

SMURFs: standard monitoring units for the recruitment of temperate reef fishes

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Received 22 April 2002; received in revised form 7 July 2003; accepted 28 August 2003

Abstract

I evaluated a standard monitoring unit for the recruitment of reef fishes (SMURF) as a tool for ascertaining spatial and temporal patterns of reef fish recruitment in central California, USA. SMURFs consisted of a 1.0×0.35 m dia. cylinder of fine mesh plastic grid that contained a folded section of larger mesh plastic grid. SMURFs collected new recruits of 20 species of fish with 92% of the individuals collected from 10 species, mostly rockfish (genus *Sebastes*). An experiment varying depth of SMURFs in the water column (surface, mid-depth, or bottom) showed that surface SMURFs collected the greatest diversity of species and significantly greater abundance for eight species, with two species having significantly greater abundance on mid-depth SMURFs and three species having significantly greater abundance on bottom SMURFs. A comparison of cumulated recruitment from SMURFs that varied in sampling frequency (removal of new recruits every 1–3, 7, or 28 days) suggested that increasing the time between sampling caused a significant decrease in recruitment estimates for some species but not for others. To determine how well temporal patterns of recruitment to SMURFs reflected patterns to nearby reefs, I compared within season temporal patterns of recruitment to SMURFs with that at nearby reefs, estimated by visual transect surveys conducted on scuba. Temporal patterns of recruitment to SMURFs were significantly and positively related to early recruitment on reefs for one group of benthic-algal associated rockfish species when diver surveys were lagged by 30 days ($r=0.87$) and for another group of canopy-algal associated rockfish species when lagged by 5 days ($r=0.72$). SMURFs appeared to be an effective and efficient method for indexing relative rates of delivery of competent juveniles for many temperate nearshore reef fishes.

Published by Elsevier B.V.

Keywords: Recruitment; Reef fish; Sampling method; *Sebastes*; Settlement; SMURF; Temperate reef

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1. Introduction

Variation in recruitment can be a major determinant of population dynamics of marine organisms with a pelagic larval stage (Connell, 1985; Doherty and Williams, 1988; Sale, 1990). Documenting spatial and temporal patterns of variation in recruitment is crucial to understanding how such variation influences the structure and dynamics of marine populations (Ralston and Howard, 1995; Caley et al., 1996; Love et al., 1998). Estimates of recruitment rates can be used to forecast dynamics and demographic structure for some species. For example, in the western Australian rock lobster, the index of annual pueruli settlement accurately predicts the catch rate of the fishery 4 years later (Morgan et al., 1982). In addition, comparing patterns of recruitment with physical variables can often provide insights into the relative importance and scale of environmental conditions that may influence dynamics of open marine populations (Roughgarden et al., 1988; Farrell et al., 1991; Kingsford and Finn, 1997; Dixon et al., 1999). Moreover, documenting spatial and temporal patterns in recruitment is essential for the proper placement and evaluation of marine reserves (Carr and Reed, 1993). The many applications of recruitment statistics demonstrate the need for accurate and repeatable methods for quantifying this important parameter.

Marine ecologists have used a variety of methods to quantify larval abundance (larval supply), settlement, and recruitment of reef fish. These include towed and fixed nets, light traps, and underwater visual surveys. Each of these methods has certain advantages and limitations. Towed nets generate density estimates of pelagic larvae and juveniles (e.g., Choat et al., 1993; Larson et al., 1994), but are generally constrained to sampling only one site at a time, and thus may not adequately sample the spatially and temporally patchy distribution of pre-settlement reef fishes. Multiple fixed nets, such as channel nets (e.g., Thorrold et al., 1994; Kingsford, 2001), can sample several sites simultaneously, but only when currents are sufficient to force larvae into them. Light traps can provide estimates of the relative abundances of pre-settlement larvae at several sites (e.g., Milicich et al., 1992; Dixon et al., 1999), but only at night and only for phototactic species. Underwater visual surveys can provide estimates of density or relative abundances of many newly settled reef fishes (e.g., Jones, 1990; Carr, 1991; Levin, 1994), but must contend with the physical factors that may limit underwater observations, such as turbidity, surge, currents, and cold (Ebeling and Hixon, 1991). Although these methods have been used extensively for addressing specific questions regarding recruitment issues, they may not be appropriate or feasible for more general recruitment monitoring in some reef fish systems.

A promising alternative approach is the use of standardized units of artificial substrate that attract ready-to-settle reef fish. This approach relies on the thigmotaxic behavior (i.e. affinity for physical structure) of many reef fishes. Artificial substrates can be used in a manner that overcomes some of the limitations of more traditional methods of quantifying settlement and recruitment. For example, when visually surveying recruits in natural habitat, variation in available habitat can strongly influence estimates of settlement, especially in the dynamic macroalgal dominated temperate reef regions (Levin, 1993; Anderson, 1994; Carr, 1994). However, this is less of a concern when using artificial substrates because the amount of habitat used in replicate units is easily controlled and standardized.

In addition, post-settlement mortality due to predation may be reduced on artificial substrates because the units can be placed away from reefs and associated resident predators (Connell, 1997) and because the structurally complex substrate may provide juvenile fish with shelter from more mobile predators (Hixon and Carr, 1997). Reduced post-settlement mortality allows sampling interval to be extended, without compromising the accuracy of estimates of settlement.

Unlike towed net surveys, which can provide only a temporal snapshot and in general cannot sample multiple sites simultaneously, artificial substrates are continuously available for potential settlers and arrays of replicate units can be placed over large areas. Therefore, artificial substrates may better integrate the highly variable temporal abundance and resolve the often patchy spatial distribution of pre- and post-settlement juveniles (Gaines and Bertness, 1993). In this regard, artificial substrates are similar to light traps (see Doherty, 1987), however artificial substrates, lacking a waterproof light and battery mechanism, are simpler in design and therefore more economical to construct and maintain. For certain fish species in temperate regions, substrate-based collectors were found to be more efficient than light traps in collecting settlers (Steele et al., 2002).

Standardized units of artificial substrate can be an even more effective approach when combined with a means of easily removing fish that settle to these units. This is usually accomplished by making the units portable, meaning that they can be taken out of the water without loss of recruits. This feature allows collecting, identifying, and counting of recruits to be done more accurately and efficiently out of the water. Examples of portable artificial substrates used to measure recruitment of juveniles include tufts of rope fibers used for spiny lobsters (Morgan et al., 1982; Montgomery, 2000) and anguillid glass eels (Silberschneider et al., 2001), artificial seagrass units for crustaceans and post-larval fishes (Hair et al., 1994; Kenyon et al., 1999), units of coiled wire for post-larval coral reef fishes (Schroeder, 1987), and units of folded plastic grid for a temperate reef serranid (Findlay and Allen, 2002; Steele et al., 2002).

The objective of this study was to experimentally evaluate the performance of a portable artificial substrate used as a standard monitoring unit for the recruitment of fishes (SMURF) in central California, USA. For SMURFs to be used effectively for estimating the delivery of competent larvae, settlement, or recruitment of reef fish the following methodological issues must be addressed. The macroalgal dominated nearshore reefs of the California coast, with their characteristic top-to-bottom vertical structure, are habitat for juvenile fishes that utilize depth specific strata as part of their ontogenetic development (Carr, 1991; Love et al., 1991; Nelson, 2001). Because the mechanisms responsible for this depth-based habitat selection may also affect recruitment rates to SMURFs, I compared recruitment patterns to SMURFs suspended at three different depths in the water column.

Several species-specific, time-dependent, and density-dependent processes such as emigration, recruitment facilitation, and mortality from predation may modify initial settlement patterns to SMURFs. The effect of these post-settlement processes should be more pronounced with increasing time since settlement. Thus, SMURFs cleared of fish on a relatively frequent basis (i.e. short sampling interval) will experience reduced post-settlement effects compared to SMURFs cleared of fish on a less frequent basis (i.e. long

sampling interval). In the presence of strong post-settlement effects, more frequent collections of recruits would result in counts that more closely approximate actual settlement patterns. Alternatively, if post-settlement processes do not influence recruitment to SMURFs, then less frequent sampling should yield similar recruit abundances as that of more frequent sampling. I test the influence of sampling interval on cumulated recruitment to surface moored SMURFs by comparing SMURFs in which fish recruits were removed at three different frequencies.

I also test whether temporal patterns of recruitment to SMURFs relate with those estimated by diver visual surveys on nearby reefs. This is important to know, because ultimately recruitment to SMURFs will be used as a proxy to represent recruitment rates of fish on nearby reefs. For SMURFs to provide a meaningful index of recruitment, the patterns of recruitment obtained from SMURFs should be similar to those occurring on nearby reefs.

2. Materials and methods

2.1. Study site

This study was located near Point Cabrillo (36°37.78 N; 121°54.52 W) on the south side of the Monterey Bay, CA, USA. SMURFs were placed in a sand plain of 18–19 m bottom depth and located 100 m offshore of a rocky reef kelp forest and west of Hopkins Marine Life Reserve (HMLR). The SMURF site had an array of three rows of moorings oriented parallel to shore with 20 m between rows (Fig. 1).

2.2. SMURF and mooring design

SMURFs used in this study (Fig. 2a) were adapted from a design used by Steele et al. (2002). Each SMURF (1.0 × 0.35 m dia.) was constructed using a 1.2 × 1.0 m section of green plastic mesh with 2.5 cm grid (Grow Guard™, model #038-2416, Israel) rolled into a cylinder. A haphazardly folded 4.5 × 1.2 m section of black plastic mesh with 5.0 × 7.5 cm grid (Conwed Plastics, model #XB 5968-100-SSF, USA) was inserted into the cylinder. The outer mesh of 2.5 cm grid did not restrict movement of settlement size fish into or out of the SMURF, it did however, prevent entry of larger fish.

SMURFs were moored at three depths; surface, mid-depth, and bottom. Each surface SMURF was attached to a 20-m mooring line that was fixed to the sand bottom by an earth anchor, suspended at the middle (8 m) by a foam float and buoyed at the surface by a spar buoy (Fig. 2b). The spar buoy was designed to prevent buildup of drifting macroalgae by tilting to a horizontal position under the drag of the attached macroalgae. Attached drift macroalgae would have the undesirable effect of increasing the amount of habitat and affecting the attractiveness of the SMURF to potential fish recruits. Mid-depth and bottom SMURFs were attached to separate mooring lines and held vertically with a subsurface float (Fig. 2b). As a result of the anchoring method surface SMURFs were always maintained at 1 m below the surface

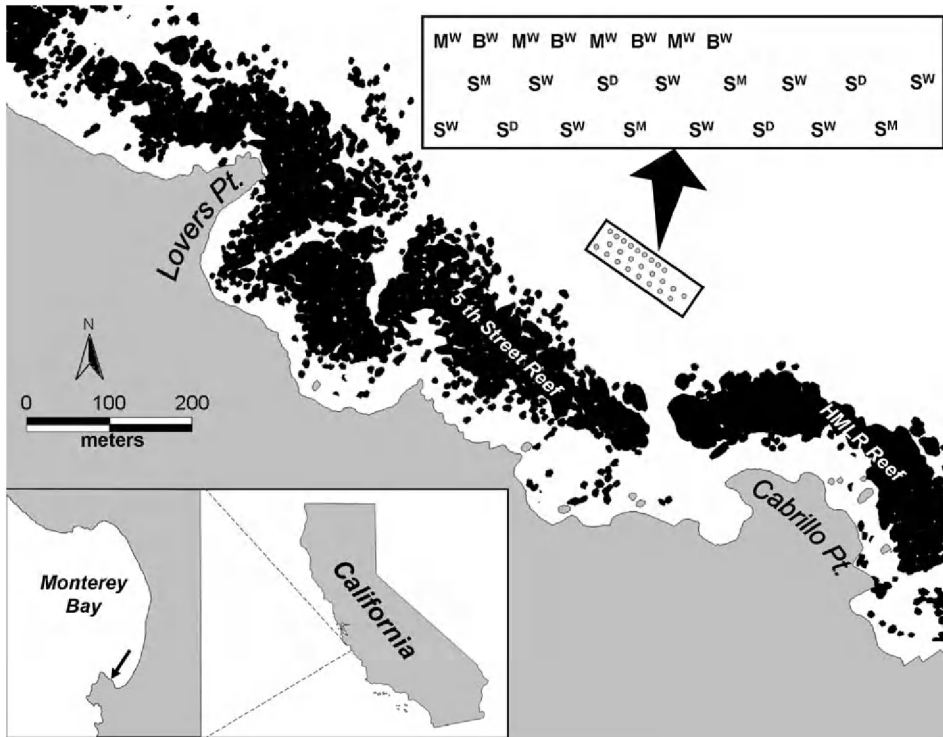


Fig. 1. Map of experimental SMURF array and reef locations. Letters show individual SMURFs with uppercase indicating depth level and superscripts indicating sampling interval: S^M=surface sampled monthly (28 days), S^W=surface sampled weekly (7 days), S^D=surface sampled daily (1–3 days), M^W=mid-depth sampled weekly, B^W=bottom sampled weekly. Black areas indicate kelp canopy and rocky bottom.

regardless of tidal height, while mid-depth and bottom unit depths varied with tidal height (± 2.5 m).

2.3. Collection of fish recruits

Fish were collected by enclosing each SMURF in a 4.8-mm square mesh BINCKE net (see Anderson and Carr, 1998), detached and brought into a boat, where it was removed from the net and placed in an 80 l plastic tub. Fish and mobile invertebrates were washed into the tub by pouring seawater over the SMURF while shaking it. Those fish entrapped in the BINCKE net were also added to the collection for that SMURF. After collecting fish recruits, the cleared SMURF was immediately returned to its mooring. Collected fish were immediately iced and later identified to species, measured, and frozen. Juveniles of the genus *Sebastes* that are similar in appearance were resolved to species when possible based on coloration, pigment patterns, meristics, and morphology (Anderson, 1983; Laidig and Adams, 1991). SMURFs near the surface were retrieved by snorkeling, while those at mid-depth and bottom were retrieved using scuba.

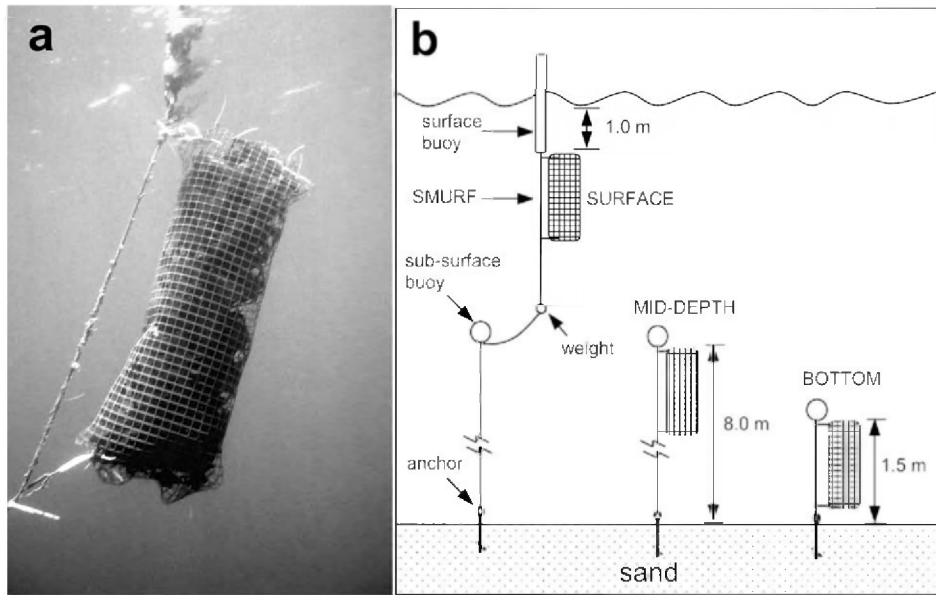


Fig. 2. (a) Portable artificial substrate (1.0 m long \times 0.35 m dia.) used as a standard monitoring unit for the recruitment of fish (SMURF) in Monterey Bay, CA, USA. (b) Method of deployment for SMURFs used in the depth level experiment (not to scale).

2.4. Effect of depth on recruitment of fish to SMURFs

I examined the effect of position in the water column on the species composition and rate of fish recruitment to SMURFs placed at three depth-levels (Fig. 2b): surface (1 m below the surface; $n=8$), mid-depth (8 m above the bottom; $n=4$) and bottom (1.5 m above the bottom at 18 m bottom depth; $n=4$). The extra surface replicates were part of a specimen collection program concurrent to this experiment and added to insure collection of enough individuals. All treatments were cleared of fish every week. The surface replicates were 20 m apart and systematically interspersed among two staggered rows of eight surface units just inshore of the mid-depth/bottom row (Fig. 1). Mid-depth and bottom treatments were alternately arranged with 20 m between replicates. The subsurface units were arranged in a single row to allow for a separate mooring line for each unit while maintaining the 20 m between replicate spacing and to facilitate finding units in the often low visibility conditions.

For analysis, the number of recruits collected from each SMURF was cumulated over the total sampling period (19 May to 13 July 2000), and this sum was used as a replicate. These data (and those of the following experiments) were examined for analysis of variance (ANOVA) assumptions of normality and homoscedasticity by inspecting normal probability plots and box plots, and when necessary, data were transformed to conform to these assumptions. Total number of recruits of all species and those species with enough individuals (>10) were analyzed for the effect of depth on recruitment using a one-way

ANOVA on square-root ($x+0.5$) transformed data. When significant differences in recruit numbers were detected among depths, the post-hoc Tukey pairwise comparison test was used to determine which depth levels differed from one another.

2.5. Effect of sampling interval on recruitment of fish to SMURFs

I examined the effect of varying sampling interval (time between collections) on recruitment to 16 continuously deployed surface SMURFs. SMURFs within this array were assigned to one of three sampling intervals: daily (cleared of fish every 1–3 days; $n=4$), weekly (cleared of fish every 7 days; $n=8$), and monthly (cleared of fish every 28 days; $n=4$). To control for SMURF location within the array, replicates were systematically interspersed among the two rows (offshore, inshore) of surface moorings (Fig. 1). For each SMURF, the number of recruits collected over the total sampling period (19 May to 7 Sept. 2000) was cumulated and this sum was used as a replicate in the analysis. Thus, the total number of recruits over this period was the sum of 65 collections for the daily sampling interval, 16 collections for the weekly sampling interval, and four collections for the monthly sampling interval. Total number of recruits of all species and those species with enough individuals (>10) were analyzed using a two-way ANOVA with factors of sampling interval (levels; daily, weekly, or monthly) and SMURF position (levels; offshore or inshore) to test for differences in recruitment. When significant differences in recruit numbers were detected among the main effects, the post-hoc Tukey pairwise comparison test was used to determine which levels differed from one another.

2.6. Comparing within season temporal patterns of recruitment of fish between SMURFs and diver visual transect surveys

The goal of this part of the study was to compare the estimates of recruitment derived from SMURFs with those derived from diver visual transect surveys. I specifically wanted to know if recruitment within a season to SMURFs scaled linearly with early recruitment to nearby reefs. If so, then recruitment to SMURFs, at least within a season, represents a reasonable index of patterns of recruitment to nearby natural reefs.

Comparisons were made for those species represented in both SMURF collections and visual transect surveys. During some transect surveys occasionally poor visibility made it difficult to visually identify similar appearing new recruits to species. Therefore these species were combined into functional groups based on similar morphology, coloration, and behavior (Anderson, 1983). Recruits of *S. melanops* Girard, *S. flavidus* Ayers, and *S. serranoides* Eigenmann and Eigenmann are similar in appearance, form mixed species aggregations, and normally occupy rocky bottom habitats in association with macroalgae (Anderson, 1983; Carr, 1991). These species were grouped and collectively referred to as the BYO complex. Recruits of *S. caurinus* Richardson, *S. carnatus* Jordan and Gilbert, *S. chrysomelas* Jordan and Gilbert and *S. atrovirens* Jordan and Gilbert are similar in appearance, form mixed species aggregations and initially recruit to the canopy formed by *Macrocystis pyrifera* (L.) C.Ag. (henceforth *Macrocystis*). These species were grouped and collectively referred to as the kelp complex.

Diver visual surveys were conducted at two rocky reef kelp forests adjacent to the SMURF site; 5th Street Reef and HMLR Reef. These reefs have a depth range of 3–13 m and have substrates composed of bedrock and boulders of 1–3 m vertical relief with occasional patches or channels of sand. Surveys were performed by a scuba diver swimming along haphazardly placed $2 \times 2 \times 30$ m transects at two depth levels; bottom (0–2 m above the reef) and canopy (0–2 m below the surface and through the canopy of *Macrocystis*). These depth levels were chosen to sample new recruits of species that occupy macroalgal habitats of different depths (see Carr, 1991). Bottom transects were designed to record the BYO complex recruits and were conducted from April through September 2000. A total of 52 and 35 bottom transects were sampled at 5th Street Reef and HMLR Reef, respectively. Canopy transects were designed to record the kelp complex recruits and were conducted from July to September. Prior to July, an absence of *Macrocystis* canopy negated canopy transects. A total of 33 and 19 canopy transects were sampled at 5th Street Reef and HMLR Reef, respectively.

Divers identified, enumerated and visually estimated the total length (TL, to the nearest cm) of all fish observed in each transect. Prior to surveys, underwater visual size estimation was practiced using fish models and then checked for accuracy by visually estimating TL of a juvenile fish then collecting that fish by spearing or netting and actually measuring it. Visual estimates were found to be within 1 cm of actual TL for fish less than 10 cm. Visual surveys were performed only if horizontal visibility was greater than 3 m.

Abundance of recruits to surface SMURFs from April through September was used to calculate a daily catch rate by dividing the mean number of recruits per SMURF by the number of days since those SMURFs were last sampled. During the peak recruitment period of May through August, these SMURFs were sampled every 1–3 days (mean 1.7 days). This time series was compared with the mean number of recruits per transect from each day of the diver visual transect surveys. Since I was interested in comparing patterns of recruitment between the two sampling methods, it was necessary to designate a maximum size for classification of juveniles observed on transects as new recruits. This was done based on the size of the first juveniles observed recruiting, which was ≤ 60 mm TL for the BYO complex and ≤ 30 mm TL for the kelp complex. Because SMURFs measured input of new settlers arriving over the previous 1–3 days while diver visual transect surveys estimated accumulation of recruits from the previous week or weeks, I expected a temporal mismatch between these two methods. To address this I used cross-correlation function plots to determine if abundance patterns in diver surveys lagged behind SMURF daily catch rates. The relationship of lag corrected diver surveys and SMURF daily catch rate was examined using correlation analysis.

3. Results

3.1. Species collected from SMURFs

A total of 2605 fish belonging to 23 species from nine families were collected from SMURFs (Table 1). Twenty of these twenty-three species were collected as new recruits. The genus *Sebastes* (family: Scorpaenidae) was the dominant group with 10 species.

Table 1

Fish collected from Standard Monitoring Units for Recruitment of Fishes (SMURFs) with 16 surface replicates from 19 May to 7 Sept. 2000 and four mid-depth and four bottom replicates from 19 May to 13 July 2000. Max new recruit is the maximum TL considered to be a fish that settled to a SMURF as a new recruit. TL=total length (mm)

Common name	Scientific name	N	% Total	Mean TL (± 1 S.D.)	Range	Max new recruit
CGB complex ^a		807	30.9	29.7 (5.4)	18–60	40
black rockfish	<i>Sebastes melanops</i>	447	17.1	49.3 (4.5)	39–70	60
kelp rockfish	<i>Sebastes atrovirens</i>	321	12.3	29.0 (5.0)	20–46	40
yellowtail rockfish	<i>Sebastes flavidus</i>	312	12.0	48.6 (3.8)	39–67	60
snailfish	<i>Liparis</i> spp.	245	9.4	12.6 (1.2)	10–21	20
cabezon	<i>Scorpaenichthys marmoratus</i>	129	4.9	54.0 (17.9)	38–150	60
bocaccio	<i>Sebastes paucispinus</i>	84	3.2	36.9 (7.9)	26–65	50
olive rockfish	<i>Sebastes serranoides</i>	52	2.0	50.4 (6.7)	43–77	60
sculpin	unidentified	42	1.6	16.7 (4.9)	11–35	20
stripetail rockfish	<i>Sebastes saxicola</i>	32	1.2	38.5 (2.7)	29–44	50
blackeye goby	<i>Coryphopterus nicholsi</i>	25	1.0	30.4 (2.4)	26–36	40
kelpfish	<i>Gibbonsia</i> spp.	25	1.0	30.5 (3.4)	26–38	40
painted greenling	<i>Oxylebius pictus</i>	24	0.9	35.2 (2.6)	31–41	40
splitnose rockfish	<i>Sebastes diploproa</i>	23	0.9	23.0 (3.1)	19–30	30
rockweed gunnel	<i>Apodichthys fucorum</i>	9	0.3	141.7 (33.5)	100–200	–
kelp greenling	<i>Hexagrammos decagrammus</i>	9	0.3	68.0 (5.4)	62–80	80
northern clingfish	<i>Gobiesox maeandricus</i>	8	0.3	15.2 (1.9)	13–18	20
saddleback sculpin	<i>Oligocottus rimensis</i>	5	0.2	18.4 (5.2)	13–24	20
medusafish	<i>Ichthyos lockingtoni</i>	3	0.1	52.0 (23.1)	26–70	–
penpoint gunnel	<i>Apodichthys flavidus</i>	2	0.1	235.0 (91.9)	170–300	–
lingcod	<i>Ophiodon elongatus</i>	1	<0.1	83.0	–	90

^a CGB complex=copper rockfish (*Sebastes caurinus*), gopher rockfish (*S. carnatus*), and black-and-yellow rockfish (*S. chrysomelas*).

Ninety-two percent of the individuals collected were from 10 species: *S. caurinus*, *S. carnatus*, *S. chrysomelas*, *S. melanops*, *S. atrovirens*, *S. flavidus*, *Liparis* spp., *Scorpaenichthys marmoratus* Girard, *S. paucispinus* Ayes, and *S. serranoides*. Because the *S. caurinus*, *S. carnatus*, and *S. chrysomelas* could not always be distinguished from each other, these species will be referred to collectively as the CGB complex.

A relatively small number of larger specimens with dark pigmentation were collected from SMURFs; these individuals may have migrated to SMURFs from drifting seaweed or by traveling up the mooring line from the sand bottom. Such individuals were excluded from estimates of recruitment. Maximum TL of new recruits (Table 1) was based on observed sizes of recently settled recruits (Anderson, 1983) and maximum sizes of pelagic juveniles (Larson et al., 1994).

3.2. Effect of depth on recruitment of fish to SMURFs

Cumulated recruitment of all species combined was significantly greater for surface level SMURFs than mid-depth or bottom level SMURFs, however the effect varied among species (Table 2). Significantly greater numbers of *Oxylebius pictus* Gill, *S. saxicola*

Table 2

Mean (± 1 S.E.) cumulative number of fish per SMURF from three depth levels (surface, mid-depth, bottom) collected from 18 May to 13 July 2000. Fish were collected every 7 days. *P*-values given for one-way ANOVA on effect of depth on recruitment using square-root ($x+0.5$) transformed data. When factors were significantly different (*P*-value <0.05), levels were compared using a post-hoc Tukey pairwise comparison test (S = Surface, M = Mid-depth, B = Bottom). *n* = number of replicate SMURFs sampled at each depth level

Species	Surface (<i>n</i> = 8)		Mid-depth (<i>n</i> = 4)		Bottom (<i>n</i> = 4)		<i>P</i> -value	Post-hoc
<i>Sebastes melanops</i>	29.1	(3.0)	4.4	(0.4)	2.3	(0.6)	<0.000	S>M=B
<i>Sebastes flavidus</i>	17.6	(3.0)	4.6	(1.0)	1.8	(0.8)	<0.000	S>M=B
<i>Sebastes serranoides</i>	3.9	(0.7)	0.0	–	0.0	–	<0.000	S>M=B
<i>Sebastes diploproa</i>	2.1	(0.9)	0.0	–	0.0	–	0.037	S>M=B
<i>Sebastes paucispinus</i>	3.6	(0.7)	1.3	(0.6)	0.0	–	<0.000	S>M=B
CGB complex ^a	25.5	(2.0)	12.3	(0.5)	2.9	(1.1)	<0.000	S>M>B
<i>Scorpaenichthys marmoratus</i>	5.4	(0.7)	1.8	(0.5)	5.0	(0.9)	0.004	S=B>M
<i>Liparis</i> spp.	2.8	(0.6)	11.7	(2.5)	6.8	(2.3)	0.007	M>S
<i>Coryphopterus nicholsi</i>	0.5	(0.2)	1.8	(0.8)	0.3	(0.2)	0.047	M>S=B
Unidentified sculpin	1.0	(0.4)	0.6	(0.5)	5.1	(0.5)	0.001	B>S=M
<i>Oxylebius pictus</i>	0.0	–	0.5	(0.3)	7.0	(2.1)	<0.000	B>S=M
<i>Sebastes saxicola</i>	0.0	–	0.0	–	6.5	(1.0)	<0.000	B>S=M
All species combined ^b	94.3	(7.2)	41.0	(3.7)	38.8	(2.5)	<0.000	S>M=B

^a *Sebastes caurinus*, *S. carnatus* and *S. chrysomelas*.

^b Includes species not shown.

Gilbert, and an unidentified sculpin species were collected at the bottom level. Significantly greater numbers of *Coryphopterus nicholsi* Bean and *Liparis* spp. were collected at the mid-depth level. *S. marmoratus* had significantly greater numbers at the surface and bottom levels compared to the mid-depth level. The majority of taxa, including *S. melanops*, *S. flavidus*, *S. serranoides*, *S. diploproa* Gilbert, *S. paucispinus* and the CGB complex were significantly more abundant at the surface level. Surface SMURFs collected the highest diversity of fish (15 spp.) compared to mid-depth (13) and bottom (11).

3.3. Effect of sampling interval on recruitment of fish to SMURFs

Cumulated recruitment of all species combined decreased with increases in sampling interval (time between subsequent removals of new recruits) from continuously deployed surface SMURFs (Table 3). Results of the two-way ANOVA showed that cumulative recruitment was significantly different for all three sampling intervals ($p < 0.001$; Table 3) and that significantly greater numbers of recruits were collected on SMURFs in the offshore row compared to the inshore row ($p = 0.0173$). The ANOVA model showed no significant interaction between sampling interval and position.

Results by species shows significantly greater cumulative recruitment of *S. paucispinus* and *Liparis* spp. from SMURFs with fish removed on a daily basis compared to SMURFs with fish removed every week or every month (Table 3). The CGB complex had significantly greater cumulative recruitment at the daily compared to monthly, and the weekly compared to monthly sampling intervals. Significantly greater cumulative recruitment of *S. flavidus* occurred on daily compared to monthly sampling intervals. In contrast,

Table 3

Mean (± 1 S.E.) cumulative number of fish per SMURF for each of three sampling intervals collected from 18 May to 7 Sept 2000. Treatments were daily (every 1–3 days), weekly (every 7 days) and monthly (every 28 days). *P*-values given for two-way ANOVA for factor sampling interval. Results for position factor and interaction reported in text. When factor was significantly different (*P*-value < 0.05), levels were compared using a post-hoc Tukey pairwise comparison test (D = daily, W = weekly, M = monthly). ns = not significant. *n* = number of replicate SMURFs sampled at each sampling interval

Species	Daily (<i>n</i> = 4)		Weekly (<i>n</i> = 8)		Monthly (<i>n</i> = 4)		<i>P</i> -value	Post-hoc
<i>Sebastes melanops</i>	27.5	(5.2)	29.1	(3.0)	19.5	(8.9)	0.164	ns
<i>Sebastes flavidus</i>	25.5	(6.2)	18.1	(3.1)	10.0	(4.5)	0.011	D>M
<i>Sebastes serranoides</i>	3.3	(0.5)	4.0	(0.7)	2.0	(0.9)	0.281	ns
<i>Scorpaenichthys marmoratus</i>	3.5	(1.0)	5.9	(0.7)	3.8	(1.0)	0.172	ns
<i>Sebastes atrovirens</i>	22.6	(2.5)	20.3	(2.6)	22.8	(4.5)	0.764	ns
CGB complex ^a	62.2	(8.9)	45.9	(3.7)	22.8	(2.6)	0.001	D>M, W>M
<i>Sebastes paucispinus</i>	10.9	(1.3)	4.1	(0.8)	1.3	(0.9)	0.001	D>W = M
<i>Liparis</i> spp.	36.3	(4.3)	3.4	(0.8)	1.8	(1.2)	0.001 ^b	D>W = M
All species combined ^c	200.1	(20.0)	141.5	(10.5)	87.6	(8.5)	< 0.000	D>W>M

^a *Sebastes caurinus*, *S. carnatus* and *S. chrysomelas*.

^b Log transformed data.

^c Includes species not shown.

four species; *S. melanops*, *S. serranoides*, *S. atrovirens* and *S. marmoratus* showed no significant difference in cumulative recruitment between the three sampling intervals. *S. melanops*, *S. flavidus*, and *S. serranoides* had increased cumulative recruitment for weekly compared to monthly sampling intervals, but these trends were not significant ($p = 0.209$, 0.090 and 0.197 respectively).

Only two species showed an effect for row position; *S. melanops* and *S. flavidus*, with significantly greater cumulative recruitment on SMURFs in the offshore row compared to the inshore row ($p < 0.002$). Because these two species comprised 69% of the total number of recruits collected, they were driving the row pattern observed in the analysis of all species combined. When *S. melanops* and *S. flavidus* are removed from all species combined the effect of position becomes non-significant ($p = 0.639$).

Cumulating recruitment from each replicate SMURF over time tended to smooth out variation between groups of SMURFs sampled at any one time. Although this procedure is appropriate for examining patterns in total recruitment within a season, it may be necessary to use estimates of recruitment at each collection when examining fine scale temporal or spatial patterns in recruitment. To compare how these two methods may affect sample size, I examined recruitment data for the CGB complex, this species group being the most abundant and also recruiting throughout the sampling period. SMURFs collected on a daily basis ($n = 4$) had a mean (± 1 standard deviation) that ranged from zero to 7.0 (5.3) with a mean across all 65 collections of 1.0 (0.8). SMURFs collected on a weekly basis ($n = 8$) had a mean that ranged from 0.1 (0.4) to 11.0 (6.3) with a mean across all 16 collections of 2.9 (2.1). SMURFs collected on a monthly basis ($n = 4$) had a mean that ranged from 2.0 (2.2) to 11.5 (6.5) with a mean across all 4 collections of 5.7 (3.4).

To examine the effect of temporal variability associated with each of the three sampling frequencies on sample size (i.e. number of replicate SMURFs), I used the mean and SD of

the means for each collection in a power analysis for a two sample t -test with $\alpha=0.05$ and $P=0.80$. The sample size required to detect an increase in the mean of 25, 50 and 100% was 226, 69 and 19 for daily; 159, 46 and 16 for weekly; and 104, 31 and 11 for monthly, respectively. In contrast, when using the mean and SD for SMURFs cumulated over the entire sampling period, the sample size required to detect an increase in the mean of 25, 50 and 100% was 25, 9 and 4 for daily; 23, 8 and 4 for weekly; and 15, 6 and 3 for monthly, respectively.

3.4. Comparing within season temporal patterns of recruitment between SMURFs and diver visual transect surveys

The BYO complex had similar patterns of recruitment for both surface SMURFs and bottom transects, although temporally shifted (Fig. 3). Patterns of recruitment for the BYO complex was characterized by a major pulse lasting 20 days and quickly followed by a minor pulse lasting 5 days. For the kelp complex species, the portion of the recruitment season that could be adequately sampled with the canopy transects (July through September) showed a similar pattern of recruitment compared with that of surface SMURFs, with a major pulse lasting 10 days in mid-July, followed by a period of no recruitment in late July, then an intense peak in recruitment in early August and followed by consistent recruitment until the end of August (Fig. 4).

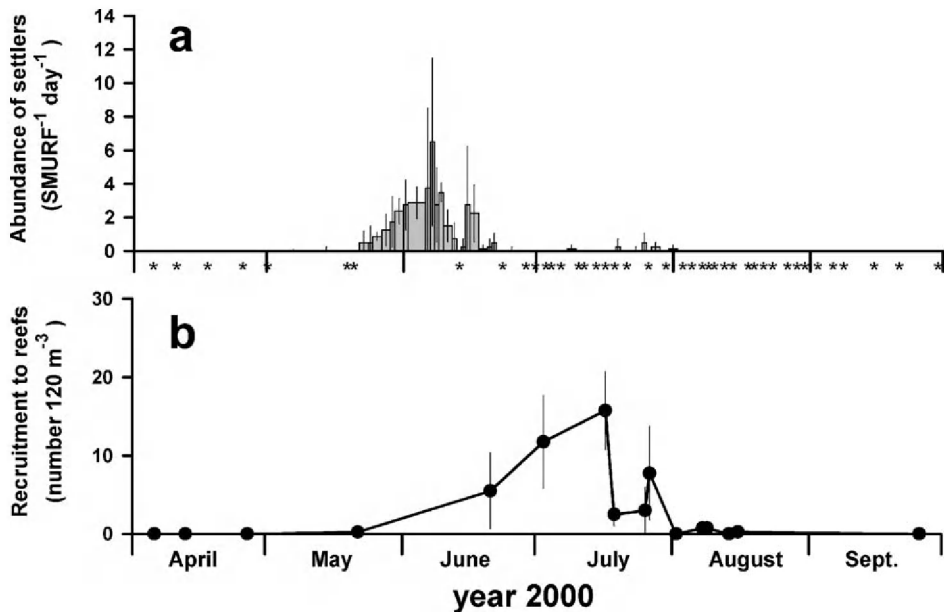


Fig. 3. Comparison of recruitment of BYO complex (*S. melanops*, *S. flavidus* and *S. serranoides*) from (a) SMURFs ($n=4$, surface units, error bars are ± 1 S.E., *=sampling effort but no recruits) and from (b) diver visual transect surveys done near the bottom at adjacent natural reefs (data represent fish of TL ≤ 6 cm, $n=3-9$, error bars are ± 1 S.E.).

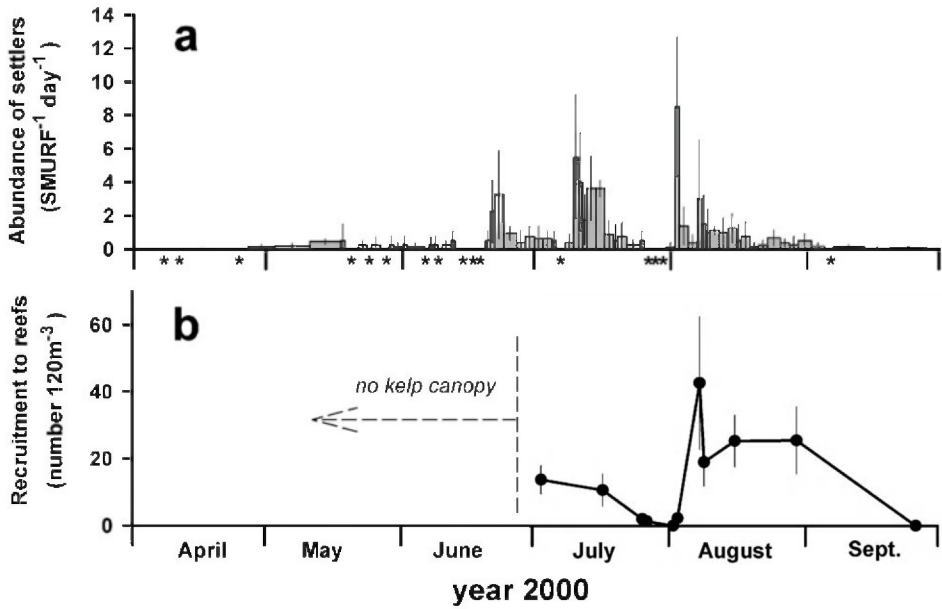


Fig. 4. Comparison of recruitment of kelp complex (*S. caurinus*, *S. carnatus*, *S. chrysomelas*, and *S. atrovirens*) from (a) SMURFs ($n=4$, surface units, error bars are ± 1 S.E., *=sampling effort but no recruits) and from (b) diver visual transect surveys done in the kelp canopy at adjacent natural reefs (data represent fish of TL ≤ 3 cm, $n=3-8$, error bars are ± 1 S.E.).

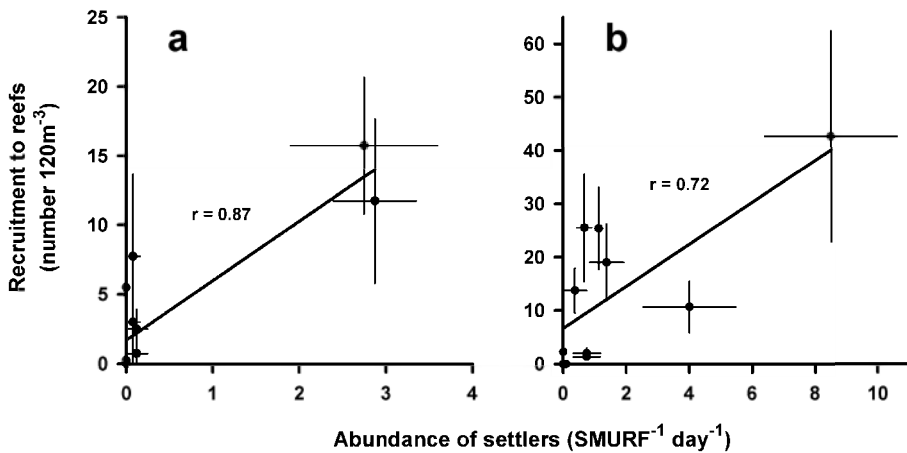


Fig. 5. Relationship between abundance of recruits on reefs and SMURF daily-catch rate for (a) the BYO complex species ($n=13$) and (b) the kelp complex species ($n=11$). Each point is the mean (± 1 S.E.) for a survey-day with $n=4$ for SMURFs and $n=3-9$ for diver transects at adjacent reefs. Recruitment to reefs was adjusted for a 30-day lag for the BYO complex and a 5-day lag for the kelp complex.

Cross correlation analysis of the BYO complex revealed that SMURF daily catch rates correlated best with diver bottom transect surveys lagged by 30 days ($p < 0.001$, $r = 0.87$; Fig. 5a). BYO complex recruits collected from SMURFs were smaller, with a mean of 47.7 mm TL, than the estimated size of those observed on bottom transects, 50–60 mm TL. Cross correlation analysis of the kelp complex revealed that SMURF daily-catch rates correlated best with diver canopy transect surveys lagged by 5 days ($p < 0.012$, $r = 0.72$; Fig. 5b). Kelp complex recruits collected from SMURFs averaged 27.1 mm (TL), and were similar in size to new recruits observed on reefs, which were estimated at less than 30 mm TL.

4. Discussion

SMURFs used in this study attracted many fish species, the majority being rockfish (genus *Sebastes*), but also sculpin, snailfish, gobies, greenlings, clingfish, and kelpfish. Most of these juveniles appeared to have recently arrived to the nearshore habitat because they were relatively small in size compared to recruits seen on natural habitat and because they exhibited a lack of pigmentation suggesting a recent pelagic existence.

SMURFs did not collect settlers of some species that were observed recruiting to nearby reef areas during this study. For example, recruits of *S. mystinus* Jordan and Gilbert, a very common species in nearby kelp forests, were not collected by SMURFs. *S. mystinus* recruits display habitat preference for high relief rocks, crevices and boulders (Anderson, 1983). SMURFs also failed to collect two other rockfish species that utilize nearshore reefs as juveniles, *S. miniatus* Jordan and Gilbert and *S. pinniger* Gill. Anderson (1983) reported that juveniles of these species have a habitat preference for the rock–sand interface of nearshore reefs. The above rockfish recruits do not strongly associate with algal habitats, however, the rockfish recruits that were collected by SMURFs all demonstrate an affinity for algal structure (Carr, 1991). It appears that SMURFs provide acceptable settlement habitat for species that will settle to algal habitats but not to those that prefer rocky habitat. In spite of this, the overall utility of SMURFs may be justified because they collected several common and ecologically important reef fish species, including some species that are not adequately sampled with diver visual surveys (e.g. cryptic *S. marmoratus* recruits).

In this study the depth of a SMURF in the water column had a dramatic effect on recruitment estimates and species composition. SMURFs at the surface collected more species and greater abundances of these species than mid-depth and bottom SMURFs. Other studies using artificial collecting devices to examine the abundance of late-stage fish larvae with depth in the water column have also indicated species-specific depth distributions (Hair et al., 1994; Fisher and Bellwood, 2001; Hendriks et al., 2001; Findlay and Allen, 2002).

The juveniles of several species of fish were collected on SMURFs at a depth that matched the depth of their preferred natural settlement habitat. The juveniles of *S. caurinus*, *S. carnatus*, *S. chrysomelas*, and *S. paucispinus* initially settle to the surface canopy of *Macrocystis* (Carr, 1991) and were significantly more abundant on surface SMURFs. Also, two species that recruit to bottom habitats; *S. saxicola* and *Oxylebius*

pictus were significantly more abundant on bottom SMURFs. The agreement in vertical distributions between natural habitat and SMURFs suggests that these pre-settlement juveniles may occupy a depth in the water column similar to the depth of their preferred settlement habitat. In contrast, three species that are predominantly associated with the algal structure near the bottom as juveniles; *S. melanops*, *S. flavidus*, and *S. serranoides* (Anderson, 1983; Carr, 1991) showed the strongest preference for SMURFs at the surface. If these species arrive to nearshore habitats at the depth that they settled to SMURFs (i.e. surface), they would have to either migrate down the kelp plants to the bottom following settlement or descend through the water-column just prior to settlement. Other possible mechanisms to account for recruitment patterns with SMURF depth include depth-dependent emigration and mortality rates. Which mechanisms are responsible for the depth distributions observed on SMURFs are difficult to determine. Nevertheless, the existence of these patterns suggests that depth should be considered when targeting other species using a similar sampling method.

Another important consideration, given the generally limited resources and availability of field personnel for most research projects, is the variation in sampling effort with SMURF depth. In this study, the surface deployed SMURFs required considerably less effort to sample (a single snorkeler 5–10 minutes per SMURF) compared to mid-depth and bottom deployments (two scuba divers 15–30 minutes per SMURF).

The mid-depth and bottom SMURFs were located in a row 20–40 m offshore of the surface units and if recruitment rates varied with offshore/inshore orientation this arrangement may have been a confounding factor in analysis of this experiment. Position of replicates for the sampling interval experiment did show an effect for two species (*S. melanops* and *S. flavidus*) with significantly greater recruitment on the offshore replicates. If this pattern had also occurred during the depth experiment, it would have enhanced recruitment to the mid-depth and bottom SMURFs. In spite of this, it would not have changed the conclusions of the depth experiment, since surface SMURFs still had significantly greater recruitment.

The effect of sampling interval in this study varied markedly between species. Some species had relatively low loss rates of daily compared to monthly sampling intervals; 30% for *S. melanops*, 33% for *S. serranoides*, and no loss for *S. atrovirens* and *Scorpaenichthys marmoratus*. Sampling interval for these species could be relatively long (e.g. 28 days) and still provide similar cumulative estimates of recruitment as those obtained using more frequent sampling regimes. The above species, with the exception of *S. atrovirens*, are relatively large at settlement and may not be negatively affected by the presence of other juveniles and thus experienced relatively little loss on the monthly SMURFs. Two possible explanations may account for the very low loss of *S. atrovirens*. Even though this species is relatively small at settlement its recruitment season is later relative to the other species, thus it did not frequently co-occur with other larger recruits. In addition, the presence of conspecifics may facilitate subsequent recruitment of *S. atrovirens* (Ammann, 2001), and thus potentially compensate for other sources of loss.

Other species were significantly affected by increasing sampling interval with relatively high loss rates of daily compared to monthly sampling intervals; 95% for *Liparis* spp., 88% for *S. paucispinus*, 64% for the CGB complex, and 60% for *S. flavidus*. Two of these species, *Liparis* spp. and *S. paucispinus*, also showed significant decreases in abundance

with increasing sampling interval from daily to weekly with a loss rate of 91% and 67%, respectively. With the exception of *S. flavidus*, these species are relatively small at settlement, and may be negatively affected by the presence of recruits that are larger at settlement. For these species, extended sampling intervals will greatly underestimate total settlement rates to SMURFs.

Several studies have demonstrated that significant loss rates can occur within 1 or 2 days after settlement (Booth, 1991; Minchinton and Scheibling, 1993; Hixon and Carr, 1997; Moksnes and Wennhage, 2001). Although, for most species collected on SMURFs in this study, loss rates were comparatively low. Ultimately, the type of information desired will dictate the sampling interval. If an absolute rate of settlement is desired, then sampling interval must be very short, to limit any potential post-settlement affects. On the other hand if only a relative settlement rate is required, then sampling interval could be longer, assuming that post-settlement affects are similar between sites and over time.

Other factors that may influence estimates of recruitment obtained from SMURFs include variation in attractiveness due to variation in turbidity, biofouling, or distance to adjacent natural settlement habitat. Turbidity did not seem to affect abundance estimates in this study because high abundance estimates occurred during times of both high and low turbidity. Although, biofouling occurred on SMURFs in this study, it may not have biased estimates because it was relatively constant between SMURFs and stable during the peak recruitment season. Biofouling may be a confounding factor when levels are variable over space and time, and thus this issue warrants attention.

In this study two species, *S. melanops* and *S. flavidus*, had significantly greater recruitment to offshore replicates compared to inshore replicates. The mechanism for this pattern is unknown, but it could be the result of reduced attractiveness of the inshore replicates due to their closer proximity to natural settlement habitat, increased loss (due to migration or predation) on the inshore replicates, or depletion of available pre-settlement fish by the offshore replicates (i.e. recruitment shadow; Gaines et al., 1985). Montgomery (2000) found a similar pattern in spiny lobster with increased numbers of recruits on collectors farther offshore compared to collectors adjacent to reefs. Although, in this study, offshore and inshore rows of SMURFs were relatively close together, only 20 m apart, compared to the 200 m separating the collectors in Montgomery's study. This explanation seems unlikely given that the two rows did not differ much in their distance to natural settlement habitat, 100 and 120 m, respectively. Varying loss rates also seems unlikely, again given the closeness of both rows to natural settlement habitat and because no other species showed a difference in recruitment between the two rows. A recruitment shadow effect seems plausible if delivery of competent juveniles is consistently from the same direction and these juveniles quickly settle to the first available habitat they encounter. If true then the orientation of replicates in relation to each other and the direction of delivery of pre-settlement juveniles should carefully be considered in the placement of replicates.

Recruitment to SMURFs showed considerable temporal variation between consecutive samples. The power analysis of the CGB complex recruitment data suggests that to detect small differences between means will require sample sizes so large, as to be logistically untenable. However, detecting differences of less than 50% may not be biologically meaningful, given the highly variable nature of fish recruitment. In this study, recruitment

was sporadic and consecutive samples often varied by more than 100% (see Figs. 3a and 4a). Nevertheless, to detect a difference of 100% in consecutive samples or between sites using relatively short sampling periods, will require a sample size of greater than 10. On the other hand, if one was interested in inter-annual differences at a particular site or intra-annual differences between sites, then the procedure of cumulating recruitment to each replicate SMURF over the recruitment season could be used, thus increasing power and greatly reducing the required sample size.

The significant positive relationships between patterns of daily recruitment to SMURFs and density of recruits observed on diver surveys was fairly direct for the kelp complex species (5-day lag), but temporally shifted for the BYO complex species (30-day lag). This difference in lag time between SMURFs and diver surveys was consistent with the difference in size of recruits between the two methods. The relatively short time lag and small size difference for the kelp canopy species suggests that both methods record similar temporal patterns in abundance. On the other hand, for the BYO complex species, the relatively long time lag and large difference in size between the two methods suggests that SMURFs may be collecting newly settled juveniles, but that new settlers are not observed in diver surveys until about 30 days later. On reefs, the new recruits of the BYO complex may initially be very difficult to see, and only became conspicuous after they have grown and/or changed behavior. This is consistent with the difference in behavior between the two species groups; BYO complex species are quite skittish and tend to swim away from approaching divers, while the kelp complex species will allow divers to approach very closely. Overall, recruitment to SMURFs and estimates of early recruitment from diver visual surveys are in good agreement for the kelp complex species, although for the BYO complex species, SMURFs may be recording new recruits before they are observed in diver visual transects.

5. Conclusions

The portable artificial substrate units evaluated in this study (SMURFs) appeared to be an effective tool for indexing relative rates of delivery of competent juveniles for many species of ecologically and commercially important nearshore reef fishes in Monterey Bay, CA. SMURFs may overcome some of the limitations that have hindered temperate reef fish ecologists' attempts to address several important questions regarding recruitment processes, because SMURFs standardize habitat, integrate recruitment over time, and are easy and inexpensive to produce and deploy. Comparisons between patterns in recruitment to SMURFs and nearby reefs suggest that SMURFs can provide an index of relative recruitment rates for some species. The optimum depth of deployment and sampling frequency will be determined by the species of interest and the type of information desired. For most species collected in this study, surface deployed SMURFs were most effective. Relatively long sampling intervals can be used for some species and still provide good estimates of total recruitment. This type of sampling regime can be utilized over a large geographic area or continued over many years. Alternatively, very frequent sampling on the order of days can provide more accurate estimates of larval supply or settlement. This type of sampling regime can be used to describe fine-scale patterns in delivery and explore

how they relate to oceanographic and/or behavioral mechanisms of delivery. The relatively low cost and effort required to deploy and sample SMURFs may permit more robust spatial and temporal replication to resolve the often patchy and episodic nature of reef fish larval supply, settlement, and recruitment.

Acknowledgements

I thank the many enthusiastic volunteer divers that helped with the fieldwork for this project. Critical and constructive advice on many aspects of this project was given by M. Carr, P. Raimondi, G. Bernardi, P. Levin, and D. Schroeder. Assistance with data analysis was provided by T. Minchinton and C. Syms. Thanks to M. Donnellan for help with the site map. This manuscript was greatly improved by Y. Springer, M. Steele, and M. Carr. This project was supported by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), a long-term ecological consortium funded by the David and Lucile Packard Foundation. Additional support came from the Dr. Earl H. Myers and Ethel M. Myers Oceanography and Marine Biology Trust and from the Friends of the Long Marine Laboratory. This is contribution #122 from PISCO. [AU]

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