Enhancing Coral Reef Recovery After Destructive Fishing Practices: Initial Results in Komodo National Park

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1. INTRODUCTION

1.1 Blast fishing

Coral reefs are among the earth's most productive, diverse, and valuable habitats. However, pressures from rapid population and economic growth in Southeast Asia have brought many reef ecosystems to the brink of collapse. It is estimated that less than 3 % of the reefs in Indonesia remain in excellent condition (>75% live coral cover) and these are being rapidly degraded, as few of the marine protected areas that exist on paper are effectively managed (Chou, 1997; Wilkinson *et al.*, 1994).

A devastating threat to reefs comes from dynamite or "blast" fishing, which not only kills organisms within the blast radius (including the targeted fish), but also pulverizes the coral skeletons themselves, leaving a shifting, unstable rubble field that inhibits, if not prevents, colonization. Despite being illegal, blast fishing is widespread, practiced in nearly 30 countries in Southeast Asia and Oceania and has reportedly caused major reef degradation in half of the countries in the South Pacific (Ruddle, 1996). In this study, we are investigating factors that inhibit or enhance coral regeneration and ways to accelerate recovery of coral reef communities damaged by blast fishing in Komodo National Park.

One of the most serious problems associated with blast fishing is that new coral colonies are not growing back, even when the damaged area is protected from further impact. Blast fishing destroys living coral at a rate far beyond its capacity to regenerate, since with extensive reef destruction the sources of coral recruits (the adult colonies) are eliminated. As more of a reef is blasted, there is increased pressure on the areas that remain healthy, potentially leading to a cascade of ecosystem collapse (McManus, 1997). Furthermore, the potential long term economic costs of destructive fishing in loss of sustainable fishery income, coastal protection, and tourism is more than 50 time higher than the short term benefits (Cesar, 1996).

1.2 Coral recovery

The widespread use and devastating effects of blast fishing have been well documented (Alcala and Gomez, 1987; McManus *et al.*, 1997; Pauly *et al.*, 1989), yet little is known about the process of recovery once a reef has been blasted. In general, coral larvae from seasonal spawning events provide the primary means for recovery. While some living fragments might initially survive, hard corals (scleractinians) are less likely to recover either from chronic disturbance or disturbance that alters the physical environment; blast fishing falls into both categories (Connell *et al.*, 1997). Furthermore, heavily disturbed or overfished sites often undergo a "phase shift" to communities dominated by soft corals and macroalgae, which limit recovery of hard coral colonies (Done, 1992; Hughes, 1994; Roberts, 1995). In Komodo National Park, large fields of the soft coral *Xenia spp.* often grow on top of rubble (H. Fox, pers. obs.). Not only is *Xenia* a successful colonizer, with high fecundity and several dispersal modes, but also a superior competitor (Benayahu and Loya, 1985). Soft corals also can inhibit larval recruitment of scleractinian corals via allelopathy (Maida *et al.*, 1995). However, there are also cases where soft corals and macro algae do *not* invade space cleared by the death of hard corals (Fabricius, 1997).

To rehabilitate damaged reefs, some workers have experimented with transplantation of living coral colonies or cultivation of coral "gardens" to re-seed areas (Harriott and Fisk, 1995; Rinkevich, 1995). Clark and Edwards (1995) found that simply stabilizing the substrate with concrete mats, onto which new coral settled, resulted in recovery comparable to that of transplantation to the concrete mats. Many rehabilitation methods are expensive, labor intensive, and, if transplantation is attempted, can result in high mortality of transplants (Clark and Edwards, 1995; Harriott and Fisk, 1995). Furthermore, they are not designed specifically for the type of damage done by blast fishing, or for the limited conservation resources of developing countries. This project focuses on exploring relatively inexpensive, cost-effective, and locally available technologies to enhance coral reef rehabilitation. Since substrate stability and topographic complexity are crucial to survival of coral recruits, we predict that the recovery of coral communities can be accelerated by stabilizing loose rubble and creating three-dimensional surfaces for coral settlement (Harriott and Fisk, 1995; Schuhmacher, 1988). Effective methods could be incorporated in other regions in Indonesia, as well as in existing reef management programs in other Southeast Asian and Oceanic countries facing this problem.

1.3 Research Objectives

There are many factors that can influence variation in recovery rates, including source of larvae (adult coral colonies), substrate stability and condition, currents and hydrologic processes, and species interactions, such as presence of coral predators and algal grazers. We are focusing on the effects of source coral, water movement, and substrate size and condition, and seek to answer the following questions:

1. Is coral recovering naturally in rubble fields in KNP?
2. Is there potential for coral recovery, i.e. source larvae?
3. How does current strength affect natural recovery?
4. Do soft corals help or hinder hard coral recovery?
5. Can we enhance coral recovery with reef rehabilitation techniques?

Taken together, these linked objectives will allow us to determine factors influencing coral recovery. We predict that the succession of a reef community will begin once the structural foundation of the reef is reestablished, given adequate source coral populations.

2. MATERIALS AND METHODS

2.1 Study Area

To monitor accurately the recovery of the reef community from anthropogenic impacts, the study requires a well-managed marine reserve that is no longer being heavily blasted. Located in eastern Indonesia between the major islands of Sumbawa and Flores, Komodo National Park (KNP) fulfills this need. The park encompass areas where blast fishing has occurred at varying levels since the early 1950s, declining dramatically due to efforts by The Nature Conservancy. In 1996, weekly patrols were established to monitor extractive activities in the park and enforce the ban on destructive fishing practices. In addition, a coral monitoring program was established to evaluate the reef environment of KNP and map the extent of damage by destructive fishing methods. The coral monitoring project and relatively high level of protection that KNP now enjoys, combined with the many, diverse sites that have been heavily damaged by blast fishing, make KNP an ideal site to conduct the bulk of this research, which began in January 1998.

2.2 Methodology

1. *Is coral recovering naturally in rubble fields in KNP?*

Nine large (~300 m^2) rubble fields approximately 8-10 m deep in areas with a wide range of current strength were selected (Figure 1). Using video surveys and line intercept transects, we have estimated benthic cover within the site and at 6 control areas nearby that have higher coral cover. Natural recruitment is assessed every six months by counting and measuring the size of hard coral recruits in ten, randomly located 1 x 1 m quadrats and in four, 1 x 1 m permanently marked quadrats.

2. *Is there potential for coral recovery, i.e. source larvae?*

Levels of source larvae are being assessed with settlement tiles. Five pairs of 10 x 20 cm terra cotta settlement tiles are installed within the blast site and at the control area, and are collected and replaced every 6 months. Each pair is vertically oriented with a gap of approximately 1 cm between the tiles to create an environment favourable to coral settlement (Harriott and Fisk, 1987). Collected tiles are examined with a dissection microscope and location on the tile, size (measured with a micrometer in the microscope ocular), and family of the coral spat are identified to determine if recruitment rate is correlated to coral cover within the rubble field.

3. How does current strength affect natural recovery?

It is inferred that a primary reason for lack of coral recovery is the continued motion of unconsolidated substrate leading to abrasion or smothering of any recently-settled coral colonies (Clark and Edwards, 1995), however, the actual extent of movement has not to our knowledge been documented. In this case, we determined the extent of rubble movement and current strength to see how each relates to levels of coral recruitment to the rubble. At each site, 30 pieces of rubble were collected of each of three size classes. The rubble was painted bright yellow, weighed and measured, and placed at precise locations within each plot. Every 3-5 days after initial placement, the position of each rubble piece was re-measured. From this, the distance and direction of rubble movement per day was estimated. In addition, weighed blocks of dental cement were employed at all sites for the same 24 hour period, since the tides, and thus strength of current, is related to the lunar cycle. The blocks were then collected, dried, and re-weighed, in order to calculate the dissolution rate, which is correlated with current strength.

4. Do soft corals help or hinder hard coral recovery?

To determine if soft corals are inhibiting or facilitating hard coral growth, soft coral removal plots and permanent mixed soft and hard coral quadrats have been established. At each of two sites, soft coral colonies were cleared from the underlying rubble in seven, 1x1 m and two, 2x2 m quadrats. Four, 1x1 m control plots and six, 1x1 m “mixed” plots of approximately 50% soft coral and 50% hard coral were also marked. The number, size, and taxa of hard coral recruits were identified at all plots. In four of the 1x1 m plots and one 2x2 m plot, soft coral was re-cleared monthly; in the other removal plots it has been allowed to recolonize the bare rubble naturally. Sites were established, surveyed, and photographed in November-December 1999, and were re-surveyed and re-photographed in April 2000.

5. Can we enhance coral recovery with reef rehabilitation techniques?

Methods to stabilize loose rubble in 1x1 m plots are being examined. Two to four replicates of each of the following locally available treatments were installed at each blast site in April or October 1998: a) fishing net pinned to the rubble, b) cement slabs, half of which had pieces of coral rubble inserted for greater surface complexity and c) piles of rocks. There are also four untreated controls per site. These sites are revisited every six months to measure size, number, and taxa of corals recruiting under the different treatments in comparison with untreated, control areas. The material costs, time, and labor necessary to install each treatment is also being recorded, for cost-benefit analyses. Statistical analyses (repeated measures ANOVAs) have been performed to determine the most effective rehabilitation treatment.

Based on the pilot studies, rocks were found to be the most practical and effective rehabilitation treatment. At each of the 9 blast sites, 3-4 larger rock piles of approximately 1-6m^3 were installed April-May 2000. These have been piled high (70-90 cm) in an attempt to avoid rubble burial. Bamboo stakes have been driven in leaving exactly 40 cm above the rubble surface and are re-measured every 1-2 months, in order to monitor if rubble is getting deeper or shallower at each location.

3. INITIAL RESULTS AND DISCUSSION

3.1 Natural Recovery

Preliminary data analysis of the line-intercept transects clearly shows the high amount of rubble, and low cover of hard corals (Figure 2). Although site 4 appears to have less rubble, there is in fact rubble underlying the soft coral abundant at that site. In general, there is low natural recruitment at all sites.

3.2 Source Corals

Results from the settlement tile studies indicate that even in rubble fields with extremely low coral cover, source larvae are in the water, so there are potential coral recruits at all sites. There is no correlation between "potential" recruits, i.e. the coral larvae in the water as assayed by the settlement tiles, and "actual" recruits to the bare rubble fields.

3.3 Rubble Movement and Current

Based on the marked rubble studies, pieces of rubble move several cm per day at all sites, with some pieces moving 10-15, or even 50 cm per day. Results from the bamboo stakes hammered to a known height above the rubble indicate a constant shifting landscape (Figure 3). Over the course of each 1-2 month monitoring period, the rubble becomes approximately 2-10 cm deeper or shallow, with no consistent pattern. Clearly, even in low current areas, this amount of rubble motion is sufficient to abrade or bury small coral colonies that had settled on the rubble. Indeed, sites with stronger current (based on the dissolving blocks) and greater rubble movement have lower natural recruitment (Figure 4).

3.4 Competition with Soft Coral

Results from the April 2000 re-survey show statistically greater numbers of hard coral recruits per square meter in quadrats cleared of soft coral (Figure 5). This would suggest that soft coral is competing with hard coral, at least in the short term. Sites would need to be followed for an extended period to determine whether soft coral can facilitate hard coral recovery by stabilizing the loose rubble.

3.5 Rehabilitation Treatments

Overall results indicate that there is good potential to rehabilitate destroyed reefs in Komodo National Park. At all nine sites, chosen to broadly represent rubble fields in the Park, there was increased coral recruitment to the treatments, as compared to untreated, bare rubble (Figure 6). In some cases, recruitment (number of colonies per square meter) was over 20 times higher in the experimental plots than on untreated rubble. However, in some cases the cumulative movement of the vast rubble fields encroached on, or even buried completely, the experimental plots, perhaps because they were too small. The larger rock piles showed considerable recruitment of hard corals after only 5 months (Figure 7), with 10-20 recruits per square meter at some sites. Most recruits are Acroporids or Pocilliporids, with fewer Porites or other massive corals. This rapid colonization suggests that transplantation would be unnecessary in KNP, and that creating stable, 3-dimensional substrate is sufficient to enhance coral recruitment.

By continuing to monitor where, when, and how rubble moves, as well as track the recruitment to the larger rock piles, we hope to be able to construct and place rehabilitation treatments that will be resistant to rubble burial. Techniques that result in enhanced regeneration can lead to management measures and policy decisions to accelerate rehabilitation of reefs. This will be valuable not only in Komodo but also in other regions in Indonesia, Southeast Asia, and Oceania that have been damaged by a history of blast fishing but currently have successful enforcement and alternative livelihood programs to reduce future damage.

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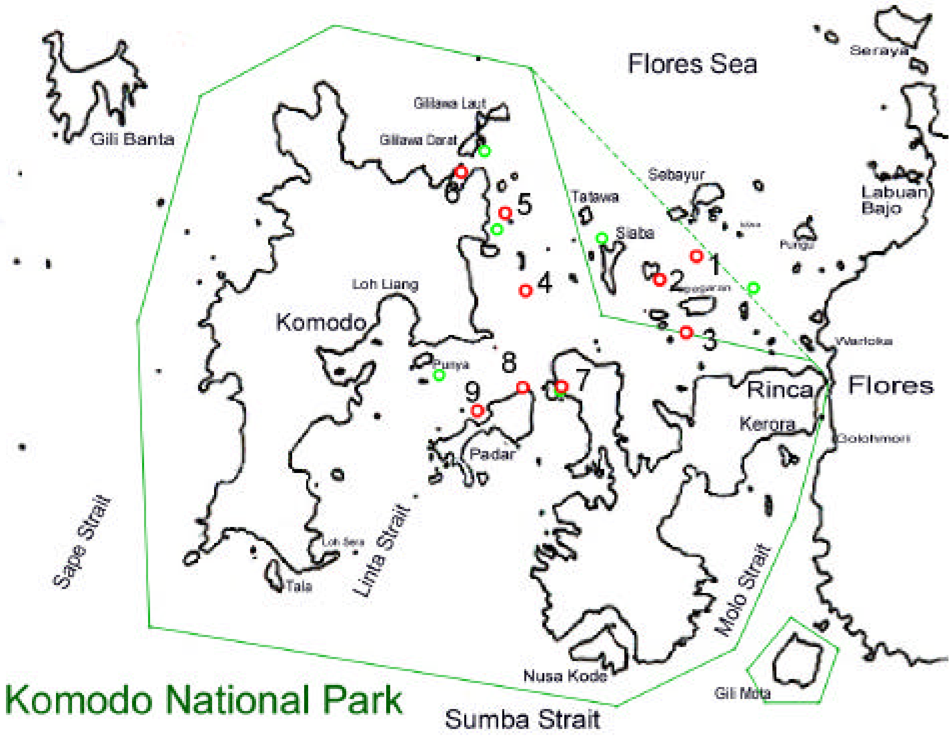

Figure 1. Locations of the nine rubble field sites (numbered red circles) and comparison sites with higher live coral cover (green circles).

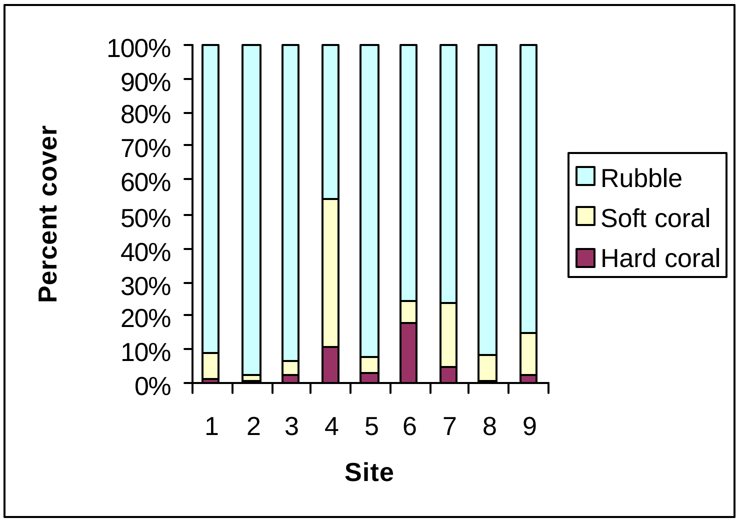

Figure 2. Percent cover of rubble, soft coral, and hard coral at each of the rubble field sites. Note the extremely low level of hard coral (Scleractinia). The soft coral in site 4 is growing on top of underlying rubble.

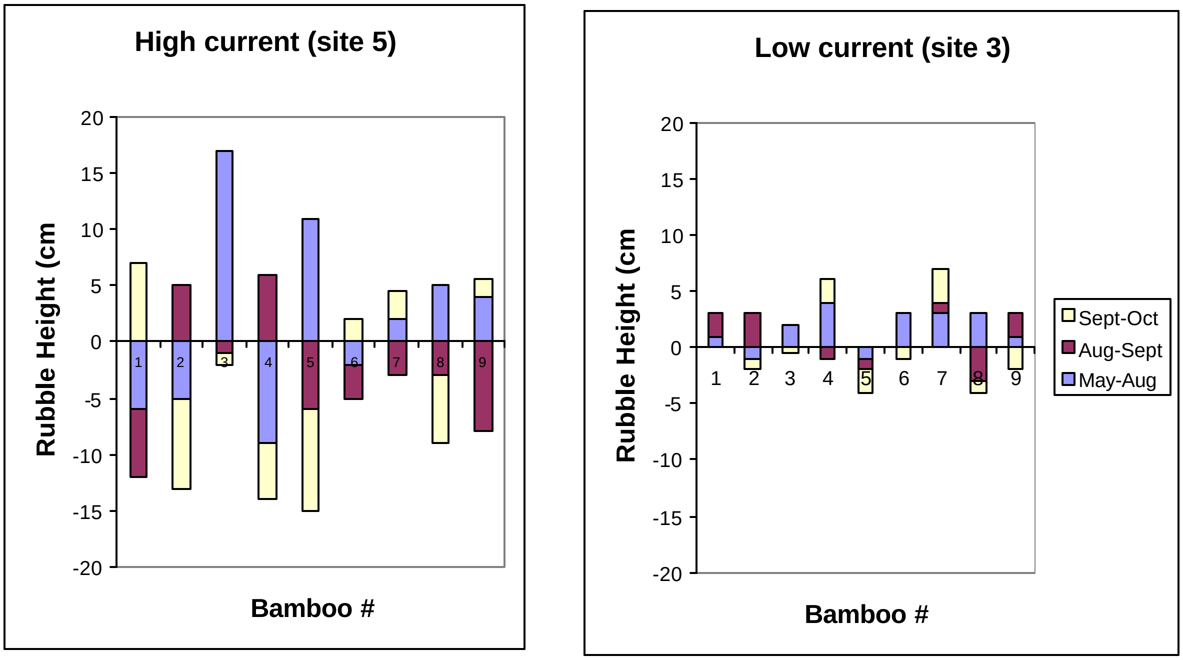

Figure 3. Change in height of rubble (in cm) at each of 9 bamboo stakes within high current (left) and low current (right) blast sites based on 3 survey periods May-October 2000. Note that there is not a consistent pattern of the rubble getting deeper or shallower.

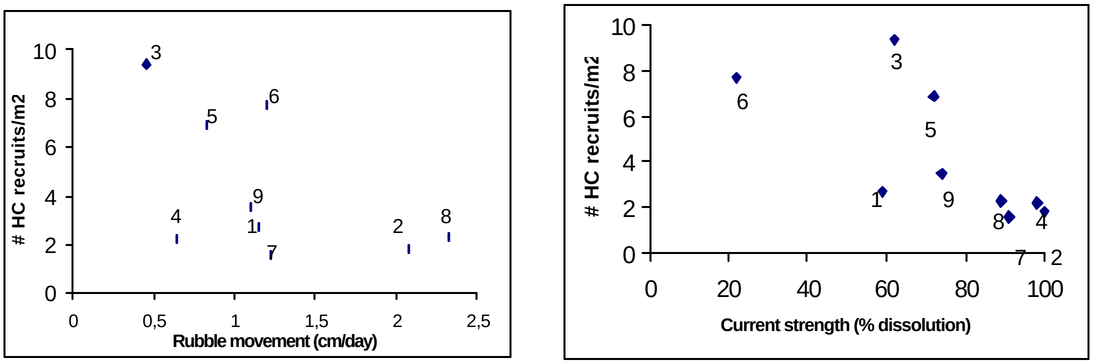

Figure 4. The relationship between average numbers of coral recruits per square meter to rubble movement (left) and current strength as measured by dissolving blocks of dental cement (right). Note that the stronger the current and greater the rubble movement, the lower the natural recruitment.

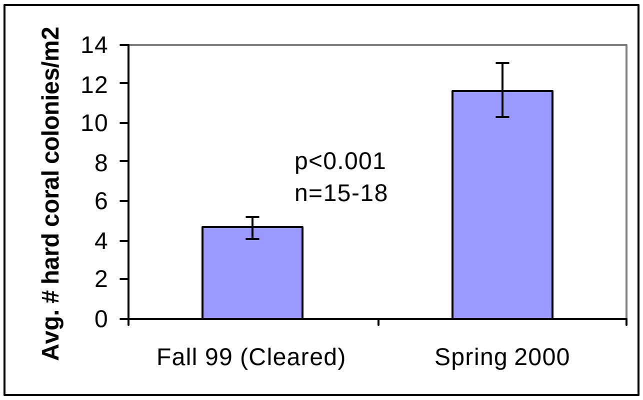

Figure 5. Results from soft coral removal studies. Plots that had been cleared of soft coral colonies showed subsequent increases in number of hard coral colonies (right) as compared to when newly cleared (left).

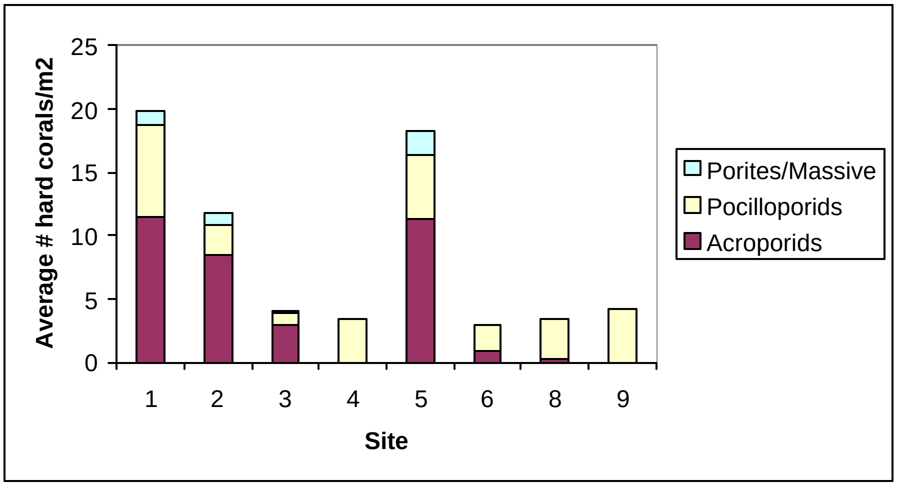

Figure 7. Average number per square meter of dominant families of hard coral recruits after 5 months (May-October 2000) to larger rock piles at rubble field sites in KNP.

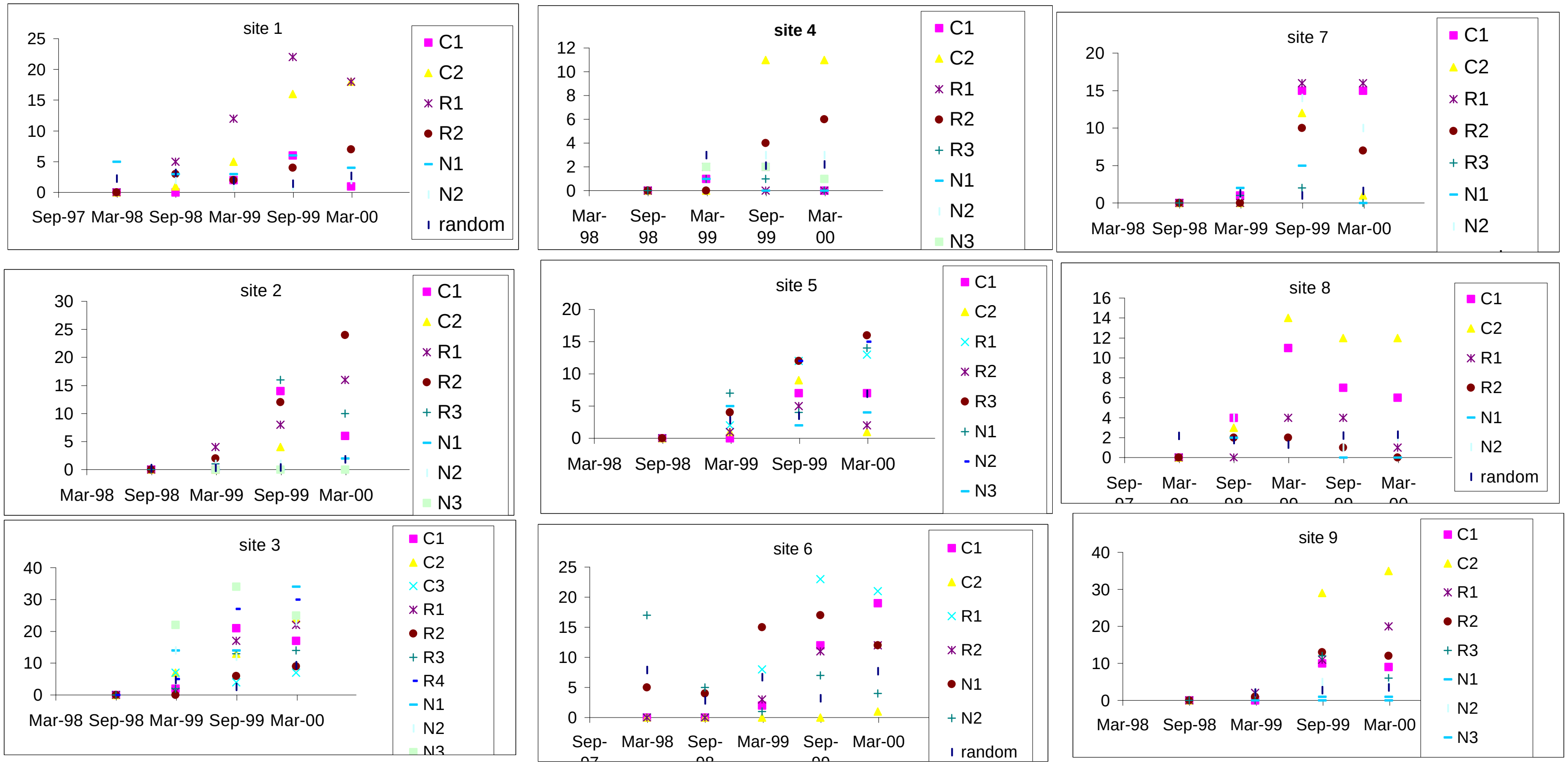

Figure 6. Number of hard coral recruits (y-axis) per survey period on untreated rubble (random) and replicates of cement slabs (C), piles of rocks (R) or netting pinned on the rubble (N)