Vertical Movement of Invertebrates from the Hyporheic Zone and Its Importance in Stream Colonization

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Abstract

The contribution to substrate colonization of the vertical migration of invertebrates from the hyporheic zone was studied at ten sites over a six week period in Tenderfoot Creek, Gogebic County, Michigan. Wire-mesh trays filled with invertebrate-free substrates were placed on cleared areas of the streambed to provide a natural environment for invertebrate colonization. Experimental trays were lined with fine mesh plastic, whereas the controls were not lined.

Neither treatment (control vs. experimental) nor time interval (three vs. six weeks) had a significant effect on invertebrate colonization. Rates of colonization were found to be relatively constant and rapid over the six week period. Differences existed in the number of colonized organisms in two sites, possibly due to the differences in detrital accumulation. Herbivores were found to be the initial colonists of substrates. Analysis of the data for specific genera and treatments revealed that an emergence of one genera was immediately followed by the colonization of another.

This study showed that the hyporheic zone was not a significant contribution to the colonization of benthic substrates in Tenderfoot Creek.

Colonization can be defined as "the invasion of species into disturbed and newly created habitats" (Mayr 1964). Streams are continually altered by seasonal changes. In addition, storms and chemical pollutants can affect a streams's physicochemical variables. These disturbances are major factors in the reorganization of ecosystems (Pickett and White 1985) as the existing populations lose their immediate environment and the resources available to them (Sousa 1984; Resh et al. 1988). The power of such natural disturbances may remove attached organisms from sediments (Fisher et al. 1982) and displace or kill benthic macroinvertebrates (Siegfried and Knight 1977). Thus, biotic processes within a stream must be able to respond to these changes. The presence of such processes is evident in temporary and disturbed streams that respond to perturbations via colonization. Studying the response patterns of species abundances to variations in habitat complexity may provide further information on the mechanisms responsible for significant species-habitat complexity relationships (Tonn and Magnuson 1982).

Studying a highly variable environment can be accomplished using simultaneous placement of experimental trays (Ulfstrand 1968). Simultaneous placement of artificial substrates allows experimental and control trays to be placed in the stream at the same time and removed at a predetermined time. Such an approach will allow the monitoring of seasonal changes in species composition and species richness. Species colonization is rapid with representatives of most species colonizing within the first three days (Townsend and Hildrew 1976; Ciborowski and Clifford 1984; Clements et al. 1989). Complete colonization, however, takes approximately 28 days (Williams and Hynes 1976; Williams 1977). The observations of rapid colonization agree with those of Diamond and Reice (1985) who found a decrease in the variability of taxa once a rock was colonized. The above findings, however, differ with those of Thorp et al. (1985) who found that the number of principal taxa increased over time. In addition, rates of colonization have been found to be species-specific (Peckarsky 1986). Maintaining a relatively constant stream insect fauna in streams following physicochemical changes depends on the success of insect colonization.

Sources of colonization are continually being studied in an effort to establish colonization mechanisms as well as to determine how and why insect dispersal is possible. One of the major sources of colonizing insects in streams is movement patterns (Delucchi 1989). Patterns such as downstream drift, aerial dispersal and lateral and vertical movements within the substrate allow organisms to establish themselves in a variety of ways. However, Brooks and Boulton (1991) found that vertical migration rather than drift appeared to be the major source of recolonizing fauna. One aspect of movement, of which little is known, is the vertical movement of species from deep substrates. Williams (1977) discovered that the existence of vertical movements from within the substrate is the main source of organisms in the recolonization of a temporary stream. As a stream dries up, organisms burrow below the streambed to an area known as the hyporheic zone. Here, they remain dormant until water returns and recolonization of the streambed surface can begin. Therefore, the hyporheic zone has proven to be a critical refuge for invertebrates when conditions in overlying areas are unfavorable (Williams and Hynes 1974). Although the existence of the hyporheic zone has been linked to the potential colonization of temporary streams, little is known about the movements from the zone and its importance in permanent streams. It has been hypothesized that vertical movements could prove to be important if taxa are found within the substrates (Williams and Hynes 1974). Existence of organisms in the hyporheic zone and their vertical movement to the surface is an important aspect of stream colonization.

Methods and Materials

A section of Tenderfoot Creek, Gogebic County, Michigan, located on the University of Notre Dame Environmental Research Center (UNDERC) property was chosen as the site for this experiment. Ten sites representing four distinctly different habitats were used. The sites were chosen to exemplify colonization rates within fast flow, slow flow, vegetated, and sandy areas. Forty, 0.093 m screen-bottomed (1.35 cm) wooden trays were obtained from the UNDERC supplies and were filled with invertebrate-free substrates. The trays were placed on the surface of the streambed as to provide as natural an environment as possible for colonization. Rocks surrounding the area of placement were washed of any invertebrates, algae, and sediments and then placed in the trays. Trays were then left for three or six weeks depending on the tray's treatment.

Twenty trays had durable black gardener's plastic stapled onto their frames. The fine mesh plastic contained holes small enough to allow for water flow but were too small to allow invertebrates to pass through. Trays of this nature were the experimental trays. The remaining twenty trays, the controls, had no plastic and allowed for invertebrate colonization via normal water movements. The control trays had red flags stapled onto them and the experimental trays had yellow flags thus facilitating identification of the treatments. Trays were collected in two groups: twenty after three weeks of colonization (ten controls, ten experimentals) and twenty after six weeks (ten controls, ten experimentals). An additional blue flag was added to twenty trays marking them as the trays to be removed after three weeks. Likewise, green flags were placed on the remaining twenty trays identifying them as the six week group. When the trays were placed at the various habitats, four trays were placed at each site, a set of three and six week trays (two controls and two experimentals). To avoid disturbance of the trays when it came time for removal, the six week trays were placed in front of the three week trays. The trays were placed so that a three week experimental tray was always found downstream of a six week control tray and a three week control was always found downstream of a six week experimental tray.

Site 1 and 2 were the farthest upstream and represented the fast flow riffle area. Just downstream sites 3,4,5 and 6 were placed to display characteristics of a medium flow riffle area. Site 7 was located within a stand of cattails representing the vegetated area. Two more sites, 8 and 9, were placed in a medium flow, rocky area of the stream. The final site, site 10, was placed in a sandy area near the right bank of the Creek.

Placement of the trays took 2 days. After three weeks (19 days), two of the trays from each set (one control, one experimental) were removed. The trays were approached from the downstream side to avoid disturbing the remaining two trays. A Surber net was placed immediately downstream of each site to catch any organisms that were dislodged when the trays were removed. The rocks of each tray were then placed in a bucket and washed of any invertebrates before being returned into the creek. Sediments with organisms were then sieved through an aquarium net (mesh of 480 m), placed in jars with 80% ethanol, and taken back to the laboratory. In laboratory, the sediments were sorted, and organisms were placed in fresh 80% ethanol. Three week samples were subsampled and identified to genus when possible under a dissecting microscope (10X) during the three week interim period. Core samples were attempted in the areas representing the four different habitats; however, the shallow nature of the streambed and hardness of the bedrock inhibited sampling. Removal of the six week trays was conducted in the same manner as the three week ones. Differences in invertebrate abundance and number of taxa between the four habitats on Tenderfoot Creek were analyzed using one-way ANOVA's.

Results

The number of organisms from the six week experimental tray at site 1 was not included in the calculations because the tray was washed downstream. As for the remaining nineteen trays, the experimental and control were not significantly different at each site. Between the three and six week experiments, there were no differences in the treatments. In addition, there were no differences between the number of organisms colonized in the experimental or control trays pooling dates and sites. The same conclusion was drawn between the number of organisms within the three and six week trays; no difference existed. However, there was a significant difference in the number of organisms colonized at site 3 versus site 6 (P=0.046). Site 6 had the largest number of colonized invertebrates while site 3 had the smallest number. The other eight sites were not significantly different from each other. Examining diversity between three and six weeks, revealed no significant difference. However, when the change in the number of organisms within a specific genera and treatment were examined, significant differences were found. When analyzing the control treatments, three genera were found to be significantly different over the six week period: Baetis sp. (P=.005, range 0-42), Diplectrona modesta (P=.000, range 0-74), and Chimarra sp. (P=.049, 0-42). In contrast, the experimental treatments showed Diplectrona modesta (P=.000, range 0-72), Chimarra sp. (P=.000, range 0-58), Baetis sp. (P=.000, range 0-8), and Stenelmis sp. (P=.023, range 0-3) were significantly different between the three and six week periods. All the remaining genera found within the experiment showed no significant difference.

Discussion

The colonization of all trays, control and experimental, occurred quickly. Previous studies have reported that colonization can take place within three days of the placement of colonization trays (Ciborowski and Clifford 1984; Clements et al. 1989; Townsend and Hildrew 1976). It has been suggested that colonization of a disturbed area may occur rapidly due to immigration of organisms from areas in close proximity of the trays (Lamberti et al. 1991). Throughout the experiment, the number of species colonizing trays did not vary significantly between three and six weeks. Relatively constant, colonization rates could be a result of the "colonization cycle" proposed by Muller (1954). This cycle suggests that various movement patterns act as a means of keeping population densities in balance with the carrying capacity of a stream.

When an ecosystem begins to recolonize, herbivores tend to be the first macroinvertebrates present within the first year (Lamberti et al. 1991). This explains why 14 out of 21 taxa found over the six week experiment were classified primarily as herbivores (Merritt and Cummins 1984).

When looking at the significant differences between sites three and six, the amount of available detritus could be important. Detritus is a major source of food for invertebrates. Thus, there could be a direct relationship between the number of colonists and the amount of detritus available to the organisms (Hynes 1970). Although there were accumulations of detritus at all sites in Tenderfoot Creek, site 6 had more than the other sites (E. Vogel personal observation). Site 6 was immediately downstream from a submerged log that was decaying, whereas site three was on the other side of the creek, away from any influence of the submerged log. Thus, the availability of detritus, combined with the fact that site 6 was in deeper, faster flowing water, which lends itself to higher colonization rates, could explain the difference in numbers (Peckarsky 1986). At the end of six weeks (after the spring's high water receded), site 6 still had a moderate discharge covering the trays while site three had a reduced pace from that of the preceding three weeks.

Finding that there were no significant differences in the numbers of organisms colonizing the control and experimental trays leads to a rejection of the initial hypothesis that organisms in the hyporheic zone and their vertical movement to the surface is an important aspect of stream colonization within Tenderfoot Creek. A possible explanation could be that eliminating the variable in question may not have been sufficient to detect colonization differences. It is likely that any colonization that occurred due to the other three drift mechanisms (aerial dispersal, lateral movement, and downstream drift) could have obscured any contribution by the hyporheos via vertical movement. This could be tested by eliminating all of the variables except vertical movement. Set-up for this experiment would consist of using pot samplers under the streambed (Coleman and Hynes 1970). However, due to the shallowness of the bedrock, this approach would not be practical in Tenderfoot Creek. When Delucchi (1989) studied the hyporheic zone, she also found vertical movement to and from the hyporheic zone to be insignificant.

After finding no significant differences in the number of organisms colonized within the control and experimental trays, analysis of the effect of treatment on specific genera was examined. As seen in the results section, three genera were shown to be significantly different within the controls while four genera were significantly different within the experimentals. When examining the placement of the four genera at all of the sites, it appears that Diplectrona modesta existed primarily during the first three weeks while Chimarra sp. was prevalent during the last three weeks. It is possible that Diplectrona modesta emerged within the first three weeks; and in its absence, Chimarra sp. colonized. Both Trichoptera are classified as clingers that either have sac-like nets or fixed retreats. Each consumes detritus via filtering for their diet, and both colonize the underside of submerged rocks within riffle areas (Merritt and Cummins 1984). According to Wiggins (1977), Diplectrona modesta prefers cooler streams than that of Chimarra sp.. This could explain why Diplectrona modesta was found earlier in the summer when the water was colder. As for the other two significant genera, a similar situation exists. Both Baetis sp. and Stenelmis sp. are clingers and scrapers. It is possible that, as in the situation above, the Baetis sp. emerged and their territory was recolonized by Stenelmis sp.. Both of these situations are a possiblity due to the characteristics of the organisms; however, further analysis is needed to verify it.

After studying Lamberti et al. (1991), it is difficult to tell whether of not this study represented a "natural disturbance". Before placing the trays on the substrate, all organisms were washed away from the rocks, thus leaving a "clean" surface for colonization. Also, it is presumable that all existing organisms and structures surrounding the site were disturbed when the trays were placed. If this true, the habitat may have been destroyed and thus the experiment would represent a truly recolonized habitat. Within my experiment, Cheumatopsyche sp. dominated all sites (collected in 38 of the 39 sampled trays). Such dominance of one species seems strange, however, Clements et al. (1987) found that Cheumatopsyche sp. was the most prevalent organism found in rock trays. Sousa (1984) proposed that a recovering ecosystem may contain organisms that existed prior to and withstood the disturbance. Such an idea could explain the significantly higher numbers of Cheumatopsyche sp. However, a clear evaluation of this idea cannot be obtained due to a lack of previous representative samples, limited timing within the stream this summer, and an inability to continue sampling (Lamberti et al. 1991).

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Table 1. Taxa Found In Tenderfoot Creek

Organized according to Merritt and Cummins (1984)

Order Ephemeroptera
- Family Baetidae
  - *Baetis* spp.
- Family Oligoneuriidae
  - *Isonychia* sp.

Order Odonata
- Suborder Anisoptera
  - Family Aeshnidae
    - *Boyeria* sp.
  - Family Gomphidae
    - *Ophiogomphus* spp.
    - *Progomphus* sp.

Order Plecoptera
- Family Perlidae
  - *Acroneuria* spp.

Order Megaloptera
- Family Corydalidae
  - *Nigronia* sp.

Order Trichoptera
- Family Hydropsychidae
  - *Cheumatopsyche* spp.
  - *Diplectrona* sp.
  - *Hydropsyche* spp.
- Family Leptoceridae
  - *Ceraclea* spp.
- Family Limnephilidae
  - *Pycnopsyche* spp.
- Family Philopotamidae
  - *Chimarra* spp.
- Family Polycentropodidae
  - *Nyctiophylax* spp.
  - *Polycentropus* spp.

Order Coleoptera
- Family Elmidae
  - *Stenelmis* spp.

Order Chironomidae

Other organisms found:
- Crayfish, leeches, Oligochetes and Adult Caddisflies

Fig. 1 Total # of Organisms Colonized Over 6 Week Period

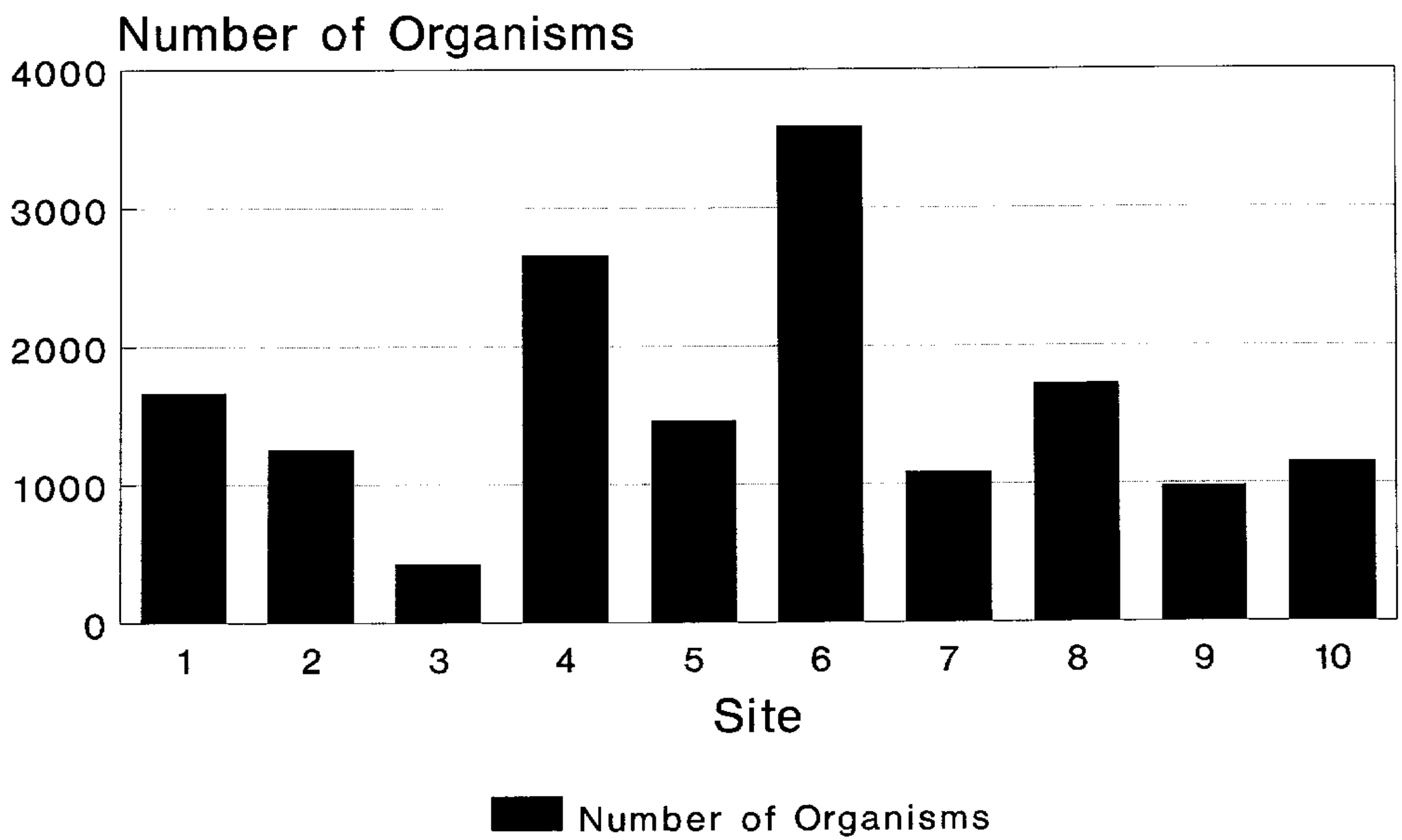
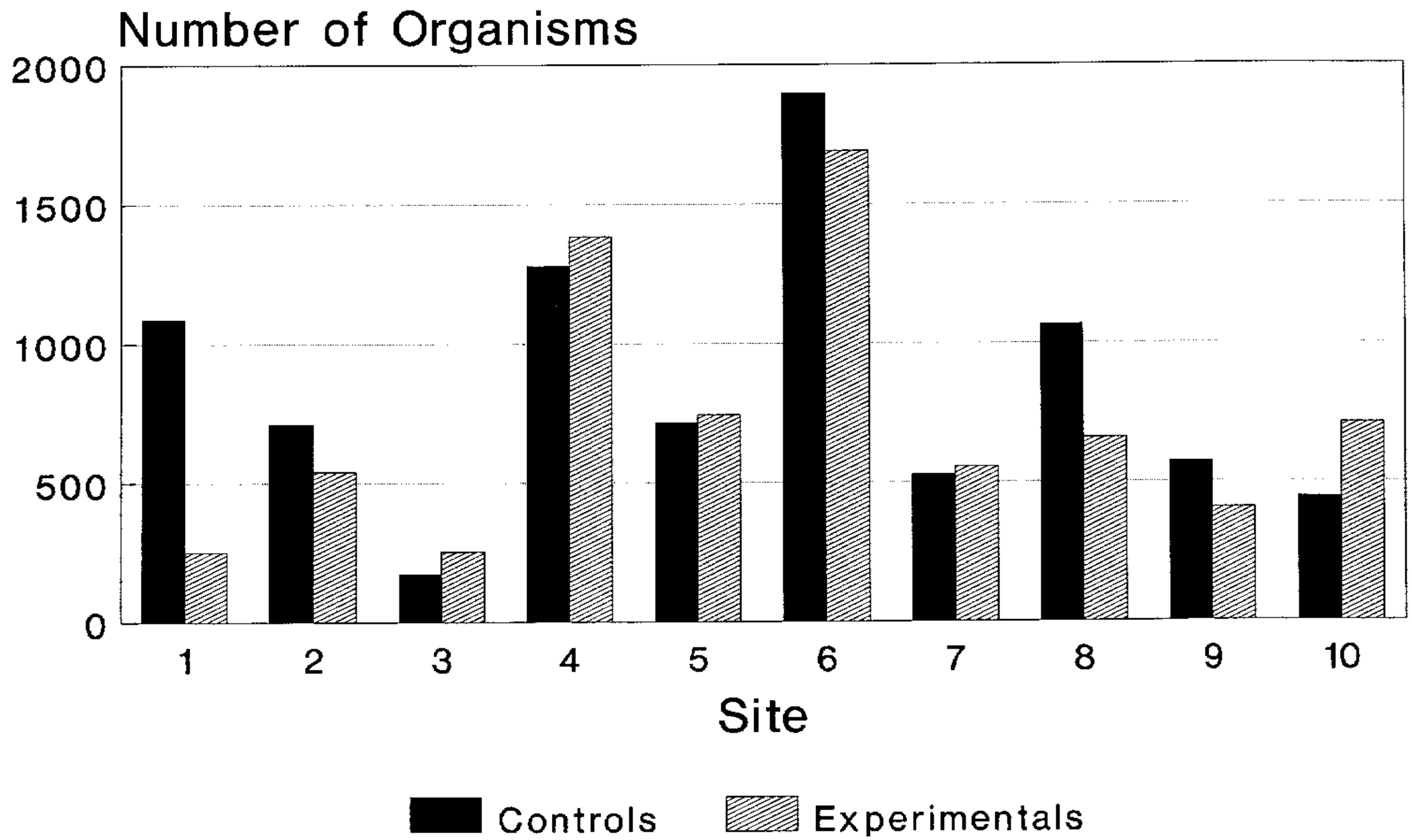
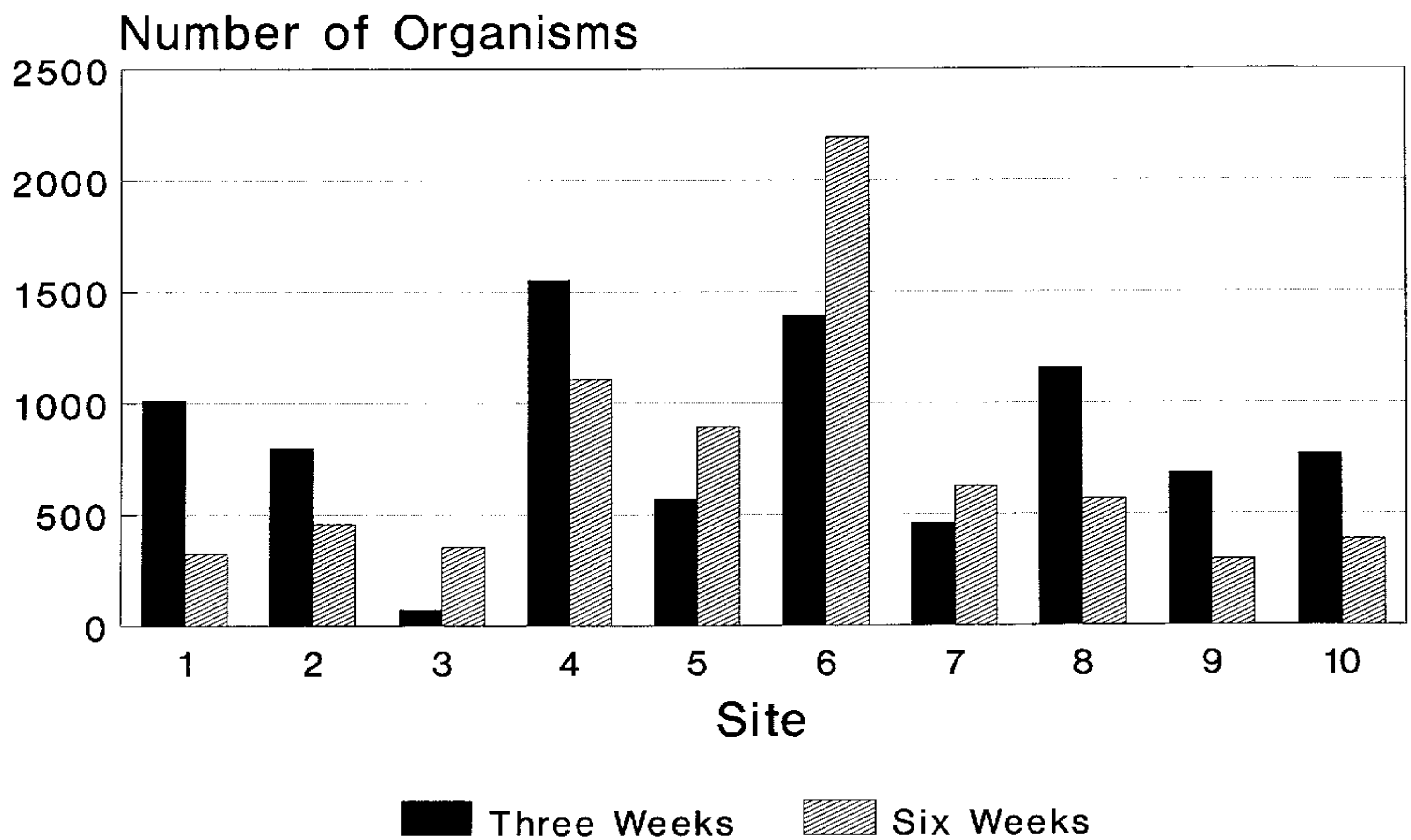


Fig. 2 Total # of Organisms According to Control and Experimental Treatments



Site 1- 6 Week Exp. Tray Dislodged

Fig. 3 Total # of Organisms Colonized After 3 and 6 Weeks



Site 1- 6 Week Exp. Tray Dislodged