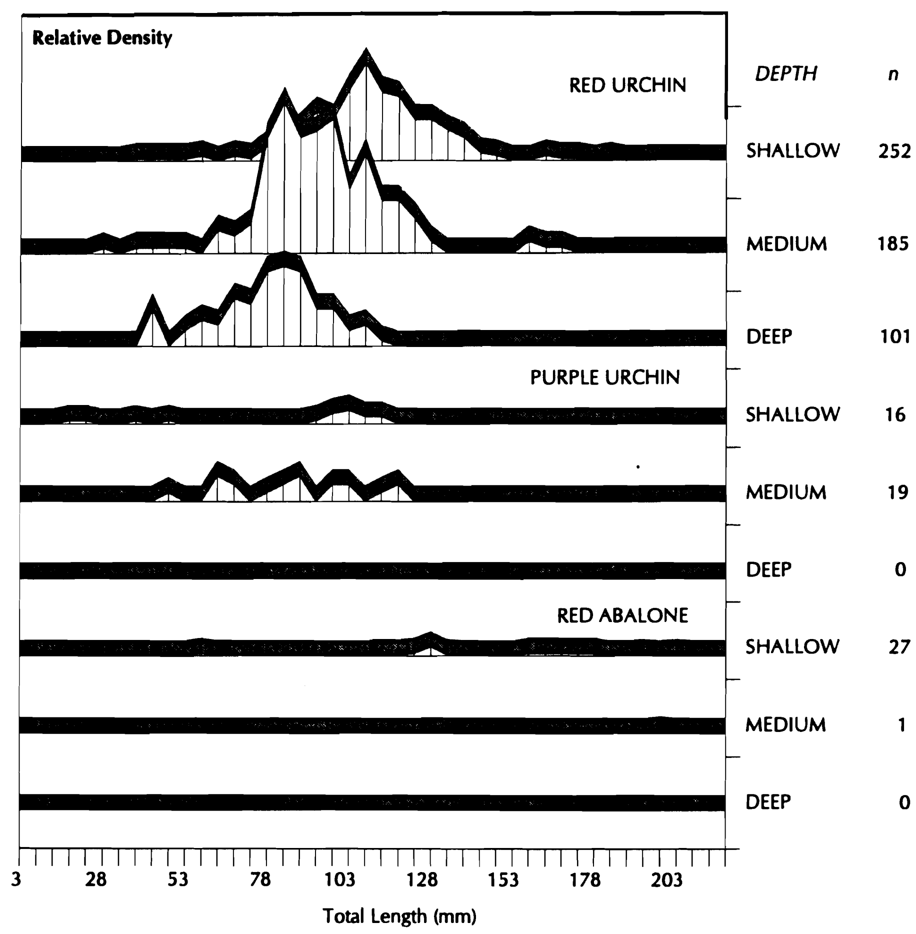

FIGURE 3. Red urchin, purple urchin, and red abalone relative density by size frequency for emergent transects off Fitzgerald Marine Reserve.

A size frequency peak of 83 mm was present for red urchin in shallow invasive transects but absent from the shallow emergent transects (Figures 3 and 4). Thus the shallow invasive size-frequency distribution is bimodal, with modes at 83 mm and 97 mm, and the shallow emergent distribution is monomodal, with a single peak at 103 mm.

Unlike red abalone, red urchin showed little difference in CV between emergent (CV=23) and invasive (CV=27) transects (Table 9). Juveniles (<=50mm) comprised 4% of red urchin measured on emergent transects and 8% on invasive transects.

Canopy - Subcanopy

Red urchin that were sub-canopy to adults were largely absent from emergent and rare in invasive transects (Table 10). Only one sub-canopy individual, 25 mm in length, was found among 538 red urchin measured on emergent transects. On invasive transects, 18 sub-canopy individuals were found; those individuals comprised 30% of the juveniles and 2.4% of all red urchin found on invasive transects. One-half (9 individuals) of the sub-canopy urchin were found at shallow stations and one-half at

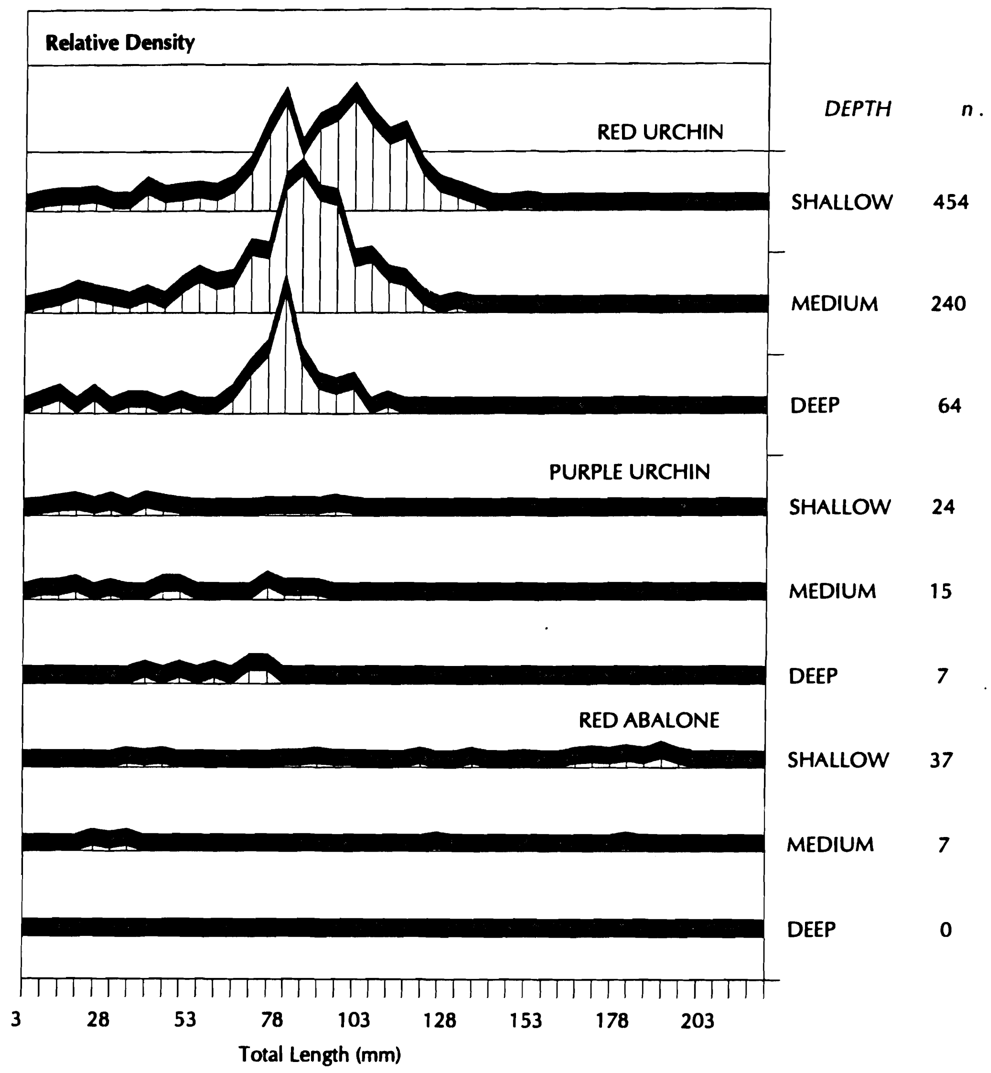

FIGURE 4. Red urchin, purple urchin, and red abalone relative density by size frequency for invasive transects off Fitzgerald Marine Reserve.

medium stations. The shallow individuals ranged from 8 to 48 mm long with a MTD of 24 mm. The medium individuals ranged from 13 to 48 mm long with a MTD of 29 mm.

Purple Urchin

In both emergent and invasive transects, purple urchin were found in low densities. Densities were comparable to red abalone densities at shallow stations, but in contrast to red abalone densities, remained low at medium and deep stations (Figures 3 and 4; Table 11). Purple urchin densities were similar at emergent and invasive transects at 0.11 m^{-2} and 0.09 m^{-2} respectively (Table 8). Differences were significant by location but not by depth or interaction (Table 6).

The MTD of purple urchin was smaller in invasive transects (48 mm) than in emergent transects (83 mm) (Table 11). The size range was greater in the emergent transects (15 to 115 m) than in the invasive transects (7 to 97 mm). Juvenile purple urchin (<=30 mm) were found mostly at shallow stations (62% emergent and 42% invasive), and were absent from all deep stations. In invasive transects, the size range, and consequently the CV, decreased with depth. Like red abalone but unlike red urchin, the CV for purple urchin size was substantially higher in invasive transects (CV=54) than in emergent transects (CV=31).

Sea stars

Among sea stars, bat stars had the highest average density (0.79 m^{-2}), followed by *Pisaster* sp. (0.47m^{-2}), sunflower stars (0.11 m^{-2}), and unidentified sea stars (0.06 m^{-2}) (Table 12). Density differences were significant by interaction for sunflower stars, by depth and location for *Pisaster* sp., and by depth, location and interaction for unidentified sea stars (Table 6). *Pisaster* sp. density was similar at medium (0.65 m^{-2}) and deep (0.63 m^{-2}) stations, but was lower at shallow stations (0.32 m^{-2}). Unidentified sea stars density increased with depth, from 0.02 m^{-2} (shallow) to 0.17 m^{-2} (deep).

Discussion

Habitat - Substrate and Algal Cover

The predominance of reef (90.4 to 92.3%) and low proportion of movable boulder (2.1 to 2.6%) or cobble (5.3 to 4.1%) alone does not indicate the actual amount of cryptic habitat available at FMR. Rugosity of the reef can provide considerable cryptic habitat even without moveable substrate. The 83 mm peak in red urchin size found only at shallow invasive stations implies that some form of cryptic habitat was being utilized off FMR (see Discussion on red urchin). Unfortunately ruggoisty was not quantified as part of the survey nor was the substrate type where urchin or abalone were found quantified. Future surveys should include some assay of both factors to identify area available for recruitment of abalone.

The results also show a gradient of increasing algal abundance from deep to shallow stations. Surface canopy was lacking for both bull kelp, found mainly in northern California, and giant kelp, *Macrocystis sp.*, found mainly in central and southern California. Tegner et al. (1993) described the coastal areas near San Francisco Bay as less than optimal for abalone relative to northern or central California due to turbid waters and outflow from San Francisco Bay. Smith (1993) found a lack of bull kelp but "good abalone habitat" at FMR, which was described as a diversity of algal assemblages of understory browns, fleshy reds, and crustose and articulated corallines.

A large-scale urchin and abalone dive survey off the Mendocino-Sonoma coast in 1989 and 1990 (Kalvass et al. 1991, Kalvass and Taniguchi 1993), at depths comparable to the present FMR survey, found areas of greater abalone abundance and similar urchin abundance. Levels of sub-canopy, turf and encrusting algae in the Mendocino-Sonoma studies (averages: 17%, 37%, and 59% respectively) were comparable to those found in the present study (averages: 11%, 37%, and 49% respectively). The Mendocino-Sonoma canopy estimate (mostly bull kelp reaching to the surface) of 7% was not found at FMR.

In September 1985 an aerial surface-kelp survey off California was conducted for CDFG. The only surface kelp found off San Mateo County was 0.018 km^2 found within two kilometers of Año Nuevo; none was found at FMR or between Point Lobos and Pigeon Point (Van Wagenen 1990). The area of Sonoma and Mendocino counties surveyed for urchin and abalone by Kalvass et al. (1989) and Kalvass and Taniguchi (1991) had 12.4 km^2 of surface canopy.

Abalone

Red Abalone

Red abalone densities observed in FMR are comparable to those reported by previous studies in FMR. Smith (1993) reported a density of 0.061 m^{-2} at shallow depths (4-7 m) off Monument and Nye rock in 1992; that value is comparable to our estimate of 0.04 m^{-2} for all shallow stations. A 1986 study (Ebert and Ebert 1986) of 2,640 m^2 at six stations in both shallow subtidal (4-7 m) and intertidal depths (0-3 m) inside the boundary of FMR found emergent red abalone densities of 0.016 m^{-2}.

The abalone densities observed off FMR are extremely low relative to those reported from study areas in Sonoma and Mendocino counties that are also heavily utilized by sport fisheries. Abalone density in emergent transects at all depths off FMR (0.02 m^{-2}) is 1/10 the lowest density reported by Parker et al. (1988) at three heavily utilized sport-fished sites in Sonoma and Mendocino counties. Emergent densities in the Parker et al. (1988) study ranged from 0.21 to 0.43 m^{-2}.

Management Implications

Catch declines

The low densities of red abalone off FMR are likely the combined result of less than optimal habitat, overharvest by sport and commercial fisheries, competition with urchins, and predation by sea stars. Smith (1993) reported a linear decline of about 50% in abalone effort in FMR from 1972 to 1992. Miller et al. (1974) described a decline in catch-per-unit-effort (CPUE, in units of abalone taken per hour) in San Mateo and Santa Cruz counties from 2.08 to 1.40 h^{-1} from 1960 to 1972. Karpov et al. (1993) reported comparably low CPUEs from Pedro Point to Pigeon Point in San Mateo County (1.2 to 1.0 h^{-1}) from 1989 through 1992. Karpov et al. (1993) also reported continued high CPUE levels ranging from 2.2 to 3.1 h^{-1} in Sonoma, Mendocino, and Humboldt counties.

Refuge by Depth

Another observable contrast between the area along FMR and the Sonoma and Mendocino County locations is the difference in relative abundance of red abalone with depth. We found only 3% of our red abalone from emergent transects at medium and deep stations; Parker et al. (1988) found 25% of red abalone observed at comparable depths in Van Damme, Salt Point, and Fort Ross State Parks. Those depths (>8.05 m) are generally inaccessible to free divers (Karpov pers. obs.). Differences at this depth along FMR are likely an effect of commercial take, and not sport harvest.

Additional evidence of human impacts on red abalone populations off FMR is suggested by the low numbers of red abalone that are large enough for sport or commercial harvest in emergent transects at all depths (11% sport; 4% commercial). At three northern California sites, Parker et al. (1986) found 50% to 91% of the red abalone on emergent transects were large enough for sport harvest and 13% to 24% were large enough for commercial harvest. At Van Damme State Park the range for sport-legal adults is 29% to 33% (K. Karpov unpublished).

Low red abalone densities, such as those found in our FMR study area, have been insufficient to sustain fisheries on Santa Rosa Island in southern California, an area also exposed to high fishing pressures at all depth ranges by sport and commercial fisheries (SCUBA is used by sportfishers in southern California). Tegner et al. (1989) studied that area extensively from 1978 to 1982 and found emergent densities at all depths of 0.06 m^{-2}. In the same area Davis et al. (1993) reported a trend of decline in emergent abalone from 0.100 to 0.006 m^{-2} from 1983 to 1990. In 1993, the same locations produced only six abalone for a density of 0.006 m^{-2} (Peter Haaker CDFG, pers. comm.). CPUE levels have also declined for party boats on Santa Rosa Island from 1978 to 1987 (Karpov et al. 1993).

Another area of concern is potentially low recent recruitment, based on observed young-of-the-year. We found three (7%) young-of-the-year red abalone (<= 31 mm) at a density of 0.004 m^{-2}. However, any interpretation of red abalone size data in our study must be tempered by the small number of abalone available to measure. In addition, interannual variation in recruitment is not well understood. In a seven-year study off Santa Rosa Island in southern California, Tegner et al. (1989) used invasive transects to find young-of-the-year density ranged from 0.005 to 0.036 m^{-2} (5 to 23% of the populations). Karpov (unpublished) used invasive transects to find a young-of-the-year density of 0.07 m^{-2} at Van Damme State Park in 1990 and also found fluctuations in yearly recruitment from 1989 to 1993.

Increasing numbers of abalone researchers and managers have come to realize that size limits alone have not protected abalone stocks from overfishing (Davis et al. 1993; Karpov et al. 1993; Karpov and Tegner 1993; Tegner et al. 1993). Tegner et al. (1989) could not explain, based on egg-per-recruit models, why the red abalone stock collapsed in southern California. Sluczanowski (1984) was the first to suggest that yearly spawning variability may undermine management models of abalone based on egg production and that additional measures such as rotating area closures could provide "insurance" against excessive fishing pressure. Parker et al. (1986) and Karpov and Tegner (1993) have suggested that the northern California closure to sport SCUBA and commercial take provides a defacto refuge in deep water.

Such an approach, where sport SCUBA is already prohibited, could be initiated off the San Mateo coast by commercial closure. However, unlike northern

California, little parent stock remains at medium and deep depths, in waters inaccessible to free divers. With low densities of shallow water populations as the only parent stock available for recruitment, recovery is unlikely without added protection from current sport harvest.

A keystone predator of abalone and sea urchin, currently not re-established at FMR, is the sea otter, *Enhydra lutris,* (Hines and Pearse 1982; Bob Breen San Mateo Parks, pers. comm.). The current range of the animal includes a population of 14 animals off Año Nuevo approximately 32 km to the south of FMR (Figure 1) (J. Ames CDFG, pers. comm.). If the range of this animal is re-established to the north, shellfish management for human harvest will effectively be precluded (Tegner et al. 1993).

Other Abalone

Flat abalone are reported to range in depth from subtidal to 21 m and are generally not abundant (Cox 1962). Our density estimate of 0.004 m^{-2} indicates they are indeed rare at FMR. This species is not taken by commercial fishermen and has never been recorded in sport fishery creel surveys in northern California or off FMR (K. Karpov CDFG, unpublished).

Black abalone are recorded as taken intertidally off Pigeon Point, San Mateo County, in the 1992 CDFG abalone creel survey (CDFG unpublished). They were not found in our subtidal survey nor in intertidal stations in 1986 and 1992 surveys (Smith 1993; Ebert and Ebert 1986). Black abalone depth distribution is reported as intertidal (Morris et al. 1980) and their absence from our subtidal survey stations does not preclude their occurrence intertidally in FMR.

Although targeted in our survey, pinto abalone were not found, indicating the species is rare or absent off FMR. Cox (1962) reported that the species is not common in central California but is generally found in 11 to 16 m depths, occasionally in large numbers.

Competitors

Sea urchins are generally recognized as major competitors of abalone in Australia and the Pacific coast of North America (Leighton 1968; Shepherd 1973; Tegner 1989; Tegner and Levin 1982). In Australia, two species of sea urchins. *Centrostephanus rodgersii* and *Helicidaris erythrogramma*, are known to compete for food and space with black lip abalone (*H. ruber*) (Shepherd 1973). In southern California red and purple urchin have been described as competing with red abalone for food and space (Leighton 1968; Tegner and Levin 1982; Tegner 1982). All three species are drift algal nocturnal feeders, and show a preference for similar brown algae including giant kelp (Leighton 1968; Tegner and Levin 1982; Tegner 1989).

Red Urchin

The significantly lower densities of red urchin observed at deep invasive and emergent transects off FMR are likely the result of decreased food availability and increased commercial take. The low availability of understory algae (only 4% turf) at deep stations relative to medium (23%) and shallow (53%) suggests food was a limiting factor. In addition, our shallow stations were close to the reserve boundary or in the reserve, where urchin harvest is prohibited. Thus deep and medium stations were also likely to be impacted by commercial removal.

Overall densities observed at medium-depth stations (1.55 m^{-2} emergent and 1.61 m^{-2} invasive) were similar to the density of 1.62 m^{-2} reported from comparable depth emergent transects off the Sonoma-Mendocino coast in 1988 (Kalvass et al. 1990). Kalvass and Taniguchi (1993) reported that medium depth densities had declined significantly to 1.22 m^{-2} at the same locations by 1991. Invasive densities of red urchin reported by Tegner et al. (1989) from 1978 to 1982 at Johnson's Lee ranged from 1.83 (s.e.=0.67) to 2.87 (s.e.=0.54) m^{-2}, which is greater then our combined-depth invasive density of 1.55 (s.e.=0.06) m^{-2}.

Decreases in red urchin MTD by depth at FMR were consistent with those observed off Sonoma and Mendocino counties (Kalvass et al. 1990 and 1991; Kalvass and Taniguchi 1991), where MTD declined at three depth zones from 1988 to 1991 as larger animals were removed by fishing. Shallow-depth size off Sonoma and Mendocino counties declined from 108 mm to 91 mm, medium-depth size declined from 89 mm to 86 mm, and deep-depth size declined from 86 mm to 62 mm. In addition, shallow stations declined from 68% legal (>89 mm) in 1989 to 55% in 1991. At deep stations the decline was even more dramatic, from 42% legal in 1989 to 21% in 1991.

Our shallow MTD of 106 mm is similar to the Sonoma-Mendocino 1988 sizes with a higher percentage of commercially legal (86%). Our deep MTD of 76 mm is intermediate between the 1988 and 1991 Sonoma-Mendocino values, and our 22% commercially legal is the same as the 1991 Sonoma-Mendocino value. Our results suggest that larger sizes at shallow stations in FMR may partially reflect protection from harvesting pressures. At Point Cabrillo Reserve in Mendocino County, an area protected from urchin harvest at all depths, Kalvass et al. (1991) and Kalvass and Taniguchi (1993) found MTD ranged from 93 to 96 mm in 1989 and 91 to 97 mm in 1991, with no consistent trend by depth.

Two additional factors increased the MTD of red urchin at shallow stations in FMR: 1) absence of an 83-mm modal class and 2) an increase in juveniles (<= 50 mm) with depth. The absence of the 83-mm mode in shallow emergent but not invasive transects seems the likely result of increased use or availability of cryptic habitat at shallow depths. Whether that resulted from increased rugosity in habitat or behavior change is difficult to determine in our study since rugosity or placement of urchin in the habitat was not quantified by depth. The increase in moveable boulder and cobble habitat and effect of wave action from deep to shallow (1.6% to 9.8%) at FMR would produce a more hazardous environment at shallow depths, possibly encouraging greater use of crevice and ledge habitat.

Recruitment and Sub-Canopy

Increased numbers of juvenile red urchin with depth were also noted by Kalvass et al. (1991) and Kalvass and Taniguchi (1993). Kalvass et al. (1993) suggested two plausible explanations that could also be applied to our FMR results; 1) relative recruitment is actually greater at deep depths or 2) decrease in foliose algal turf with depth increased the likelihood of emergent divers finding juveniles. Our finding of increased percentage of juveniles in both emergent and the more thoroughly-searched invasive transects lends support to the first alternative. In southern California, Pearse et al. (1970) and Tegner and Dayton (1978) reported an inverse relation between the presence of macroalgae such as *Macrocystis sp.* and recruitment of red urchin. Macroalgae were not found at FMR.

Juvenile recruitment at FMR (4% emergent and 8% invasive) was comparable to the 7% emergent value found on the Mendocino-Sonoma coast in 1989 (Kalvass et al. 1991) but lower then the 28% value found in 1991 (Kalvass and Taniguchi 1993). Only 30% of FMR juveniles were sub-canopy to adults, compared to 45.6% and 50.0 % in Mendocino-Sonoma in 1989 and 1991 respectively.

Purple Urchin

Caution needs to be exercised in interpreting our purple urchin results from emergent transects. The large sizes encountered (up to 115 mm Test Diameter (TD)) may have resulted from one of the emergent divers misidentifying red urchin as purple urchin. Purple urchin larger than 100 mm TD have not been found subtidally in extensive surveys off Sonoma and Mendocino counties (Kalvass CDFG, pers. comm.). Only smaller sizes have been found intertidally by Ebert and Russell (1988) who found a maximum 91 mm TD off Sunset Bay, Oregon and 63 mm TD off FMR. It is unlikely that this problem was encountered among invasive transects where animals were removed and diver training was more rigorous.

The low densities of purple urchin found subtidally relative to red urchin are typical in northern California (Kalvass and Taniguchi 1993) and are likely the result of competitive exclusion and differential subtidal predation. Red urchin have been described in southern California as out-competing purple urchin by exclusion from more desirable habitat (Schroeter 1978). Tegner and Dayton (1987) described purple urchins, with relatively short spines, as more vulnerable to predation than red urchin by sunflower stars, California sheepshead, *Semicossphyus putcher,* and spiny lobster, *Panulirus interruptus*. Bat stars, the most abundant sea stars at FMR, were also described as preying on urchin (Tegner and Dayton 1987).

Purple urchin sizes at FMR showed the inverse of the trend seen among red urchin, with evidence of more juveniles (<=30 mm) at shallow and none at deep stations. Interestingly, both species showed a parallel increase in maximum size from deep to shallow. Among purple urchin, both size extremes were common at shallow depths that produced a corresponding increase in CV that was not apparent for red urchin. The size distribution trends for purple urchin do not carry over to intertidal areas. At two intertidal transects off FMR, Ebert and Russell (1988) found purple urchin sizes ranged from 2 to 63 mm with a CV of 26.1. Ebert (1968) found extreme plasticity in sizes of intertidal purple urchin off Sunset Bay, Oregon. The urchin were able to grow or shrink depending on weather, food or habitat type. Animals from more exposed eel grass beds achieved modal sizes of 57 ± 5 (1 s.d.) mm compared to adjacent boulder fields with a modal size of 70 ± 7 (1 s.d.) mm. It is likely that larger sizes observed in my shallow stations could be attributed to differences in habitat, available food, predation, or competition.

Sea stars

Sea stars play an important role subtidally as predators on abalone and urchin. Sunflower stars, the third most abundant sea star encountered subtidally at FMR, were described as predators of abalone (Tegner et al. 1989) and of both red and purple urchin (Tegner and Dayton (1987). Bat stars, the most abundant sea stars subtidally at FMR, have been described in southern California as predators of purple urchin but not red urchin or red abalone (Tegner and Dayton 1987; Tegner et al. 1989). *Pisaster giganteus* was described as not attacking unstressed abalone in southern California (Tegner et al. 1989).

Conclusion

The current red abalone fishery off FMR is unsustainable. Existing management has failed to protect the fishery and may ultimately lead to a localized spawning failure. Recent increase in commercial demand coupled with continued inshore pressure by sport divers and shorepickers, competition from sea urchins, and predation is likely to further degrade stock density to potentially dangerous levels.

Karpov (1994) reported a 239% increase in the ex-vessel value of abalone from 1983 to 1992 during a period when inflation, based on the Consumer Price Index, increased by only 52%. Increased demand has led to continued landings off FMR in spite of the extremely low levels of stock density that we have reported. Coupled with this increase in demand has been poaching in shallow waters inside the FMR boundry (Steve Morse, CDFG, pers. comm.). The existing 6.1 m exclusion to commercial take off FMR is difficult to enforce (Mervin Hee and Steve Mores, CDFG, pers. comm.) effectively adding pressure to shallow areas already impacted by sport take.

Loss of remaining adults at FMR and adjacent areas could lead to localized spawning failure precluding future recovery of the reduced stock of red abalone. Removal of adult-sized Australian abalone *H. rubra* created localized areas of no larval recruitment (Prince et al 1987). Abalone are broadcast spawners, expelling eggs or sperm through the respiratory holes for external fertilization (Cox 1962). A study on southern Australian abalone *H. laevigata* showed adults aggregated to increase chance for successful spawning (Sheperd 1986). It is unlikely that future stock recovery or protection of remaining spawners will occur without a concurrent moratorium on both sport and commercial take.

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TABLE 1. Location codes, descriptions, and GPS coordinates for 10.7 meter (35 foot) dive stations off Fitzgerald Marine Reserve.

Code	Location Landmarks	Target Latitude	Longitude
A	Ellendale Street	37° 31.528 N	122° 31.475 W
B	Nye Rock	37° 31.425 N	122° 31.304 W
C	Cypress Point	37° 31.200 N	122° 31.316 W
D	Monument	37° 30.981 N	122° 31.162 W
E	Wash rock (Red House)	37° 30.729 N	122° 31.046 W
F	North - Frenchman's Reef	37° 30.641 N	122° 31.053 W
G	South - Frenchman's Reef	37° 30.443 N	122° 30.815 W

TABLE 2. Target and actual depths for invasive and emergent stations at Fitzgerald Marine Reserve, September 14-16, 1993.

Survey Type	Description or Code	Target Depth(m,ft)	Target Depth(m)	Target Depth(ft)	Number Transects
Emergent	Shallow 3	3.0, 10	1.5-4.6	5-15	1
	Shallow 6.1	6.1, 20	4.6-6.1	15-20	13
	Shallow	-	-	-	14
	Medium	10.7, 35	9.1-12.2	30-40	7
	Deep	16.8, 55	15.2-18.3	50-60	4
	Deep*	16.8, 55	15.2-18.3	50-60	4.5
	<6.2	-			6
	>6.1	-			20
	All Depths				26
Invasive	Shallow 3	3.0, 10	1.5-4.6	5-15	5
	Shallow 6.1	6.1, 20	4.6-6.1	15-20	26
	Shallow	-	-	-	31
	Medium	10.7, 35	9.1-12.2	30-40	16
	Deep	16.8, 55	15.2-18.3	50-60	9
	<6.2	-	-	-	15
	>6.1	-	-	-	41
	All	-	-	-	56

Survey Type	Depth	Achieved Depth(m)	Achieved Depth(m)	Average Depth(m)	1SD	Std.Error	No. Trans.
Emergent	Shallow 3	4.21	13.8	4.2, 13.8	0.0	0.0	1
	Shallow 6.1	4.63-8.05	15.2-26.4	6.3, 20.6	1.0, 3.3	0.3, 0.9	13
	Shallow	4.21-8.05	13.8-26.4	6.1, 20.1	1.1, 3.6	0.3, 1.0	14
	Medium	9.48-13.1	31.1-43.0	10.8, 35.5	1.1, 3.5	0.4, 1.3	7
	Deep	14.2-17.7	46.7-57.9	16.5, 54.0	1.3, 4.4	0.7, 2.2	4
	Deep*	14.2-17.7	46.7-57.9	16.2, 53.1	1.3, 4.4	0.6, 2.1	4.5
	<6.2	4.21-5.70	13.8-18.7	10.4, 16.5	0.5, 1.6	0.2, 0.7	6
	>6.1	6.13-17.7	20.1-57.9	10.4, 34.1	3.7, 12.2	0.8, 2.8	20
	All	4.21-17.7	13.8-57.9				26
Invasive	Shallow 3	4.11-4.57	13.5-15.0	4.4, 14.3	0.2, 0.5	0.1, 0.2	5
	Shallow 6.1	4.63-8.23	15.2-27.0	6.5, 21.4	0.9, 3.0	0.2, 0.6	26
	Shallow	4.11-8.23	13.5-27.0	6.2, 20.3	1.2, 3.8	0.2, 0.7	31
	Medium	9.02-13.4	29.6-44.0	10.5, 34.3	1.2, 4.0	0.3, 1.0	16
	Deep	15.1-18.4	49.6-60.2	17.0, 55.6	1.3, 4.0	0.4, 1.3	9
	<=6.1	4.11-6.04	13.5-19.8	5.2, 17.2	0.6, 2.4	0.2, 0.6	15
	>6.1	6.13-18.4	20.1-60.2	10.6, 34.7	3.9, 12.6	0.6, 2.0	41
	All	4.11-18.4	13.5-60.2	-	-	-	56

* Depth and transect counts where urchin differed from other species.

TABLE 3. Substrate types for emergent and invasive transects by depth and location off Fitzgerald Marine Reserve.

Survey Type	Depth Category or Location	Reef	Boulder	Percent Cobble	Sand	Number of Points Measured	Number Transects
Emergent	Shallow	89.6	2.1	5	3.2	84	14
	Medium	89.8	1.7	7.1	1.4	42	7
	Deep	93.3	2.7	3.3	0.7	30	5
	<=20	86.9	3.9	6	3.3	36	6
	>20	91.5	1.6	5	1.9	120	20
	A	96.7	0	2.9	0.4	24	4
	B	89.3	1	7.3	2.3	30	5
	C	100	0	0	0	24	4
	D	86.9	6.7	6.5	0	24	4
	E	71.7	0	28.3	0	6	1
	F	97.1	0	2.1	0.8	24	4
	G	77.3	5.8	6.5	10.4	24	4
	All	90.4	2.1	5.3	2.2	156	26
Invasive	Shallow	88.6	3.4	6.4	1.6	155	31
	Medium	95.9	2.3	1.5	0.4	80	16
	Deep	98.4	0.9	0.7	0	45	9
	<=20	84.7	3.7	9.3	2.2	75	15
	>20	95	2.2	2.2	0.6	205	41
	A	95.1	2.4	2.4	0	45	9
	B	91.7	3.4	4.5	0.4	70	14
	C	92.9	1.4	4.6	1.1	35	7
	D	99.6	0.4		0	40	8
	E	87	4	7	2	10	2
	F	89.3	3.9	4.8	2.1	40	8
	G	86.5	3.3	7.5	2.8	40	8
	All	92.3	2.6	4.1	1	280	56

TABLE 4. Algal cover on invasive transects by depth and station location off Fitzgerald Marine Reserve.

Survey Type	Depth Category or Location	[------ Percent ------] Canopy	Sub-Can.	Turf	Encrust.	Number of Transects
Invasive	Shallow	0.4	13.1	53.4	42.4	31
	Medium	0	13.9	23.2	55.9	16
	Deep	0	0	3.9	48.9	9
	<=20	0.1	5.3	62	46	15
	>20	0.2	13.4	27.6	50	41
	A	0	0	39.4	66.7	9
	B	0.1	2.2	48.2	39.6	14
	C	0	0	51.4	97.1	7
	D	0	0	20.6	48.8	8
	E	0	0	1	25	2
	F	1.3	68.1	20	33.1	8
	G	0	6.5	43	25	8
	All	0.2	11.2	36.8	48.9	56

TABLE 5. Red and flat abalone densities for emergent and invasive transects by depth and location off Fitzgerald Marine Reserve.

Survey Type	Depth Description or Location	Red Abalone Count	No.-per-m^2	1SD	Stand. Error	Number of 5 sq. meter Cells	Number of Transects
Emergent	Shallow	36	0.04	0.16	0.01	164	13.7
	Medium	1	0.002	0.02	0.00	84	7
	Deep	0	-	-	-	54	4.5
	<=20	26	0.07	0.19	0.02	72	6
	>20	11	0.01	0.08	0.01	230	19.2
	A	0	0.00	0.00	0.00	48	4
	B	7	0.02	0.06	0.01	60	5
	C	15	0.07	0.23	0.04	42	3.5
	D	0	0.00	0.00	0.00	44	3.6
	E	0	0.00	0.00	0.00	12	1
	F	4	0.02	0.06	0.01	48	4
	G	11	0.05	0.19	0.03	48	4
	All	37	0.02	0.12	0.01	302	25.2
Invasive	Shallow	32	0.1	0.36	0.05	62	31
	Medium	6	0.04	0.11	0.02	32	16
	Deep	0	-	-	-	18	9
	<=20	17	0.11	0.36	0.07	30	15
	>20	21	0.05	0.23	0.03	82	41
	A	1	0.01	0.05	0.01	18	9
	B	4	0.03	0.07	0.01	28	14
	C	25	0.36	0.71	0.19	14	7
	D	0	0.00	0.00	0.00	16	8
	E	3	0.15	0.19	0.10	4	2
	F	2	0.03	0.07	0.02	16	8
	G	3	0.04	0.11	0.03	16	8
	All Depths	38	0.07	0.28	0.03	112	56

TABLE 5. (Continued).

Survey Type	Depth Description or Location	Flat Abalone Count	No.-per-m^2	1SD	Stand. Error	Number of 5 sq. meter Cells	Number of Transects
Emergent	Shallow	0	-	-	-	164	13.7
	Medium	0	-	-	-	84	7
	Deep	0	-	-	-	54	4.5
	<=20	0	-	-	-	72	6
	>20	0	-	-	-	230	19.2
	A	0	-	-	-	48	4
	B	0	-	-	-	60	5
	C	0	-	-	-	42	3.5
	D	0	-	-	-	44	3.6
	E	0	-	-	-	12	1
	F	0	-	-	-	48	4
	G	0	-	-	-	48	4
	All	0	-	-	-	302	25.2
Invasive	Shallow	2	0.01	0.05	0.01	62	31
	Medium	0	-	-	-	32	16
	Deep	0	-	-	-	18	9
	<=20	2	0.01	0.07	0.01	30	15
	>20	0	-	-	-	82	41
	A	0	-	-	-	18	9
	B	0	-	-	-	28	14
	C	2	0.03	0.1	0.03	14	7
	D	0	-	-	-	16	8
	E	0	-	-	-	4	2
	F	0	-	-	-	16	8
	G	0	-	-	-	16	8
	All Depths	2	0.00		0.00	112	56

TABLE 6. Abalone, urchin, and sea stars two-way ANOVA probability values for log transformed density comparison by area, depth, and area*depth interacton.

Transect Type	Class Variable	Red Abalone	Red Urchin	Purple Urchin	Sun Star	Ocher Star	Bat Star	Other Stars
Emergent	Area	n.s.	0.0004	0.0001				
	Depth (20,35,55)	0.013	0.0001	n.s.				
	Area*Depth	n.s.	0.0001	0.0071				
	Area	0.0004						
	Depth (20,20+)	0.0001						
	Area*Depth	0.0001						
Invasive	Area	n.s.	0.0053	0.0008	n.s.	0.0264	n.s.	0.0332
	Depth (20,35,55)	0.045	0.0109	n.s.	n.s.	0.0426	n.s.	0.0085
	Area*Depth	n.s.	0.0498	n.s.	0.0338	n.s.	n.s.	0.0009
	Area	0.0044						
	Depth (20,20+)	n.s						
	Area*Depth	n.s						

TABLE 7. Red abalone sizes for emergent and invasive transects by depth off Fitzgerald Marine Reserve. Also includes number and percent young of the year (YOY), sport legal, and commercial legal sizes.

Survey Type	Depth	No. Meas.	[---Size (mm, in)--- Min	Max	Average]	1SD	C.V.	Num. Tran.
Emergent	Shallow	27	55, 2.2	200, 7.9	139, 5.5	34	24	13.3
	Medium	1	-	-	195, 7.7	-	-	7
	Deep	0	-	-	-	-	-	4
	<=20	18	55, 2.2	200, 7.9	129, 5.1	35	27	6
	>20	10	120, 2.2	195, 7.7	162, 6.4	23	14	18.3
	All	28	55, 2.2	200, 7.9	141, 5.5	35	25	24.3
Invasive	Shallow	37	33, 1.3	193, 7.6	139, 5.5	53	38	31
	Medium	7	23, .9	178, 7.0	63, 2.5	57	90	16
	Deep	0	-	-	-	-	-	9
	<=20	17	33, 1.3	193, 7.6	128, 5.0	56	44	15
	>20	27	23, .9	193, 7.6	126, 5.0	63	50	41
	All	44	23, .9	193, 7.6	127, 5.0	61	48	56

Survey Type	Depth Category or Location	No.(%) Y.O.Y. <32mm	No.(%) >177mm	No.(%) >197mm	Num. Tran.
Emergent	Shallow	0	2 (7)	1 (4)	13.3
	Medium	0	1 (100)	0	7
	Deep	0	0	0	4
	<=20	0	1 (6)	1 (6)	6
	>20	0	2 (20)	0	18.3
	All	0	3 (11)	1 (4)	24.3
Invasive	Shallow	0	14 (38)	0	31
	Medium	3(43)	1 (14)	0	16
	Deep	0	0	0	9
	<=20	0	6 (35)	0	15
	>20	3(11)	9 (33)	0	41
	All	3(7)	15 (34)	0	56

TABLE 8. Red and purple urchin densities for emergent and invasive transects by depth and location off Fitzgerald Marine Reserve.

Survey Type	Depth	Red Urchin Count	No.- per- m^2	1SD	Stand. Error	Purple Urchin Count	No.- per- m^2	1SD	Stand. Error	No. $5m^2$ Cells	No. Tran.
Emerg.	Shal.	373	0.93	1.33	0.15	31	0.08	0.20	0.02	80	13.3
	Med.	326	1.55	1.04	0.16	48	0.23	0.40	0.06	42	7
	Deep	93	0.78	0.72	0.15	4	0.03	0.16	0.03	24	4
	A	166	1.38	0.84	0.17	0	0.00	0.00	0.00	24	4
	B	254	1.69	1.88	0.34	3	0.02	0.08	0.01	30	5
	C	85	0.94	0.98	0.23	33	0.37	0.46	0.11	18	3
	D	142	1.42	1.18	0.26	7	0.07	0.20	0.04	20	3.3
	E	38	1.27	0.16	0.07	0	0.00	0.00	0.00	6	1
	F	79	0.66	0.52	0.11	40	0.33	0.39	0.08	24	4
	G	28	0.23	0.57	0.12	0	0.00	0.00	0.00	24	4
	All	792	1.08	1.21	0.04	83	0.11	0.28	0.02	146	24.3
Invas.	Shal.	527	1.7	2.16	0.27	26	0.08	0.17	0.02	62	31
	Med.	257	1.61	1.19	0.21	17	0.11	0.23	0.04	32	16
	Deep	65	0.72	0.44	0.10	7	0.08	0.22	0.05	18	9
	A	180	2.00	2.45	0.58	4	0.04	0.15	0.03	18	9
	B	290	2.07	2.31	0.44	13	0.09	0.18	0.03	28	14
	C	53	0.76	0.69	0.18	17	0.24	0.32	0.08	14	7
	D	128	1.60	1.10	0.28	0	0.00	0.00	0.00	16	8
	E	19	0.95	0.19	0.10	1	0.05	0.10	0.05	4	2
	F	133	1.66	1.39	0.35	14	0.18	0.26	0.07	16	8
	G	46	0.58	1.02	0.25	1	0.01	0.05	0.01	16	8
	All	849	1.52	1.77	0.06	50	0.09	0.20	0.03	112	56

TABLE 9. Red urchin sizes for emergent and invasive transects by depth off Fitzgerald Marine Reserve.

Survey Type	Depth	No. Meas.	[----------Size (mm, in)--------] Min	Max	Average	1SD	C.V.
Emergent	Shallow	252	35, 1.4	180, 7.1	106, 4.2	20	19
	Medium	185	25, 1.0	165, 6.5	91, 3.6	19	21
	Deep	101	40, 1.6	110, 4.3	76, 3.0	16	21
	All	538	25, 1.0	180, 7.1	95, 3.7	22	23
Invasive	Shallow	454	8, 0.3	148, 5.8	88, 3.5	23	26
	Medium	240	8, 0.3	128, 5.0	80, 3.1	21	26
	Deep	64	8, 0.3	108, 4.3	73, 2.9	21	29
	All	758	8, 0.3	148, 5.8	84 , 3.3	23	27

Survey Type	Depth	No. Meas.	No.(%) <51mm	No.(%) >88mm	Area Search. m^2	Num. Trans.
Emergent	Shallow	252	4(2)	216 (86)	399	13.3
	Medium	185	5(3)	102 (55)	210	7
	Deep	101	10(10)	22 (22)	120	4
	All	538	19(4)	340 (61)	729	24.3
Invasive	Shallow	454	31(7)	235 (52)	310	31
	Medium	240	22(9)	71 (30)	160	16
	Deep	64	8(13)	8 (13)	90	9
	All	758	61(8)	314 (41)	560	56

TABLE 10. Red urchin sizes for individuals sub-canopy to adults for emergent and invasive transects by depth off Fitzgerald Marine Reserve.

Survey Type	Depth	No. Meas.	No. Juveniles <51mm	No. Sub-Canopy	[---- Sizes (mm, in) ------] Min	Max	Average	1SD
Emergent	Shallow	252	4	0	-	-	-	-
	Medium	185	5	1	25, 1	25, 1	25, 1	0
	Deep	101	10	0	-	-	-	-
	All	538	19	1	25, 1	25, 1	25, 1	0
Invasive	Shallow	454	31	9	8, 0.4	48, 1.8	24, 1	23
	Medium	240	22	9	13, 0.6	48, 1.8	29, 1.1	21
	Deep	64	8	0	-	-	-	-
	All	758	61	18	8, 0.4	48, 1.8	27, 1.1	22

Survey Type	Depth Category or Location	Percent Sub-Canopy	Percent Sub-Canopy of Juvenile	Area Searched (m^2)	Number of Transects
Emergent	Shallow	0	0	399	13.3
	Medium	0.5	20	210	7
	Deep	0	0	120	4
	All	0.1	5	729	24.3
Invasive	Shallow	2	29	310	31
	Medium	4	41	160	16
	Deep	0	0	90	9
	All	2.4	30	560	56

TABLE 11. Purple urchin sizes for emergent and invasive transects by depth off Fitzgerald Marine Reserve.

Survey Type	Depth	Number No. Meas.	[---- Sizes (mm, in) -------] Min	Max	Average	1SD	C.V.
Emergent	Shallow	16	15, 0.6	110, 4.3	83, 3.3	32	39
	Medium	19	45, 1.8	115, 4.5	83, 3.3	20	24
	Deep	0	-	-	-	-	-
	All	35	15, 0.6	115, 4.5	83, 3.3	26	31
Invasive	Shallow	24	7, 0.3	97, 3.8	44, 1.7	28	64
	Medium	15	9, 0.4	88, 3.5	49, 1.9	26	53
	Deep	7	38, 1.5	71, 2.8	60, 2.4	12	20
	All	46	7, 0.3	97, 3.8	48, 1.9	26	54

Survey Type	Depth Category or Location	"Juveniles" <=30mm (<=1.2 inch) No.(%)	Total Area Searched Sq.Meters	Number of Transects
Emergent	Shallow	10(62)	399	13.3
	Medium	5(26)	210	7
	Deep	0	120	4
	All	15(43)	729	24.3
Invasive	Shallow	10(42)	310	31
	Medium	5(33)	160	16
	Deep	0	90	9
	All	15(33)	560	56

TABLE 12. Sea star densities for invasive transects by depth and location off Fitzgerald Marine Reserve.

Depth	*Pycnapodia helianthoides* Count	No.-per-m^2	1SD	Stand. Error	*Pisaster* sp. Count	No.-per-m^2	1SD	Stand. Error	No. of Trans.*
Shallow	15	0.05	0.07	0.02	92	0.32	0.31	0.06	29
Medium	24	0.15	0.28	0.06	104	0.65	0.61	0.15	16
Deep	20	0.22	0.56	0.13	57	0.63	0.82	0.27	9
A	13	0.14	0.36	0.12	55	0.61	0.56	0.19	9
B	2	0.02	0.04	0.01	37	0.28	0.23	0.06	13
C	11	0.18	0.17	0.07	34	0.57	0.36	0.15	6
D	25	0.31	0.61	0.21	76	0.95	0.95	0.33	8
E	3	0.15	0.07	0.05	2	0.10	0.00	0.00	2
F	5	0.06	0.07	0.03	25	0.31	0.46	0.16	8
G	0	0.00	0.00	0.00	24	0.30	0.44	0.16	8
All	59	0.11	0.29	0.04	253	0.47	0.55	0.03	54

Depth	*Pateria miniata* Count	No.-per-m^2	1SD	Stand. Error	Other Stars Count	No.-per-m^2	1SD	Stand. Error	No. of Trans.*
Shallow	188	0.65	0.73	0.14	7	0.02	0.08	0.01	29
Medium	170	1.06	0.64	0.16	8	0.05	0.19	0.05	16
Deep	67	0.74	0.54	0.18	15	0.17	0.27	0.09	9
A	80	0.89	0.93	0.31	13	0.14	0.30	0.10	9
B	36	0.28	0.34	0.09	9	0.07	0.12	0.03	13
C	78	1.30	0.53	0.22	0	0.00	0.00	0.00	6
D	66	0.83	0.57	0.20	0	0.00	0.00	0.00	8
E	23	1.15	0.07	0.05	0	0.00	0.00	0.00	2
F	70	0.88	0.52	0.18	8	0.10	0.28	0.10	8
G	72	0.90	0.99	0.35	0	0.00	0.00	0.00	8
All Depths	425	0.79	0.70	0.03	30	0.06	0.17	0.03	54

* Counts were for the entire transect area of 10 square meters.