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Abstract

The Malibu Creek watershed, located approximately 35 miles west of Los Angeles, California, has been subjected to rapid development in recent decades. Concurrent with this development, several streams within the watershed have become degraded by nuisance algal growth. We conducted a study of streams in the Malibu Creek watershed to quantify algal biomass and algal cover, to characterize the species composition of algal communities, and to determine the principal factors promoting excessive algal growth.

We surveyed the biomass, percent cover, and species composition of benthic and floating algae, and measured nutrient (nitrogen and phosphorus) levels and physical parameters in streams in the Malibu Creek watershed in August and October 2001 and in June and August 2002. We chose stream sites with different surrounding land use patterns representing different degrees of human influence. Sites included reference, rural, high density residential, and commercial land use, as well as sites near horse stables, a golf course, multiple land use areas, and a municipal sewage treatment plant. In 2002 we also conducted a nutrient diffuser experiment at a subset of these sites to determine the existence of nutrient limitation (or lack thereof) and the identity of the limiting nutrient for algal growth limitation of algal growth in the watershed.

Algal biomass and macroalgal cover increased with increasing human influence. Algal biomass (as chlorophyll *a*) increased by three orders of magnitude from the reference sites (0.5 ±0.2 mg m^{-2} chlorophyll *a*) to sites greatly affected by human activities (up to 969.2 ±482.5 mg m^{-2}). Nutrient concentrations also varied by orders of magnitude, and were generally higher at the sites that were greatly modified by humans. A comparison of our data with literature thresholds for algal biomass indicates that most of the developed sites in the Malibu Creek watershed have chlorophyll a concentrations which exceed suggested thresholds for acceptable levels of chlorophyll. Only the reference, rural and horse sites had chlorophyll levels that were below these thresholds. Algal community composition changed dramatically with changes in light and nutrient availability; large floating mats of the macroalgae *Enteromorpha* and *Rhizoclonium* were found at sites with both high light and high nutrient levels. Multiple regression analysis indicated that the biomass of benthic algae was positively related to nutrient concentrations and current speeds, whereas the biomass of floating algae was positively related to light and nutrient levels and negatively related to current speeds. Total algal biomass was positively correlated with nutrient concentrations and light levels. The nutrient diffuser experiment showed N limitation at the reference site and the site below the Tapia water treatment plant, but we observed no algal biomass response to nutrient enrichment at other developed sites, suggesting that algal biomass at those sites was not nutrient limited. Drastic reductions in N or P loading at these sites may be required to reduce nutrient concentrations to sufficiently low levels to limit algal growth. Our results also strongly suggest that benthic and floating algae respond to different physical and chemical variables. Because blooms of both types of algae can reduce stream water quality, regulatory agencies should consider both types of algae when formulating management plans. Management of algal growth must be considered on a site-by-site basis, taking into account the types of algae causing nuisance blooms as well as the nutrient inputs and other environmental conditions, such as light levels and current speeds, which regulate algal growth.

Introduction

Human development and associated anthropogenic activities in watersheds can affect stream systems in a variety of ways. Changes in the physical and chemical environment of streams (Paul & Meyer 2001) through increased nutrient loading, and altered flow rates, stream channels and riparian habitat can engender nuisance algal blooms. For example, channelization of streams for flood control purposes and the removal of riparian vegetation increase light levels and temperatures on the bottom of the streambed, and both of these factors can boost algal production and cause stream community changes (Hill 1996, DeNicola 1996, Stevenson et al. 1996). Nitrogen (N) and phosphorus (P) concentrations in stream water can also increase as a result of agricultural and urban runoff, the wet and dry deposition of atmospheric nutrients, and industrial activity. Because the growth of stream algae is commonly limited by N or P availability, elevated concentrations of these nutrients in streams due to human activities are among the most frequent causes of nuisance algal blooms (Borchardt 1996, Carpenter et al. 1998).

High algal biomass can have many negative impacts on streams, including impacts on ecological functioning and recreational use. For example, algal blooms can create extreme daily variation in dissolved oxygen levels, from supersaturation during daylight hours to hypoxia at night, which can be harmful or fatal to aquatic invertebrates and fish (Welch 1992). In addition, nuisance levels of algae can hinder recreational activities such as fishing, wading, boating, and aesthetic appreciation.

Growth of algae in individual streams, or even reaches of streams, may be limited by N alone (Grimm and Fisher 1986, Lohman et al. 1991), P alone (Bothwell 1985, Peterson et al. 1985, Stanley et al. 1990, Borchardt 1996), N and P together (Winterbourn 1990), or some combination of other physical and chemical factors (Lowe et al. 1986, Welch et al. 1988, Duncan & Blinn 1989), such as light availability, water velocity, or disturbance regime. Because the relationship between nutrients and algae in any particular stream can be complex and difficult to predict based on studies in other stream systems (Dodds et al. 2002), the question of nutrient limitation of algal growth and biomass must be addressed on a case-by-case basis.

Multiple monitoring and experimental methods exist for assessing nutrient limitation in streams. Molar N/P ratios in stream water can be useful indicators of which nutrient limits algal biomass (Grimm & Fisher 1986, Hill & Knight 1988, Peterson et al. 1992) although, in some cases, N/P ratios have not been congruent with the limiting nutrients identified by experimental studies (Allen & Hershey 1996, Francoeur et al. 1999). Nutrient diffusing substrata (NDS) can effectively determine nutrient limitation for benthic algae (Pringle & Triska 1996, Francoeur 2001). NDS are particularly useful because they directly measure benthic algal responses to localized nutrient enrichment without altering nutrient conditions in the entire study stream. Finally, regression analyses can be used to elucidate relationships between ambient algal biomass and nutrient levels among stream sites (Dodds et al. 2002).

The Malibu Creek watershed, located approximately 35 miles west of Los Angeles, California, has been subjected to rapid development in recent decades. Concurrent with this development, several streams within the watershed have been characterized by nuisance algal growth (California EPA, 1998). We conducted a study to address two principal questions: 1) What are the types and biomass of algae present in streams in the Malibu Creek watershed? and 2) Which nutrients and nutrient levels, if any, engender increases in algal biomass in streams in the Malibu Creek watershed? Because there were few data available on the composition and abundance of algae in the Malibu Creek watershed, we surveyed algal biomass, percent cover, and species composition in streams draining this watershed. Simultaneously, we monitored physical conditions and water chemistry in these streams and assessed the identity and degree of nutrient limitation of algal biomass by examining the molar N/P ratios in stream water, by analyzing the results of nutrient diffusing substrata experiments, and by conducting regression analyses using algal abundance as the dependent variable and levels of nutrients and physical parameters as the independent variables. Because physical conditions and nutrient inputs to a stream vary with land use patterns and have known effects on algal communities, we hypothesized that stream reaches draining different land use types would show different patterns of algal species composition and nutrient limitation. Therefore, we assessed algal communities and nutrient limitation at a suite of sites, representing the principal land uses present in the Malibu Creek watershed. Because algal communities can change seasonally and inter-annually, we conducted this work in different seasons, spanning two different years (2001 and 2002).

Methods

Watershed description

The Malibu Creek watershed is located on the coast of southern California, approximately 35 miles west of Los Angeles. The Malibu Creek basin encompasses approximately 109 square miles and Malibu Creek ultimately flows into the Pacific Ocean. Malibu Creek ranges in elevation from roughly 3000 feet in the Santa Monica Mountains down to sea level at Malibu Lagoon, which forms the mouth of the creek. The watershed has many undeveloped areas, but there is a high degree of development along portions of major tributaries of Malibu Creek. For example, there is a corridor of concentrated commercial development along State Highway 101, which cuts through the center of the watershed in an east-west direction. In addition, there are areas of suburban residential development that fall partly or wholly within the watershed, in and around the towns of Agoura Hills, Westlake Village, and Thousand Oaks.

Site selection

2001

For 2001 we established a total of 12 stream sites for our algal survey, 11 within the Malibu Creek watershed and one just outside of it, in the adjacent Calleguas watershed (high density residential site 3) (Fig. 1). Ten of these sites were chosen based on immediate surrounding land use. These included 2 reference sites, 2 rural, low density residential sites, 3 suburban, high density residential sites, 1 commercial site, 1 horse stable site, and 1 golf course site (see Fig. 1 legend for detailed locations). The open space sites, which were surrounded by protected, undeveloped land, were considered to represent the reference condition. For comparison, all other sites had some degree of human-induced development. To assess the effects of a potential point source of nutrient inputs, we also established 1 site upstream and 1 site downstream of the Tapia Water Reclamation Facility (WRF), operated by the Las Virgenes Municipal Water District. Water chemistry, physical conditions, and algae were sampled twice at each site, once in August (August 22-24, 2001) and once in October (October 22-24, 2001).

2002

In 2002 we selected seven sites within the Malibu Creek watershed for our surveys and nutrient diffuser experiment (Fig. 1). As in 2001, these sites were selected to represent streams draining different land use types in the Malibu Creek watershed (1 reference site, 1 high density residential site, 2 commercial sites, 2 multiple land use sites, 1 site below the Tapia treatment plant). The two multiple land use sites on Las Virgenes Creek were influenced by both residential development and historical sludge injection fields. In addition, both of these sites were upstream of the Tapia wastewater treatment facility. Water chemistry, physical conditions, and algal cover, biomass, and species composition were sampled at a subset of five of these sites on June 24-25, 2002 (Reference 1, Residential 1, Commercial 1 and 2, and Multiple 2), and at all seven sites in August (August 27-28, 2002). Sites that were sampled in both 2001 and 2002 included the Reference 1, Residential 1, Commercial 1, and below Tapia sites.

We conducted the nutrient diffuser experiment at the following sites: Reference 1, Residential 1, Commercial 2, Multiple 1 and 2, and below Tapia sites. At each site we selected pools (where available) or slow runs (where no pools were available) for the deployment of the nutrient diffusers. Nutrient diffusers were also deployed at the Commercial 1 site but were destroyed twice preventing collection of any data.

Algal sampling

In 2001, at each site we established three cross-stream transects, each 10 m apart. In 2002, we assessed within-site variability in physical conditions (specifically light and current speed) by establishing three cross-stream transects in each of six habitat types, where possible: shaded pool, shaded riffle, shaded run, sunny pool, sunny riffle, and sunny run. At the reference site there were no entirely sunny or entirely shaded habitats, so we chose sampling locations to represent the broadest range of light conditions available. At the commercial sites there were no shady habitats present, because of stream channelization and the lack of riparian vegetation. There was a thick canopy cover at the Multiple 1 site, and only densely shaded habitats were available.

The percent cover of algae was assessed visually using the EPA Rapid Bioassessment Protocol (Barbour et al. 1999), which entails the use of an underwater viewing bucket with a grid of 50 dots on the clear, bottom surface. The type of algae underneath each dot was recorded. Percent cover was assessed at three equidistant points along each cross-stream transect. An average percent cover for each algal type was calculated for each transect, and the average of the three transects for each site (2001) or habitat (2002) was used as the percent cover of each alga present at each site or in each habitat. Macroalgae were identified to genus, and diatom films were classified as thin (<0.5 mm), medium (0.5 – 2.0 mm), or thick (>2.0 mm).

Benthic algae were sampled along each transect with a periphyton sampler modified after the sampler described by Davies & Gee (1993). Our sampler consisted of a 60 ml syringe with the bottom cut off (2.6 cm diameter). The bottom end of the plunger inside the syringe barrel was covered with Velcro, and circular scouring disks were affixed to the Velcro. The outer part of the syringe was placed on the sampled substratum, and the scouring pad on the end of the plunger was rotated 10 times clockwise and 10 times counter-clockwise so as to scrub off all periphyton on the substratum within the area circumscribed by the syringe and retain the periphyton within the scouring pad. Scouring pads with algal samples were then removed for subsequent laboratory extraction and analysis. Any remaining macroalgae attached to the substratum within the sampled area were removed with forceps and added to the sample.

In 2001, five evenly spaced subsamples were taken along each cross-stream transect, from the tops of rocks or other hard substrata (where no rocks were available), and five scouring pads were composited to make one sample per transect. If floating macroalgae were present at any subsampling location, the outer part of the syringe was used to bore a 2.6-cm diameter hole through the floating mat and the algae were retained for analysis. Floating macroalgae samples were also composited for each cross-stream transect. In 2002 we estimated the percent cover and algal biomass at each site for floating macroalgae and benthic algae, separately. Where floating macroalgal mats were present, we sampled both the mats and the benthic algae underneath the mats using the syringe sampler. Chlorophyll a concentrations were averaged for each transect, and the average of the three transects per habitat type was used as an estimate of chlorophyll a concentration for each habitat. Total cholorophyll a concentration for each transect was obtained by summing the chlorophyll a concentrations of floating macroalgae and benthic microalgae for each transect.

Algal analysis

2001 and 2002

The algal samples from 2001 and 2002 were analyzed using the same methods. In the laboratory, composited periphyton samples were rinsed from the scouring pads with deionized water and diluted to 850 ml. These composite samples were stirred thoroughly, and four, 200-ml subsamples were filtered through Whatman GF/C glass fiber filters for the analysis of cellular nitrogen and phosphorus content, and chlorophyll a concentration. The remaining 50 ml was preserved with 1 ml of 4% formalin for species identifications. Macroalgae present in samples were homogenized in 850 ml of deionized water using a Waring Commercial Blender model 31BL91 at high speed. Because these macroalgal samples were dense and filters clogged quickly, macroalgae sub-samples of 50 ml or less were filtered through GF/C glass fiber filters.

For analysis of N and P content (2001 only), filters with algal residue were oxidized using the Valderrama method (Valderrama, 1981), then analyzed for NO_3 and PO_4. Nutrients were measured spectrophotometrically on a Lachat QuikChem 8000 Flow Injection Analyzer using methods provided by the manufacturer (QuickChem Method 31-107-04-1-A for nitrate, and QuickChem Method 31-115-01-3-A for phosphate). All nutrient analyses were performed at the Marine Science Institute Analytical Lab at the University of California, Santa Barbara. Chlorophyll a was extracted with 90% acetone for 48 hours, then measured on a Turner 10-AU Field Fluorometer according to the EPA rapid bioassessment protocol for streams and wadeable rivers (USEPA 1992). To determine ash-free dry mass, filters were dried at 60° C for 24 hours and weighed; all organic material was combusted in a muffle furnace at 500° C for two hours, and the samples were then re-weighed.

Water chemistry sampling

2001 samples

In 2001 water samples were taken concurrently with algal samples from the downstream transect at each site. Samples for dissolved inorganic nutrients (NH_4, NO_3, and SRP) were filtered immediately through a 0.45 µm polycarbonate membrane filter (Poretics). Samples for total Nand P (TN and TP) were not filtered. All samples were held in the dark at 4 °C for 3-60 hours before and during transport to the laboratory, then frozen until analysis. In August 2001, samples from Residential Sites 1, 2, and 3 were held on ice for up to 60 hours before being frozen, whereas all other samples were held for <48 hours. In October 2001, water samples from the Rural 1 and 2, Reference 1, and below Tapia sites were held for up to 60 hours on ice, and all other samples were held for <48 hours.

2002 samples

In June 2002 we took samples from each habitat at each site to determine if there were any significant differences in nutrient chemistry among habitats. Because differences in water chemistry among habitats proved to be very small, we took only one water sample from a well-mixed area (mostly sunny riffles) at each site in August 2002. In June and August 2002, the water samples were taken from all sites on the last day of field sampling. All samples were collected and stored in accordance with APHA standard methods for water and wastewater sampling (APHA, 1992). Samples for dissolved inorganic nutrients (NH_4, NO_3, and SRP) and total dissolved N and P were filtered immediately through a 0.45 µm cellulose acetate membrane filter (Osmonics). Because filters used in 2001 and 2002 had the same pore size, we did not expect the choice of filter to have an effect on the results. Samples for TN and TP were not filtered. All samples were placed on ice until they could be transported to the laboratory, and dissolved inorganic nutrient concentrations were measured within 24 h of sampling.

Water chemistry analysis

2001 and 2002

After returning to the laboratory, all water samples for total nutrients (TP and TN in 2001 and 2002, and total dissolved N and P in 2002) were frozen 1 – 3 months until analysis. After thawing, all material in the total TN and TP and total dissolved N and P samples was oxidized using the Valderrama method (Valderrama, 1981) and analyzed for NO_3 and SRP as above. In 2001 dissolved inorganic nutrients were measured immediately after thawing. In 2002 dissolved inorganic nutrients were measured within 24 h of sampling. We assumed that NO_2 concentrations would be negligible in stream water, and all NO_3 was reduced to NO_2 using a cadmium reduction column. Dissolved nutrients were measured spectrophotometrically on a Lachat QuikChem 8000 Flow Injection Analyzer using methods provided by the manufacturer (as above for nitrate and phosphate; for ammonia, QuickChem Method 31-107-06-5-A). All chemical analyses for 2001 were performed on a Lachat QuikChem 8000 Flow Injection Analyzer at the Marine Science Institute Analytical Lab at the University of California, Santa Barbara. All chemical analyses for 2002 were performed on a Lachat QuikChem 8000 Flow Injection Analyzer in the J. Schimel laboratory, under the supervision of Allen Doyle at the University of California, Santa Barbara.

In both years, conductivity and dissolved oxygen were measured in the center of each transect, using an Orion 128 conductivity meter and a YSI Model 59 dissolved oxygen meter, respectively. pH was measured with a Corning 320 pH meter.

Physical conditions

2001 and 2002

In 2001and 2002, measurements of water temperature and current speed were made in situ in the center of each transect. Water temperature was measured with the YSI Model 59 dissolved oxygen meter at the same time dissolved oxygen measurements were taken and current speed was measured with a Marsh McBirney Model 201D Portable Water Current Meter.

In 2001 light was measured by R. Ambrose and S. Lee of the School of Public Health, University of California, Los Angeles, as part of a companion study. Light measurements were taken on September 14, 2001, in full sun. Light measurements were taken just above the surface of the water with a LiCor line quantum sensor (a one meter long bar which integrates incident PAR readings over a ~2.5cm X 100 cm area), and readings also were taken in an adjacent area uninfluenced by shading. From these measurements we calculated a percent reduction of light over the stream channel compared to an adjacent open area with full sunlight.

In 2002 we took measurements of percent canopy cover as an index of light availability using a Model-A spherical densiometer (Forest Densiometers, Bartlesville, OK). Canopy cover was measured facing upstream in the same locations where percent algal cover was measured and the 3 measurements per transect were averaged.

Nutrient limitation experiment

To study the limitation of periphyton biomass by nutrients in Malibu Creek, we used a modification of the method described by Biggs et al. (1998). Our nutrient diffusing substrata (NDS) experiment in 2001 used 4 oz. (120 ml) Mason jars, filled with 2% agar, with hardened ashless paper filters (Whatman 540, 70 mm diameter) as lids to serve as substrata for algal growth. We added N and/or P to the agar to create 4 experimental treatments: +N, +P, +N+P, and controls (C) with no nutrient additions (see below for additional methods). Because our nutrient diffuser experiment in August 2001 met with limited success (only 23% of the NDS units were recovered intact), we conducted a second nutrient diffuser experiment in August 2002, modifying the methods used in 2001.

In 2002 our NDS were composed of 4 oz. (120 ml) Mason jars, filled with 4% agar (Fig. 2 a). We added N and/or P to the agar to create 4 experimental treatments: +N, +P, +N+P, and controls (C) with no nutrient additions. N addition treatments contained 0.5 M $NaNO_3$; P addition treatments contained 0.5 M KH_2PO_4, and N+P treatments contained 0.5 M concentrations of both $NaNO_3$ and KH_2PO_4. We placed a 10 cm square of 20 µm Nitex polyester mesh over the mouth of each jar to serve as a substratum for algal growth. These Nitex substrata were held in place by plastic lids with a 5.6-cm diameter hole cut in the center (Fig. 2 a). To protect the NDS from abrasion and animal interference, each unit was placed in a cubical cage, 15 cm on a side, constructed of stainless steel hardware cloth with 6 x 6 mm mesh (Fig. 2 b). The cages were then affixed to 20 x 20 cm concrete cinder blocks using UV-resistant black plastic cable ties (two cages per cinder block, on opposite sides) and deployed in pools or slow runs at each site so that each NDS unit was separated from all others by either a cinder block or at least 40 cm (Fig. 2 b). Where possible, the NDS were deployed in pools or runs where ambient algal biomass had been measured. At the residential and commercial sites, these pools were too small or shallow to accommodate the NDS, which were instead deployed in pools or runs immediately downstream of where algal biomass had been measured.

Twelve diffusers were set out at each site (four treatments x 3 replicate NDS per treatment) on August 27 and 28, 2002. Algae growing on the cage walls were scrubbed off three times during the course of the experiment to prevent shading. After 31-32 days, the NDS units were retrieved, and the Nitex growth substrata were removed, transported back to the laboratory on ice, and frozen at -20° C before subsequent analysis. Because algae sometimes were found growing directly on the surface of the agar underneath the Nitex, we also scraped this surface layer of algae off the agar in each NDS and retained these samples for analysis. On September 9 (day 12 of the experiment), the diffuser arrays at the below Tapia site were found to have been removed from the water by unknown vandals. Because the diffusers were undamaged, although dry, we placed them back in the stream on Sept. 9 where they remained undisturbed until the end of the experimental period (19 days). Based on visual examination of algal growth on the Nitex substrata at this site the following week, stream algae appeared to quickly re-colonize the substrata. Because of these observations and because 19 days fell within the range of times used in other nutrient diffuser experiments (Grimm & Fisher 1986, Francoeur et al. 1999, Scrimgeour & Chambers, 2000), we are confident that the results from this site reflect algal responses to intended treatments. However, care must be taken when comparing algal biomass on experimental substrata at this site to algal biomass on NDS at other sites because they were submerged for different lengths of time.

In the laboratory, we cut the Nitex surfaces into quarters, each having a total area of 6.16 square centimeters. To extract chlorophyll a, one Nitex quarter from each NDS was immersed in 50 ml of 90% acetone and placed in a –20° C freezer. To extract chlorophyll a from the agar surface scrapes, each scrape was diluted with deionized water to a volume of 60 ml, homogenized by high-speed mixing for 5 seconds, macerated by hand with a small spatula, then mixed again at high speed for another 10 seconds. We then took a 10-ml subsample of the homogenate, added 40 mls of pure acetone, and extracted the chlorophyll in the freezer as for the Nitex samples. After 48 hours, all samples were shaken, then centrifuged for 5 minutes, and chlorophyll a in the resulting supernatant was analyzed on a Turner 10-AU Field Fluorometer according to the EPA rapid bioassessment protocol for streams and wadeable rivers (USEPA 1992). Chlorophyll a concentrations on the Nitex surface and agar scrape from each unit were summed to obtain a total chlorophyll value per unit area of growth substrata for each NDS.

Statistical analysis

Multiple regressions with backwards stepwise variable selection were conducted using chlorophyll a for floating, benthic and total algae as the dependent variables, and total N, total P, light, and current speed as independent variables. All variables were log-transformed (or log n+1-transformed where zero values were present) to meet the parametric assumptions of the regressions. Results from the nutrient diffuser experiment were analyzed using one-way analyses of variance (ANOVA), testing for the effects of nutrient treatments on chlorophyll a concentrations. For sites showing significant effects of nutrient treatments on chlorophyll from the ANOVA, means were compared using Scheffe's multiple range test to determine which treatments were different. All statistical analyses were conducted with S-Plus software (S-Plus version 4.5, (c) 1999 Brooks/Cole Publishing Co.).

Results

Percent Cover Data

2001

Benthic algae, which occurred at all sites, consisted of thin, medium or thick diatom films (Fig. 3). Thin diatom films consisted primarily of *Cymbella*, *Navicula*, *Achnanthes*, and *Nitzschia* and medium and thick diatom films consisted mostly of *Melosira*. Sites with less developed land use (e.g., reference and rural) were dominated by thin films of diatoms whereas more developed sites (e.g., residential and commercial) had greater coverage by medium and thick diatom mats. From August to October, thin diatom films became thicker at more developed sites, whereas the reference and rural sites continued to be dominated by thin diatom films.

Macroalgae occurred at stream sites surrounded by a variety of land use types (Rural, Horse, Residential 1, below Tapia and Commercial 1), but tended to have the highest cover at the Commercial site (Fig. 3). Macroalgal species composition was different among sites with the floating or benthic macroalgae, *Rhizoclonium* and/or *Enteromorpha*, dominating at the Rural 1, Residential 1, Below Tapia, and Commercial sites, the benthic alga *Spirogyra* dominating the Horse site, and the benthic alga *Cladophora* occupying substantial amounts of space at the Below Tapia site (see Appendix A). From August to October the percent cover of all macroalgae decreased at all sites where macroalgae occurred.

2002

Benthic diatom films of different thickness were found at all sites sampled in June and August (Fig. 4). In addition to diatoms, we observed the following benthic algae at the study sites: a crusty green alga (unidentified), the bluegreen alga *Nostoc*, and an unidentified bluegreen alga (collectively designated as "other"). The reference site was dominated by thin and medium diatom films in both June and August, whereas the more developed sites were dominated by various combinations of medium and thick diatom mats and macroalgae.

Macroalgae were found at all developed sites in June and at all sites, including the Reference 1 site, in August. The percent cover of all macroalgae decreased from June to August at the Residential 1, Commercial 2, and Multiple 2 sites, but increased at the Reference 1 and Commercial 1 sites.

In June, pools at the Residential 1 and Commercial 2 sites had a higher percent cover of macroalgae, primarily *Rhizoclonium* and/or *Enteromorpha*, than other habitats (Fig. 5, Appendix A). In August, macroalgal cover, primarily *Spirogyra*, *Rhizoclonium*, and/or *Enteromorpha*, was higher in pools than other habitats at four of the seven sites (Fig. 6). At the other three sites, macroalgal cover was low but higher in riffles than other habitats (riffle macroalgae = *Cladophora* at Reference 1 and Commercial 1, attached *Rhizoclonium* at Multiple 1). In June, sunny runs had a greater cover of macroalgae than shaded runs at Residential Site 1; however, there were no consistent differences in macroalgal cover between shaded and sunny habitats at other sites. In August, we observed a greater cover of macroalgae in sunny than shaded habitats at all sites except below Tapia which, in contrast to the other sites, was dominated by *Spirogyra* (Fig. 6e, Appendix A). In both months at the Reference Site, diatom films were thinner in fast flowing riffles than in pools or runs (Fig. 5a and 6a). In August at Residential Site 1, sunny habitats were dominated by macroalgae or thick diatom mats whereas shady habitats were dominated by thin or medium diatom films (Fig. 6b). At both the Multiple 2 and Below Tapia sites, macroalgae dominated in pools and medium to thick diatom mats dominated in runs and riffles.

Chlorophyll a Concentrations

2001

Mean chlorophyll a values for benthic algae ranged from 0.5±0.2 to 137.3±66.4 mg/m^2 in August and from 2.8±0.8 to 242.5±95.0 mg/m^2 in October (means ± 1 SE). Benthic chlorophyll a concentrations were generally lower in streams surrounded by less developed areas, such as the Reference 1 and 2, Rural 1 and 2 and Horse sites, than in streams surrounded by development (Fig. 7a). The Commercial 1, Golf, Residential 2, and Tapia above and below sites had chlorophyll concentrations under 50 mg/m^2 in August, but chlorophyll concentrations at these sites increased by August. The Residential 1 site had consistently high concentrations of chlorophyll in August and October, whereas the Residential 3 site had high chlorophyll concentrations in August and low concentrations in October.

We found floating algae at the Rural 1, Horse, Residential 1, Tapia below, and Commercial 1 sites with mean chlorophyll a concentrations ranging from 12.7 (n=1) to 146.5±12.2 mg/m^2 in August and from 0.6 (n=1) to 58.1±29.4 mg/m^2 in October. Floating algae chlorophyll concentrations decreased between August and October at all but the Rural site (Fig. 7b). Mean chlorophyll of floating algae at the below Tapia and Commercial 1 sites exceeded 100 mg/m^2 chl a in August.

Mean total chlorophyll values varied between 0.5±0.2 and 193.4±32.5 mg/m^2 in August and 2.8±0.8 and 295.3±97.0 mg/m^2 in October (Fig. 7c). Because benthic algal biomass dominated the values for total algal biomass, total algal biomass showed the same patterns as benthic algal biomass with lower values at less than more developed sites. The lowest chlorophyll concentrations were found at Reference sites 1 and 2, and Rural site 2 (<5 mg/m^2 chl a). Mean concentrations over 100 mg/m^2 Chl a in August and/or October were found at the Golf, Residential 3, below Tapia and Commercial 1 sites. Total chlorophyll concentrations were higher in October than August at the Golf, Residential 2, and Tapia above sites and higher in August than October at the Residential 3 site, with other sites showing relatively similar chlorophyll concentrations between months.

2002

Chlorophyll a values for benthic algae were higher in August than in June at the five sites sampled in both months (Fig. 8a). Mean benthic chlorophyll a concentrations for individual transects ranged from 0.6±0.1 to 362.6±294.7 mg/m^2 in June, and from 3.2 ±1.6 to 969.2 ±482.5 mg/m^2 in August (Fig. 10). Chlorophyll a values >100 mg/m^2 were measured for individual transects at the Multiple

2 site in June, and at all sites, except the Reference 1 site, in August. The highest chlorophyll values were measured at the Commercial 1, Multiple 1 and 2, and below Tapia sites in August (Fig. 10). Benthic chlorophyll concentrations were higher in sunny than in shady habitats at Residential Site 1 in both months, but chlorophyll concentrations in different habitat types did not show consistent patterns across months (Fig. 10b). Mean chlorophyll a concentrations for benthic algae reached almost 1000 mg/m^2 in the sunny run at Commercial Site 1 in August, but all other habitats at this site had chlorophyll concentrations <150 mg/m^2 (Fig 10c). At the Multiple 1 site, mean chlorophyll a values tended to increase from pools to runs to riffles, but variability around these mean values was high. At the Commercial 1, Multiple 2 and below Tapia sites, benthic chlorophyll a concentrations were high and varied widely across habitats without any consistent pattern relative to light and habitat type (Fig. 10c, d, e).

Chlorophyll concentrations for floating algae ranged from 2.6±2.1 to 698.4±224.9 mg/m^2 in 2002, with no consistent changes across sites between June and August (Figs. 8, 11). Floating algae were present in sunny habitats at all sites except for the Reference 1 site, and generally reached the highest levels in pools (Fig. 11). The highest concentrations of floating algae chlorophyll a (>100 mg/m^2 chl a) were found in the sunny pools at the Commercial 2 and Multiple 2 sites, the sunny pools and sunny riffles at the Residential 1 site, and the shaded pools at the below Tapia site. (Fig 11).

Similar to benthic biomass, total algal biomass (benthic and floating combined) was higher in August than in June at the Residence 1, Commercial 1, and Multiple 2 sites, but was similar in June and August at the Residential 1 and Commercial 2 sites (Fig. 8). When all habitats within a site were averaged, the lowest total chlorophyll values were found at the Reference site, and the highest at the Commercial 1 and 2, Multiple 1 and 2, and below Tapia sites, with the Residential site having intermediate values. Total algal biomass at individual transects (Fig. 9) was often primarily determined by benthic biomass.

Physical Parameters

2001

Current velocity varied from 0 to 0.28 m/s across sites (Table 1). There was no measurable current at the Reference 2, Golf, and Horse sites. Temperature was lower in October (mean: 17.0 °C) than in August (20.4 °C) and ranged from 14.1 to 25.5 °C across all sites and sampling dates (Table 1). High light levels (> 60 % full sun) were measured at the Rural 1, Residential 1, Golf, and Commercial 1 sites in September, but lower light levels (< 35 % full sun) were found at all other sites.

2002

As expected, current speed varied among habitats within each site. Current speeds ranged from 0 to 0.06 m/s in pools, from 0.01 m/s to 0.24 m/s in runs, and from 0.12 m/s to 0.76 m/s in riffles (Table 2). There were no consistent changes in current speed between June and August 2002. Temperatures did not differ between June (19.3 °C to 29.3 °C) and August (16.6 °C to 30.5°C). The sunny pools at the Commercial 2 and below Tapia sites in August, and the Commercial 1 site in

June, had higher temperatures than the other habitats within these sites. In August we also found lower temperatures in shady than sunny habitats at the Residential site.

The percent of overhead area not covered by canopy varied from 0 to 98.6 among sites, with little difference between June and August (Table 2). Differences in canopy cover between sunny and shady habitats were apparent at the Residential 1, Multiple 2, and below Tapia sites, but only sunny habitats (due to channelization and the lack of riparian vegetation) were present at the Commercial 1 and 2 sites and only densely shaded habitats were available at the Multiple 1 site (Table 2).

Water chemistry

Dissolved Oxygen, Conductivity, and pH

2001

Dissolved oxygen varied between 3.7 and 18.7 mg/l O_2 in August and October across sites (Table 1). Only Rural Site 1 showed a low oxygen concentration (3.7 mg/l O_2 in October) (Table 1). Very high concentrations of daytime dissolved oxygen (>15 mg/l) were found in October at the below Tapia and Commercial 1 sites. Conductivities ranged from 0.67 to 3.71 mS/cm across sites with little difference between August and October. The lowest conductivities were measured at the Reference 1 and 2, Rural 1 and 2, and Horse sites (<1.8 mS/cm). All other sites had conductivities >2.0 mS/cm, with the highest conductivity measured at the Residential 1 site (>3.4 mS/cm). pH differed little among sites or between sampling days, ranging from 7.35 to 8.31.

2002

Dissolved oxygen ranged from 5.1 to >20 mg/l O_2 in June and August (Tab. 2). Within most sites, variation among habitats was minimal. High oxygen concentrations were found at the commercial sites in both June and August, with higher values in August. In August, the sunny pools at the below Tapia site had higher dissolved oxygen levels than other habitats within this site. Conductivities ranged from 0.60 mS/cm to 3.73 mS/cm among sites and sampling dates, with little variation among habitats within a site (Table 2). The lowest conductivity (< 0.69 mS/cm) was measured at Reference 1 and conductivities greater than 2.40 mS/cm were recorded at all other sites. pH ranged from 7.27 to 8.22, and differed little among habitats, sites, or sampling dates (Table 2).

Nutrients

2001

SRP concentrations varied among sites and between the two sampling dates (Table 1). Reference sites 1 and 2 had SRP concentrations < 15 µg/l in August and October. At the other extreme, high levels of SRP (>50 µg/l) were recorded at the below Tapia and Golf sites in both months. Most other sites showed intermediate SRP levels, ranging from 20 to 50 µg/l P. Total phosphorous concentrations were under 60 µg/l for the Reference 1 and 2, and Rural 2 sites (Fig. 13, Table 1). The Rural 1, and Residential 1 and 2 sites had TP concentrations under 100 µg/l in August and October. All other sites had TP concentrations over 100 µg/l on at least one sampling date.

Dissolved inorganic nitrogen (DIN) concentrations were not consistently different between August and October (Table 1). Reference sites 1 and 2, Rural site 2, and the Residential 1, above Tapia, and Horse sites had DIN concentrations under 100 μg/l N (except Rural 2 in August: 106.1 μg/l N). We measured extremely high DIN concentrations at the Residential 2 and below Tapia sites (774 to 998 μg/l N). NO_3-N was the main contributor to the DIN pool at sites with high DIN concentrations. Total N concentrations showed no consistent changes between August and October across sites (Fig. 12). The Golf and below Tapia sites had extremely high TN concentrations in August (> 2 mg/l). The Residential 2 site had TN concentrations > 1 mg/l in August and October.

Molar TN/TP ratios in stream water samples ranged from 8.6 to 39.6 and there were no consistent differences in TN/TP ratios between August and October across sites (Table 1, Fig. 14). TN/TP ratios were low (< ca. 10) in August and October at the Horse and above Tapia sites, whereas TN/TP ratios > 30 were observed at Reference Sites 1 and 2, and Rural Site 2, in August, and at Residential Site 2 in August and October. All other sites had molar TN/TP ratios between 10 and 30 in August and October (Fig. 14).

2002

Nutrient concentrations also varied greatly among sites in 2002, with P concentrations varying over one order of magnitude and N concentrations varying by two orders of magnitude (Fig 12 and 13, Table 2). N and P concentrations, however, were not correlated across sites. Particulate N and P concentrations were rarely a significant proportion of total N and P concentrations, so only dissolved inorganic and total N and P data are presented in this report.

The highest total N concentrations, predominantly DIN, were found at the Multiple 1 and 2 sites (Table 2). The Residential 1, below Tapia, and Commercial 1 and 2 sites also had high N concentrations but DIN was relatively low compared to total dissolved N and TN. This indicates that dissolved organic N and particulate N must have contributed significantly to the N pools at these sites. DIN and total N were low at the Reference 1 site in August but not in October.

Multiple 1, Multiple 2, and Below Tapia had relatively high TP concentrations, with most of the TP occurring in the form of SRP. SRP was lowest at the Reference site.

Molar N/P ratios in stream water samples ranged from 2.6 to 30.1 and were lower in June then August at sites that were sampled in both months (Tab. 2, Fig. 14). Ratios were <5 in June at the Reference and Residential sites, and were low again at the latter site in August. The highest values in both months were seen at the Multiple 2 site.

Cellular N/P ratios

2001

Mean molar N/P ratios in benthic algae samples ranged from 3.0±1.7 to 192.2±41.7. We found low algal N/P ratios (3.0 to 3.5) at the Reference 2 and Residential 2 sites in October. High periphyton N/P ratios were measured at Reference Site 1 in August (192.2±41.7), at the below Tapia site in

October (46.6±18.3) and at the Commercial 1 site in October (33.8±1.1). All other sites had periphyton N/P ratios between 10 and 30 in August and October.

2002

Cellular N/P ratios in algae collected in 2002 were not measured.

Nutrient diffuser experiments

2001

Of 144 nutrient diffusers that were deployed among our study sites, only 34 were recovered intact at the end of the experiment. The loss of, or damage to, our NDS appeared to be due to disturbance by crayfish and raccoons. We recovered control NDS from only 6 sites (Reference 1 and 2, Rural 1 and 2, Golf, and Tapia above), making the results difficult to interpret.

2002

There were significantly higher levels of algal biomass on the +N diffusers than on diffusers assigned to other treatments at the Reference 1 and below Tapia sites ($p<0.01$, Fig. 15a, 15f), a result expected from the molar TN/TP ratios observed at these sites. At both of these sites, however, algal biomass on the NDS assigned to the +N+P treatment was not significantly different from the controls. There were no significant differences in algal biomass among treatments at the Multiple 2 and Commercial 2 sites ($p>0.05$, Fig. 15c, 15e). At the Multiple 1 site, all of the NDS assigned to treatments with added nutrients had lower algal biomass than the control NDS ($p<0.01$). Although the ANOVA indicated an effect of treatment on algal biomass at Residential 1, Scheffe's multiple range test indicated no significant differences among specific treatments.

Multiple regressions

2001

Benthic algae chlorophyll concentrations were significantly correlated with total P concentrations, with 66% of the variation in benthic algal biomass explained by variation in total P concentrations (Table 3). Floating algal biomass was positively correlated with light and total phosphorous levels and negatively correlated with current speed (multiple $r^2=0.55$). Total algal biomass was positively correlated with total phosphorous concentration and negatively correlated with current speed (multiple $r^2=0.78$).

2002

In 2002, benthic algae chlorophyll concentrations across sites were positively correlated with total N concentration, total P concentration, and current speed (multiple $r^2 = 0.47$, Table 3). Chlorophyll concentrations for floating algae were positively correlated with dissolved inorganic N concentration and light level, and negatively correlated with current speed (multiple $r^2 = 0.51$, model $p<0.0001$). Total algal biomass was correlated with TN, TP, and light levels (multiple $r^2 = 0.49$).

2001 + 2002

When data from 2001 and 2002 were pooled, benthic algal chlorophyll concentrations were positively related to TN and TP levels, and current speeds (multiple $r^2=0.42$, Table 3). Floating algae chlorophyll concentrations were weakly negatively correlated with current speed, and positively correlated with light levels (multiple $r^2=0.25$). Finally, total algal chlorophyll concentrations were positively correlated with TN, TP, and light levels (multiple $r^2=0.50$).

Discussion

Comparison of Malibu Creek data to suggested thresholds for algal biomass and nutrient concentration

Researchers have just begun to suggest thresholds or limits of acceptable algal biomass levels and nutrient concentrations in streams, above which problems with water quality and the recreational and aesthetic use of streams are indicated (Table 4). Most researchers have concentrated on thresholds for benthic algae and no work has focussed on recommendations for the maximum acceptable amounts of floating algae. Thus, we will compare our data on total chlorophyll concentrations in the Malibu Creek system to thresholds and classification systems dealing with benthic algae. Maximum values have been suggested for both individual chlorophyll a measurements and mean values determined from a number of replicate samples. Because we composited replicate chlorophyll a samples from individual transects, we use the term "maximum" with reference to our data to indicate the composite of five chlorophyll a values from each transect and the term "mean" to indicate the average of three transects within a given site or habitat.

Dodds et al. (1998) suggested a classification system for trophic status of streams based on mean benthic chlorophyll a values from many studies. According to this classification scheme, mean benthic chlorophyll a values <20 mg m^{-2} indicate an oligotrophic system, values between 20 and 70 mg m^{-2} indicate a mesotrophic system, and values >70 mg m^{-2} indicate a eutrophic system. Using this classification method, only our reference, rural, and horse stable sites in 2001 and the reference site in 2002 would be considered oligotrophic. Several sites in 2001 and all sites, except the reference site, in 2002 fell above Dodds et al.'s threshold for eutrophy. Dodds and Welch (2000) proposed that individual maximum benthic chlorophyll a measurements should not exceed 200 mg m^{-2} to maintain the aesthetic and recreational values of streams. By this standard, four out of twelve of our study reaches in 2001 (Residential 3, Golf, Commercial 1, and below Tapia) and six out of seven sites in 2002 (all except the reference site) exceeded acceptable levels for total chlorophyll levels (Fig. 16). Maximum benthic chlorophyll concentrations of 100 mg m^{-2} were recommended by Welch et al. (1988), Horner et al. (1983), and Nordin (1985). Six out of twelve sites in 2001 (Residential 1 and 3, Golf, Commercial 1, above and below Tapia) and six out of seven sites in 2002 (all except the reference sites) were higher than the recommended level of 100 mg m^{-2} chlorophyll a on at least one date. Comparisons of our data with literature thresholds and classification systems for algal biomass indicate that most of the stream sites in the Malibu Creek watershed that are surrounded by developed areas have chlorophyll a concentrations exceeding thresholds for acceptable levels of chlorophyll. Only the reference, rural, residential 2, and horse stable sites were below recommended thresholds.

Some researchers also have developed nutrient criteria for determining the trophic status of streams. Dodds et al. (1998), surveying data from over 1000 temperate streams, determined that streams with TP concentrations less than 25 µg/l and TN concentrations less than 700 µg/l could be considered oligotrophic, whereas streams with TP concentrations above 75 µg/l and TN concentrations above 1500 µg/l could be classified as eutrophic. Using this classification system, none of our sites would be considered oligotrophic in either year using TP criteria and both of our reference sites and the rural 2 site in 2001 would be considered mesotrophic (Fig. 13). All other sites in 2001 and all sites in 2002 would be considered eutrophic. A different pattern emerges, however, when TN criteria are used. Based on Dodds et al.'s (1998) TN thresholds, six sites in 2001 and two sites in 2002 would be classified as oligotrophic and only two sites in 2001 and two sites in 2002 would be classified as eutrophic (Fig. 12). As a consequence, contradictory conclusions drawn using TP vs. TN thresholds emphasize the ambiguity of using nutrient thresholds to determine the trophic status of streams in the Malibu Creek watershed.

Interannual variation in algal biomass and nutrient concentrations

In examining algal biomass levels and nutrient concentrations in streams affected by human activities, it is often important to determine the constancy of algae and nutrient levels from year to year to determine if algal blooms are a consistent or temporary phenomenon. In this study, we sampled four sites in both 2001 and 2002. Total phosphorus concentrations were almost twice as high in 2002 as in 2001 at the Reference 1, Residential 1 and below Tapia sites (Fig. 13); however, TP levels were similar in both years at Commercial Site 1. There were no consistent patterns in changes in total nitrogen concentrations between years among sites (Fig. 12).

Total chlorophyll concentrations did not differ greatly between years and increased with the increasing intensity of human development across sites in both years, with lowest chlorophyll concentrations at the reference site (Fig. 17). The Commercial 1 site showed anomalously low chlorophyll levels in June, 2002, perhaps owing to channel scraping by flood control personnel in spring 2002. The Reference site showed higher chlorophyll concentrations in August 2002 compared to other times, probably because of the high abundance of *Nostoc* at this site in August 2002. These nitrogen-fixing cyanobacteria may have increased in response to increased P levels in 2002 compared to 2001. Although TP was higher in 2002 than 2001 at the Residential and below Tapia sites, no major differences between years in the species composition or biomass of algae at these sites were noted. Because year-to-year changes in TP levels had little effect on algal communities, we conclude that phosphorous is probably not a limiting resource in this system. In addition, flood disturbances appeared to have few effects on algal species composition or biomass levels in this system. Although the 2000-2001 winter was wetter and characterized by more storms than the 2001-2002 winter, algal biomass was not greatly higher in the summer of 2002 than in the summer of 2001.

Nutrient limitation of algal biomass

We used a variety of approaches to examine possible nutrient limitation of algal biomass in the streams of the Malibu Creek watershed, including regression analyses focussed on relationships between algal biomass and nutrient concentrations (+ levels of physical parameters, such as light and current speed) across sites, algal responses to nutrient inputs from nutrient diffusing substrata, and the identification of limiting nutrients from nutrient levels and ratios in stream water.

Regression analyses indicated that benthic and floating algae chlorophyll concentrations were positively related to nutrient (N and/or P) concentrations, suggesting that both benthic and floating algae could be nutrient limited in Malibu streams. The statistical analyses, however, assumed linear relationships between algal biomass and nutrient levels. Without more sophisticated analyses, it is not possible to determine if algal biomass levels had reached an asymptote at the most developed sites with the highest nutrient concentrations.

Stream water molar N:P ratios have been used as predictors of nutrient limitation (Grimm and Fisher 1986, Hill and Knight 1988), with N:P>30 suggesting P limitation, N:P<10 suggesting N limitation, and 10<N:P<30 suggesting co-limitation by both N and P or limitation by neither (Schanz and Juon, 1983). A wide range of N:P ratios was observed across our study sites in 2002 when the nutrient diffusing experiment was conducted (ratios = 3.7 to 30.1). The nutrient data collected in August, 2002, provided a basis for predicting the responses of algae to nutrient treatments in the NDS experiment, which was conducted from late August to late September, 2002. The water chemistry data indicated that the below Tapia may have been strongly N limited while the other five sites may have been either co-limited by N and P or limited by neither.

The NDS experiment indicated that algae at Reference Site 1 were N limited, even though the molar N:P ratio at this site was 22.9 at the beginning of the experiment; however, the molar N:P ratio at this site was only 2.6 in June, 2002, indicating strong N limitation, and it is not known how rapidly nutrient ratios in these streams change. Nitrogen limitation at the reference site is likely owing to elevated phosphate concentrations at this site compared to other temperate streams (Dodds et al. 1998), which is probably related to the sedimentary Topanga Formation which underlies this site and is likely high in phosphate minerals (USGS 1997, Brinck, 1978). Consistent with predictions made from water column nutrient ratios, the NDS experiment also indicated that algae at the below Tapia site were strongly N limited.

Although the nature and degree of nutrient limitation of algae can be related to seasonal changes in temperature, light, current, and nutrient inputs, seasonal variation in nutrient inputs from the Tapia treatment plant could affect the nature and degree of nutrient limitation at the below Tapia site. The Tapia treatment plant discharges wastewater into Malibu Creek in the winter and spring months, but not at other times of year. Wastewater discharges from this plant could increase nitrogen availability, which would relieve the nitrogen limitation observed during our September NDS experiment; however, we cannot state this definitively without data from the winter and spring. Management strategies that reduce nitrogen from non-point sources may reduce algal biomass at this site during the summer and fall; however, these same strategies may not be effective during times of wastewater discharge.

The NDS experiment also indicated that algal biomass either did not respond to, or was depressed by, nutrient inputs at the Multiple 1 and 2 and Commercial 2 sites. Because N:P ratios at all of these sites were near or within the ambiguous range indicating co or no nutrient limitation of algae, these results support predictions based on nutrient ratios. Although molar N:P ratios can provide an indication of which nutrient limits algal biomass, it must be remembered that absolute nutrient limitation depends on absolute nutrient levels, because algal biomass will increase to an asymptote at very high nutrient levels as algae become limited by other factors (e.g., light at the stream bottom or within the algal mat, space for attachment and growth). Because of the high concentrations of dissolved N and P at the multiple and commercial sites, it seems likely that nutrient demand at these sites is probably saturated by ambient nutrient concentrations. N and P concentrations at the Multiple 1 and 2 and Commercial 2 sites were higher to much higher than the levels found to saturate algal growth in other studies (8 to 50 µg/L for P, and 500 – 700 µg/L for N; Horner et al. 1990, Bothwell 1989, Wuhrmann and Eichenberger 1975). Because the Multiple 1 and 2 sites had medium to dense canopy cover, it is possible that light limited algal growth at these sites. Although the Commercial 2 site had an open canopy, dense growths of algae in some areas at this site covered all available substrata and filled the water column, probably reducing observed nutrient concentrations and resulting in the limitation of space for algal attachment and growth.

Finally, stream water N:P ratios predicted N limitation at the residential site; however, algal biomass did not respond positively to the addition of either N or P at this site. This site also had high light levels, probably adequate to saturate growth and enable the accumulation of high standing stocks of algae (Hill 1996). The residential site was characterized by dense growths of algae, relatively high TP concentrations, and moderate N concentrations, the latter perhaps owing to the rapid uptake of N by dense algal mats.

Most of the stream sites we studied had very high chlorophyll a (>150 mg/m^2) and nutrient concentrations compared to other temperate streams (Dodds et al. 1998, Carpenter et al. 1998) and nutrient levels may have been more than adequate to saturate algal growth at many of these sites (Bothwell 1985, Borchardt 1996). Although the regression analyses indicated relationships between algal biomass and nutrient concentrations across all of our study sites, most of the sites chosen for the NDS experiment had high algal and nutrient levels, N:P ratios indicating co- or no nutrient limitation, and showed no response to nutrient inputs. Although it would be interesting to experimentally examine algal responses to nutrient additions at sites with low nutrient concentrations and algal biomass, it would appear that algae at many of the developed sites were not limited by nutrients.

Effects of physical conditions on algal biomass and composition

In general, algal biomass was lower at the sites with little or no development (e.g., reference, rural, horse stable) than at sites surrounded by extensive development (e.g., residential, commercial, multiple use) indicating general relationships between land use and algal communities. Land use changes can affect water quality and algal communities through erosion and sedimentation, nutrient inputs, the loss of the riparian canopy, and alterations in flow regimes. Our regression analyses indicated that floating algae chlorophyll concentrations were positively related to light and nutrient levels and negatively related to current speeds, reaching their highest levels at slow, sunny, enriched sites. We found floating algae, primarily *Enteromorpha* and *Rhizoclonium*, mainly in sunny pools and runs, at sites where riparian vegetation had been reduced or completely removed by human activity (Residential 1, Commercial 1 and 2, portions of Multiple 2). The growth of floating macroalgae is greatest under high nutrient and light conditions (Dell'Uomo 1991, Simpson and Crecely unpublished data). We hypothesize that floating algae are not found in fast currents because they are not attached to the stream bottom and do not reproduce quickly enough to maintain a population which is constantly being washed downstream.

In contrast, benthic algal biomass was not related to light availability though it was related to nutrient availability. For instance, at our Multiple 1 and 2 sites riparian vegetation was largely intact and light levels were greatly reduced, particularly at Multiple Site 1 where the City of Calabasas has completed extensive restoration work. Benthic diatoms, however, were still able to attain very high biomass levels under full canopy cover, probably stimulated by the high nutrient concentrations at these sites. Although light is commonly thought to limit periphyton growth in shaded streams (e.g. Hill 1996, but see Rosemond 1993), some studies have found that benthic algae, particularly diatoms, have impressive capacities for adjusting their photosynthetic efficiencies in response to shading (Hill et al. 1995). For example, Sundback et al. (1996) found that estuarine benthic diatom communities could be extremely tolerant of shading from floating macroalgae by increasing their photosynthetic efficiencies under low light levels.

Benthic algal biomass was positively related to current speed, consistent with the results of other studies which have shown that increased current speeds increase the delivery rates of nutrients to algae, particularly when benthic periphyton grow in thick, multi-layered communities (Stevenson & Glover 1993, Stevenson et al. 1996). Within algal mats, nutrient depletion can occur rapidly, both as a result of reduced nutrient transport through the intercellular polysaccharide matrix and an increased thickness in the unmixed diffusive boundary layer. Increasing the current speed decreases the thickness of the boundary layer and increases nutrient flux rates, thus increasing nutrient delivery rates to benthic algae. Many sites in our study had thick benthic algal mats, where it is likely that algal growth was limited more by the delivery rate of nutrients than by nutrient concentrations in the water column. Within the range of current speeds measured in this study, faster current speeds would thus have a positive effect on nutrient delivery rates and algal growth, resulting in increased biomass.

Conclusions

It is clear from our survey and experimental results that human development affects stream algal communities in the Malibu Creek basin. Both algal biomass and nutrient concentrations were much lower at undisturbed and rural sites than at developed sites. We observed high algal and nutrient levels at stream sites surrounded by areas with extensive human development, in some cases exceeding eutrophic or nuisance level thresholds reported in the literature. Algal biomass did not respond to N or P additions at a number of sites, suggesting that nutrients were not limiting algal biomass at those sites. At sites with the highest nutrient concentrations, both nitrogen and phosphorus concentrations exceeded the levels reported to saturate algal growth, suggesting that drastic reductions in both of these nutrients may be needed to achieve reductions in algal biomass.

Our results also indicate that benthic and floating algae respond to different physical and chemical variables. Because blooms of both types of algae can reduce stream water quality with effects on ecosystem function and recreational use, regulatory agencies should consider both types of algae when formulating management plans. For example, management actions that reduce the light available to the stream (e.g., by replanting riparian vegetation) should reduce the biomass of floating algae, but may have little effect on benthic diatoms. Increased flows in a stream would have the effect of reducing floating algae biomass, by washing it downstream, but could increase the biomass of benthic algae by increasing nutrient flux. Finally, reducing nutrient concentrations in stream water, by controlling point and non-point nutrient sources, would probably reduce the biomass of benthic diatoms, but might have less of an effect on floating macroalgae. Thus, the management of algal growth must be considered on a site-by-site basis, taking into account the types of algae causing nuisance blooms and the nutrient inputs and other environmental conditions that regulate algal growth.

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Table 1. The physical and chemical characteristics of the sites sampled in 2001. Values are averages of measurements taken from three transects per sample site. Values represent August/October values, except for light, which was only measured in September. - = no data available

Creek	Land Use	Habitat Sampled	% Full Sun	Current ($m\ s^{-1}$)	Temperature °C	Conductivity ($mS\ s^{-1}$)	pH	DO ($mg\ l^{-1}$)
Cold Creek	Reference 1	pool	7.3	0.06 / 0.03	19.0 / 15.4	0.67 / 0.67	7.78 / 7.83	8.7 / 9.4
Palo Comado	Reference 2	riffle	-	0 / 0	20.4 / 16.6	1.73 / 1.74	8.10 / 7.61	8.0 / 7.3
Cold Creek	Rural 1	pool/riffle	61.8	0.06 / 0.03	15.4 / 14.1	1.24 / 1.24	7.98 / 7.56	9.0 / 3.7
Cold Creek	Rural 2	pool/riffle	8.9	0.04 / 0.03	23.3 / 14.8	1.34 / 1.33	7.98 / 7.92	9.7 / 9.9
Medea Creek	Residential 1	run	72.0	0.09 / 0.25	19.1 / 16.3	3.45 / 3.71	7.81 / 7.48	13.6 / 6.8
Arroyo Conejo Creek	Residential 2	run	5.2	0.07 / 0.03	20.0 / 18.6	2.39 / 2.29	8.23 / 7.90	9.6 / 9.6
Lindero Creek	Residential 3	pool/riffle	4.7	0.19 / 0.06	23.3 / 16.9	2.72 / 2.72	7.85 / 7.74	9.2 / 8.1
Malibu Creek	Above Tapia	pool/riffle	34.0	0.24 / 0.15	20.7 / 17.6	2.19 / 2.51	7.76 / 7.90	12.3 / 8.9
Malibu Creek	Below Tapia	run/riffle	20.6	0.17 / 0.16	25.5 / 19.0	2.44 / 2.57	7.35 / 7.86	11.9 / 15.0
Lindero Creek	Golf course	pool/riffle	99.5	0 / 0	19.6 / 17.7	2.84 / 2.95	8.06 / 7.88	13.0 / 10.7
Triunfo Creek	Horse stables	pool	22.5	0 / 0	19.4 / 16.6	1.27 / 1.42	7.78 / 7.65	7.1 / 7.5
Medea Creek	Commercial 1	run	97.1	0.04 / 0.28	19.6 / 20.2	3.25 / 2.90	8.31 / 7.96	12.8 / 18.7

Creek	Land Use	NH_4-N ($\mu g\ l^{-1}$)	NO_3-N ($\mu g\ l^{-1}$)	TN ($\mu g\ l^{-1}$)	SRP ($\mu g\ l^{-1}$)	TP ($\mu g\ l^{-1}$)	TN/TP
Cold Creek	Reference 1	10.3 / 17.4	32.8 / 3.6	976.0 / 254.0	13.5 / 11.1	58.7 / 31.5	38.0 / 18.4
Palo Comado	Reference 2	9.2 / 7.1	1.7/ 1.6	373.1 / 368.0	7.9 /8.2	27.4 / 29.4	31.1 / 28.7
Cold Creek.	Rural 1	10.5 / 14.6	241.4 / 266.0	366.2 / 514.9	42.6 / 13.7	67.3 / 84.7	12.4 / 13.9
Cold Creek	Rural 2	85.7 / 23.7	20.3 / 15.4	560.4 / 531.2	27.1 / 11.4	32.9 / 42.0	39.0 / 28.9
Medea Creek	Residential 1	- / 11.2	- / 70.9	550.5 / 568.2	- / 46.3	88.5 / 77.4	14.2 / 16.8
Arroyo Conejo Creek	Residential 2	16.3 / 26.6	935.5 / 921.2	1124.1 / 1384.6	21.0 / 25.7	65.7 / 80.1	39.1 / 39.6
Lindero Creek	Residential 3	19.0 / 25.5	263.5 / 136.8	924.6 / 753.6	19.2 / 33.5	149.7 / 75.0	14.1 / 23.0
Malibu Creek	Above Tapia	7.9 / 30.4	15.9 / 32.1	394.6 / 733.5	73.9 / 42.6	104.5 / 131.7	8.6 / 9.1
Malibu Creek	Below Tapia	31.9 / 123.7	741.5 / 873.6	2100.0 / 394.4	119.7 / 82.9	170.0 / 99.2	28.2 / 12.7
Lindero Creek	Golf course	29.6 / 26.8	441.3 / 345.8	2044.0 / 1005.2	69.2 / 101.4	159.4 / 128.7	29.3 / 17.9
Triunfo Creek	Horse stables	10.3 / 25.2	1.2 / 6.3	321.3 / 467.3	38.6 /17.6	72.3 / 123.5	10.2 / 8.7
Medea Creek	Commercial 1	23.4 / 89.7	246.7 / 286.7	873.8 / 140.9	29.4 / 51.6	109.0 / 140.9	18.3 / 16.1

Table 2. The physical and chemical characteristics of the sites sampled in 2002. Each value represents the average of measurements taken from three transects per sample site (August, this page), from all of the habitats sampled at each site (June, this page), or from three transects per habitat (June, previous page). Values represent June/August, 2002. - = no data available.

Creek	Land Use	Habitat	% Open Canopy	Current (m s^{-1})	Temperature °C	Conductivity (mS s^{-1})	pH	DO (mg l^{-1})
Cold Creek	Reference 1	Pool (sun)	26.3/11.8	0.03/0.02	19.8/18.7	0.67/0.69	7.64/-	8.9/6.9
Cold Creek	Reference 1	Pool (shade)	21.1/10.8	0.02/0.01	20.6/20.4	0.67/0.67	7.80/-	9.0/7.7
Cold Creek.	Reference 1	Run (sun)	27.1/11.8	0.02/0.02	20.0/18.9	0.67/0.69	7.64/-	9.6/7.1
Cold Creek	Reference 1	Run (shade)	23.7/18.0	0.03/0.01	19.7/20.2	0.68/0.69	7.62/-	8.3/7.9
Cold Creek	Reference 1	Riffle (sun)	18.2/12.2	0.13/0.16	20.0/19.5	0.60/0.68	7.68/-	9.4/7.1
Cold Creek	Reference 1	Riffle (shade)	16.7/7.9	0.15/0.12	19.9/20.4	0.67/0.69	7.70/-	9.0/7.7
Medea Creek	Residential 1	Pool (sun)	86.0/88.9	0/0	23.8/20.6	3.43/3.48	7.61/-	8.1/9.5
Medea Creek	Residential 1	Pool (shade)	1.3/0.2	0/0	19.4/19.0	3.60/3.52	7.27/-	5.1/6.3
Medea Creek	Residential 1	Run (sun)	70.4/82.8	0.01/0.10	26.2/22.3	3.48/3.46	7.54/-	7.7/12.4
Medea Creek	Residential 1	Run (shade)	61.5/4.1	0.01/0.02	26.4/19.2	3.46/3.50	7.56/-	8.3/6.4
Medea Creek	Residential 1	Riffle (sun)	90.0/90.0	0.15/0.28	23.4/23.0	3.49/2.40	7.63/7.84	8.7/10.4
Medea Creek	Residential 1	Riffle (shade)	52.1/14.9	0.13/0.12	26.2/19.2	3.47/3.50	7.60/-	8.3/6.3
Medea Creek	Commercial 1	Pool (sun)	-/98.6	0.01/0	29.3/29.8	3.01/2.80	7.92/-	13.6/16.8
Medea Creek	Commercial 1	Run (sun)	-/89.6	0.18/0.24	25.6/30.3	3.03/2.70	7.88/-	14.2/18.7
Medea Creek	Commercial 1	Riffle (sun)	-/90.9	0.31/0.36	24.2/30.5	3.00/2.70	7.90/8.03	12.6/>20
Medea Creek	Commercial 2	Pool (sun)	80.4/74.5	0/0	19.6/28.6	3.10/2.91	7.81/-	13.0/18.7
Medea Creek	Commercial 2	Run (sun)	75.2/91.1	0.04/0.18	20.1/18.1	3.08/3.05	7.71/-	10.2/11.8
Medea Creek	Commercial 2	Riffle (sun)	86.3/88.9	0.76/0.23	20.3/20.8	2.99/3.04	7.71/8.22	10.9/16.5
Las Virgenes	Multiple 1	Pool (shade)	-/0.2	-/0.06	-/20.0	-/3.64	-/-	-/6.4
Las Virgenes	Multiple 1	Run (shade)	-/0.2	-/0.10	-/20.1	-/3.65	-/-	-/7.0
Las Virgenes	Multiple 1	Riffle (shade)	-/0.2	-/0.13	-/20.2	-/3.62	-/7.62	-/6.1
Las Virgenes	Multiple 2	Pool (sun)	-/55.4	0.04/0.01	20.1/18.0	3.55/3.55	7.57/-	11.0/9.9
Las Virgenes	Multiple 2	Run (sun)	-/29.7	-/0.02	-/16.8	-/3.67	-/-	-/8.4
Las Virgenes	Multiple 2	Run (shade)	8.9/1.6	0.03/0.09	19.8/16.6	3.55/3.73	7.59/-	10.1/7.8
Las Virgenes	Multiple 2	Riffle (sun)	14.6/-	0.12/-	18.8/-	3.59/-	7.59/7.88	9.1/-
Las Virgenes	Multiple 2	Riffle (shade)	1.8/2.3	0.31/0.14	19.3/16.7	3.57/3.70	7.59/-	9.7/8.1
Malibu Creek	Below Tapia	Pool (sun)	-/81.9	-/0	-/23.5	-/2.80	-/-	-/17.0
Malibu Creek	Below Tapia	Pool (shade)	-/21.4	-/0	-/20.0	-/2.82	-/-	-/10.9
Malibu Creek	Below Tapia	Run (shade)	-/0.0	-/0.04	-/19.4	-/2.83	-/-	-/7.0
Malibu Creek	Below Tapia	Riffle (sun)	-/54.7	-/0.12	-/20.0	-/2.83	-/7.86	-/9.3
Malibu Creek	Below Tapia	Riffle (shade)	-/1.8	-/0.20	-/19.6	-/2.83	-/-	-/7.6

Table 2 continued.

Creek	Land Use	NO_3-N (μg l^{-1})	NH4-N (μg l^{-1})	DIN (μg l^{-1})	Total Dissolved N (μg l^{-1})	TN (μg l^{-1})
Cold Creek	Reference 1	11.4/-	0 /-	11.4/-	130.2/960.4	91.3/1340.9
Medea Creek	Residential 1	67.6/17.5	0/43.3	67.6/60.8	418.8/746.6	460.6/686.4
Medea Creek	Commercial 1	997.2/126.6	0/50.0	997.2/176.6	1654.7/917.4	1483.5/1202.7
Medea Creek	Commercial 2	718.9/71.7	0/63.4	718.9/135.1	1438.5/899.2	-/1417.9
Las Virgenes	Multiple 1	-/2803.5	-/24.6	-/2828.1	-/2739.5	-/2747.5
Las Virgenes	Multiple 2	4294.7/3869.3	0/70.8	4294.7/3940.1	4341.3/4737.3	3832.6/3806.2
Malibu Creek	Below Tapia	-/0	-/49.6	-/49.6	-/540.1	-/686.1

Creek	Land Use	SRP (μg l^{-1})	Total Dissolved P (μg l^{-1})	TP (μg l^{-1})	TN/TP
Cold Creek	Reference 1	52.4/-	112.0/90.1	94.2/94.1	2.6/22.9
Medea Creek	Residential 1	117.5/122.8	191.1/134.3	167.2/185.5	4.9/12.3
Medea Creek	Commercial 1	136.5/76.9	213.5/98.2	185.2/137.1	17.2/20.7
Medea Creek	Commercial 2	130.1/53.0	199.8/73.0	-/87.1	15.9/27.3
Las Virgenes	Multiple 1	-/267.8	-/299.3	-/295.6	-/20.3
Las Virgenes	Multiple 2	293.6/300.7	329.9/348.4	301.4/326.4	29.1/30.1
Malibu Creek	Below Tapia	-/293.0	-/319.0	-/362.8	-/3.7

Table 3. Results of stepwise multiple regression analysis with chlorophyll a concentration as the dependent variable. All dependent and independent variables were ln, or ln (x+1) transformed before analysis.

Year	Algal type	Physical/ chemical variable	Partial regression coefficient	Significance of slope (p)	Model p-value	Multiple R^2
2001	Benthic	total P	2.22	<0.001	<0.001	0.659
	Floating	current	-1.07	0.004		
		% full sun	0.74	0.020		
		total P	1.82	0.021	0.002	0.550
	Total	total P	3.20	0.000		
		current	-0.44	0.041	<0.001	0.776
2002	Benthic	total N	3.17	0.003		
		total P	2.15	0.038		
		current	1.69	0.100	<0.001	0.469
	Floating	DIN	2.209	0.035		
		current	-3.407	0.002		
		%full sun	4.311	<0.001	<0.001	0.512
	Total	total N	3.23	0.003		
		total P	3.31	0.002		
		% full sun	1.69	0.099	<0.001	0.490
2001 + 2002	Benthic	total N	3.26	0.002		
		total P	2.55	0.014		
		current	2.07	0.043	<0.001	0.421
	Floating	% full sun	4.19	0.0001		
		current	-1.63	0.11	<0.001	0.253
	Total	total N	3.712	0.001		
		total P	4.268	0.0001		
		% full sun	2.850	0.006	<0.001	0.498

Table 4. Suggested criteria from literature studies for maximum benthic algal biomass (as chlorophyll a concentrations) to avoid problems for the recreational use and aesthetic appreciation of streams. Adapted from Dodds et al., 1998.

Upper limit of acceptable mean chlorophyll a concentration (mg chl m^{-2})	Comment	Reference
150 – 200	based on perceived impairment	Welch et al., 1989
100 – 150	based on 19 enrichment cases and surveys	Welch et al., 1988; Horner et al., 1983
150	guidelines for the Clark Fork River, Montana, U.S.A.	Tristate Implementation Council, 1996 (as cited in Dodds et al. 1998)
50 – 100	British Columbia Environment guideline	Nordin, 1985
150	based on survey of 286 cases	Dodds et al., 1998

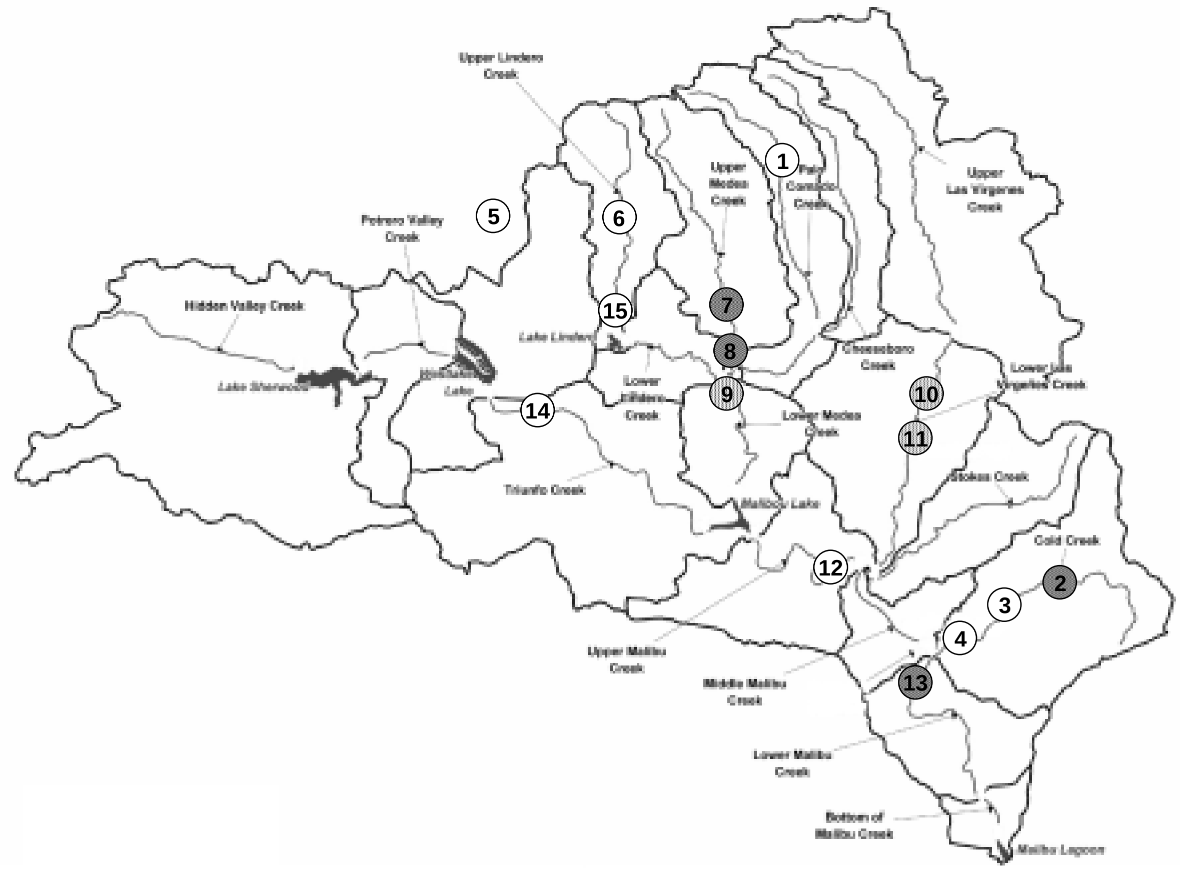

Fig 1. Map of Malibu Creek watershed. Thin black lines: streams; thick black lines: sub-watershed boundaries. White circles: sites sampled in 2001; light grey circles: sites sampled in 2002; dark grey circles: sites sampled in 2001 and 2002. 1) Reference 2 (Palo Comado Creek in the Santa Monica Mountains National Recreation Area); 2) Reference 1 (Cold Creek, Mountains Restoration Trust land); 3) Rural 2 (Cold Creek, off Cold Canyon Road); 4) Rural 1 (Cold Creek at Piuma Road; 5) Residential 3 (Arroyo Conejo); 6) Residential 2 (Lindero Creek, near Falling Star Lane); 7) Residential 1 (Medea Creek, at its intersection with Conifer Street in Agoura Hills); 8) Commercial 1 Medea Creek, close to Chumash Park); 9) Commercial 2 (Medea Creek, south of Agoura Road); 10) Multiple 1 (Las Virgenes Creek, off of Lost Hills Road at the City of Calabasas stream restoration site in Calabasas); 11) Multiple 2 (Las Virgenes Creek, at the intersection of Lost Hills and Las Virgenes Road in Calabasas); 12) Above Tapia (Malibu Creek, Malibu State Park); 13) Below Tapia (Malibu Creek, upstream of the gauging station off Malibu Canyon Road); 14) Horse (Triunfo Creek, off Triunfo Canyon Road); 15) Golf (Lindero Creek, Lindero Country Club, Thousand Oaks Blvd.).

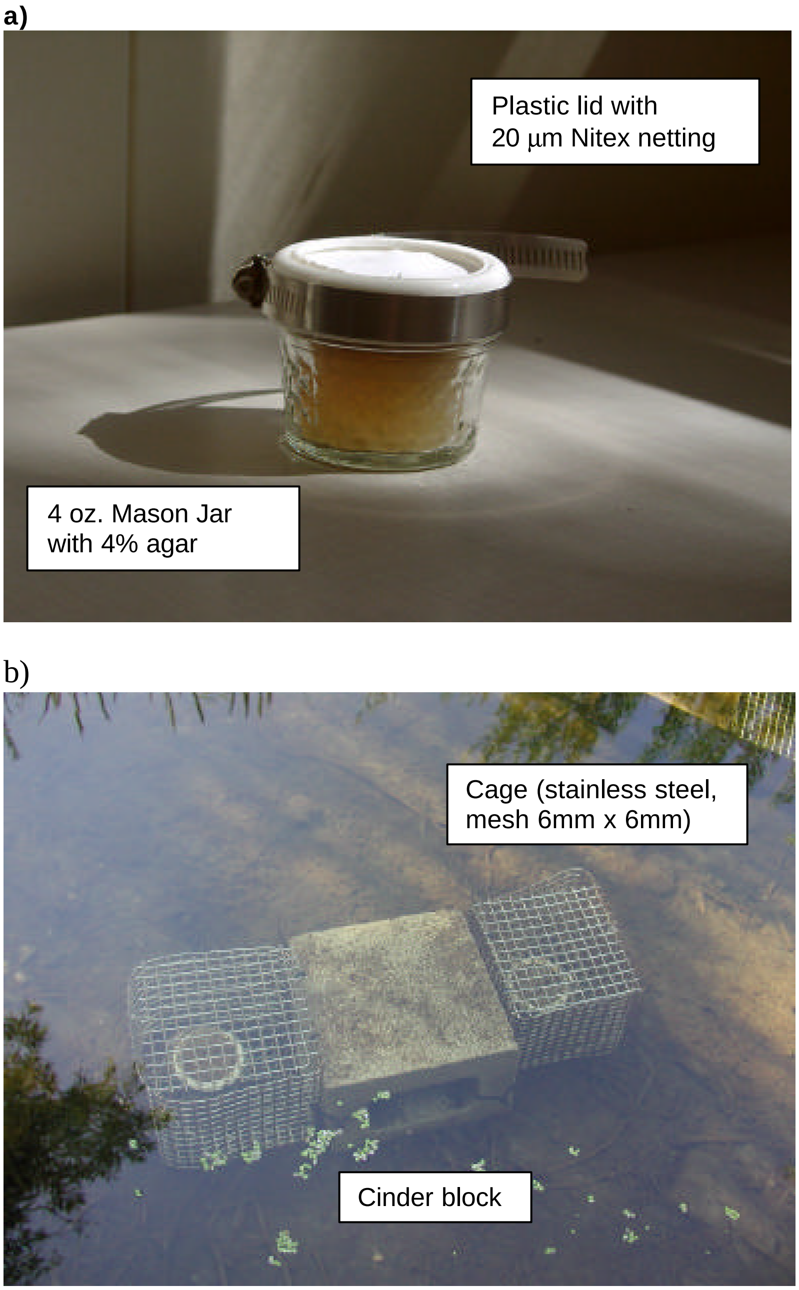

Figure 2. A Nutrient Diffusing Substratum (NDS) (a). The NDS consisted of a 4 oz. Mason jar filled with 4% agar, with 20 mm Nitex netting held in place by plastic lids (5.6 cm diameter) over the mouth of the jar. A hose clamp was attached around the plastic lid so that the NDS could be attached to a cage in the field. NDS in the field (b). Each NDS was surrounded by a cage made of stainless steel hardware cloth (6 mm x 6 mm mesh), which was attached to concrete cinder blocks with cable ties.

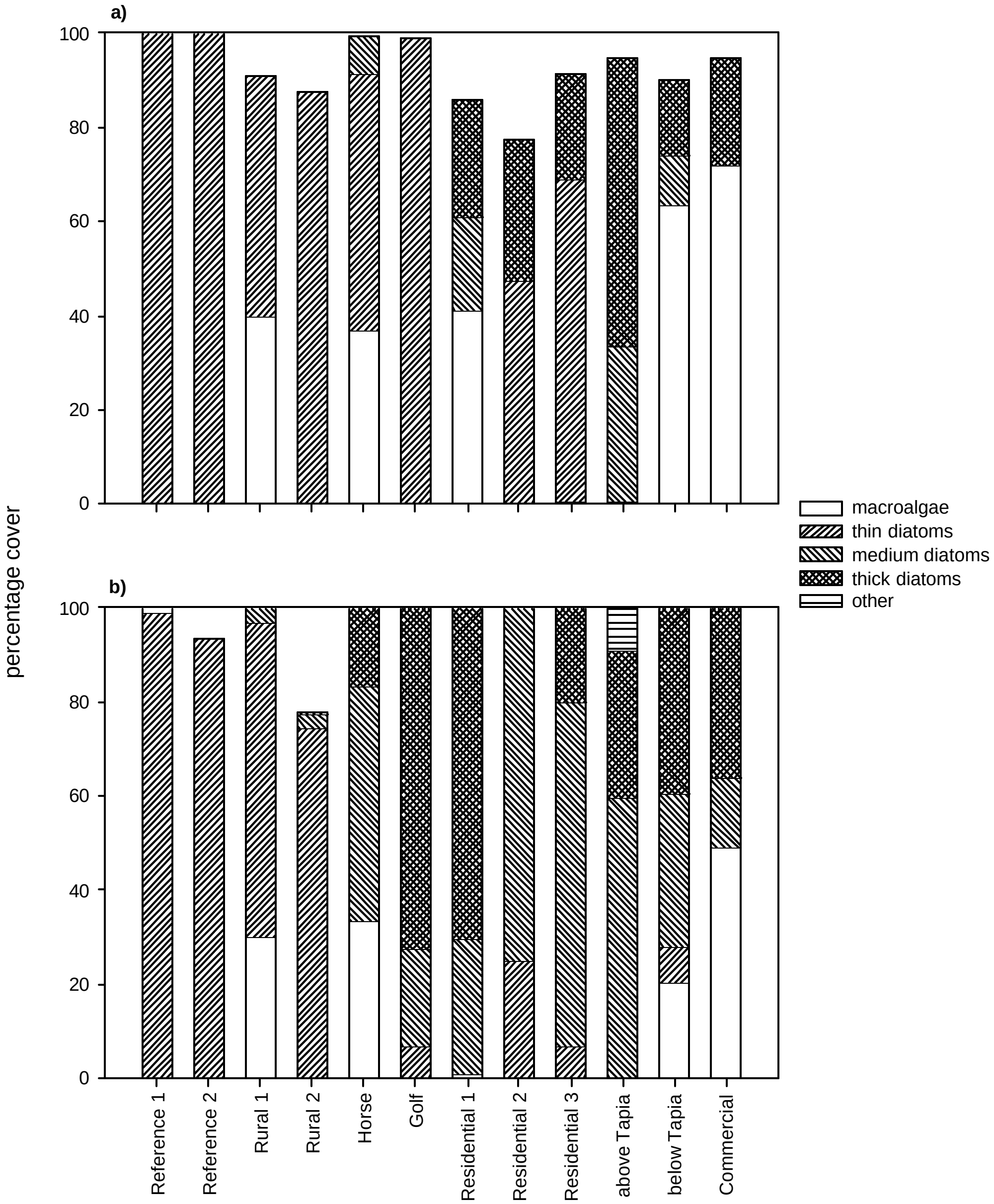

Fig. 3. Percent cover of different algal types (macroalgae; thin, medium, and thick diatom films; other algae) at the sampled stream sites in the Malibu Creek watershed in August (a) and October (b) 2001.

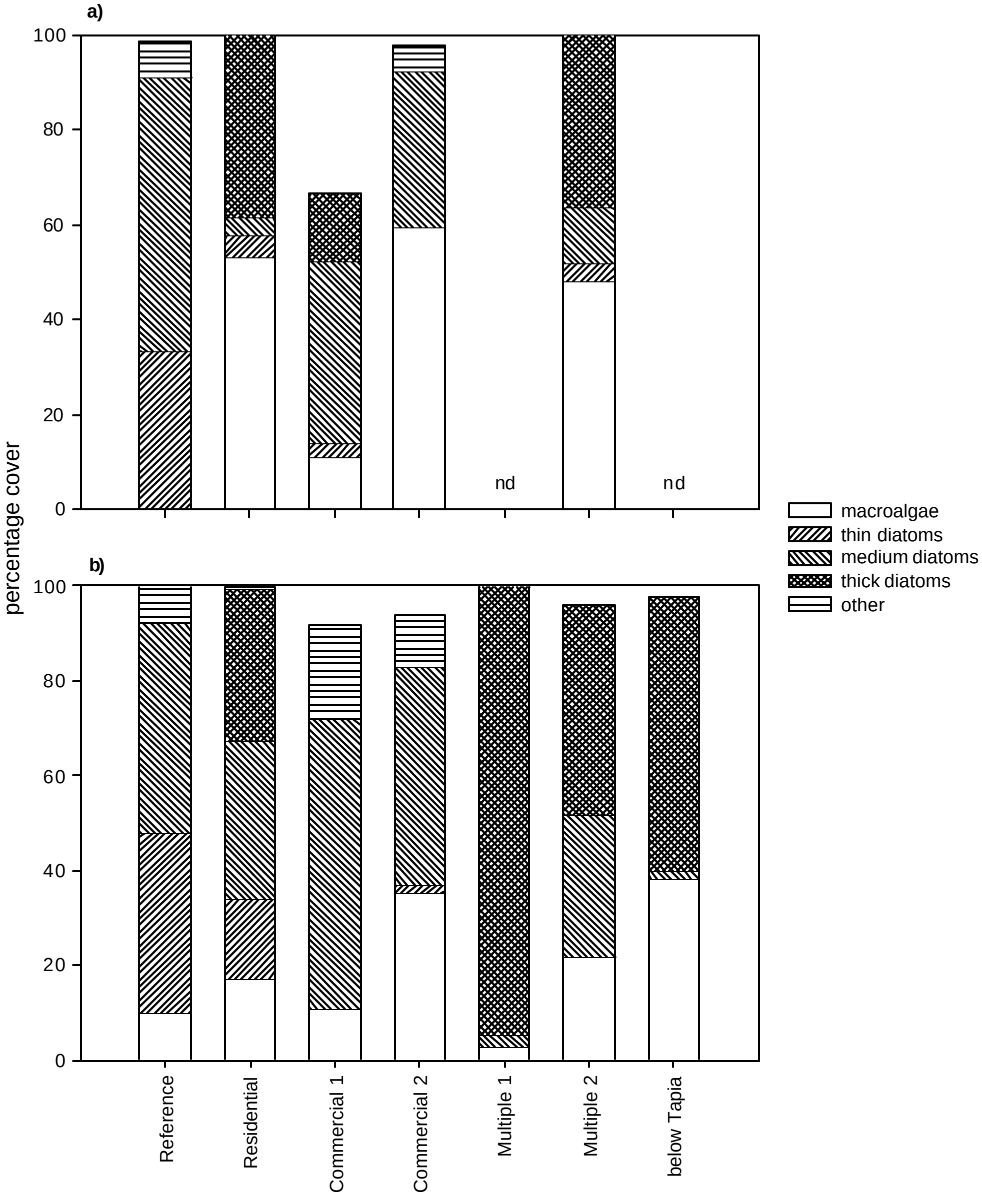

Fig. 4: Percent cover of different algal types (macroalgae; thin, medium, and thick diatom films; other algae) at the sampled stream sites in the Malibu Creek watershed in June (a) and August (b) 2002. nd: no data available, site not sampled.

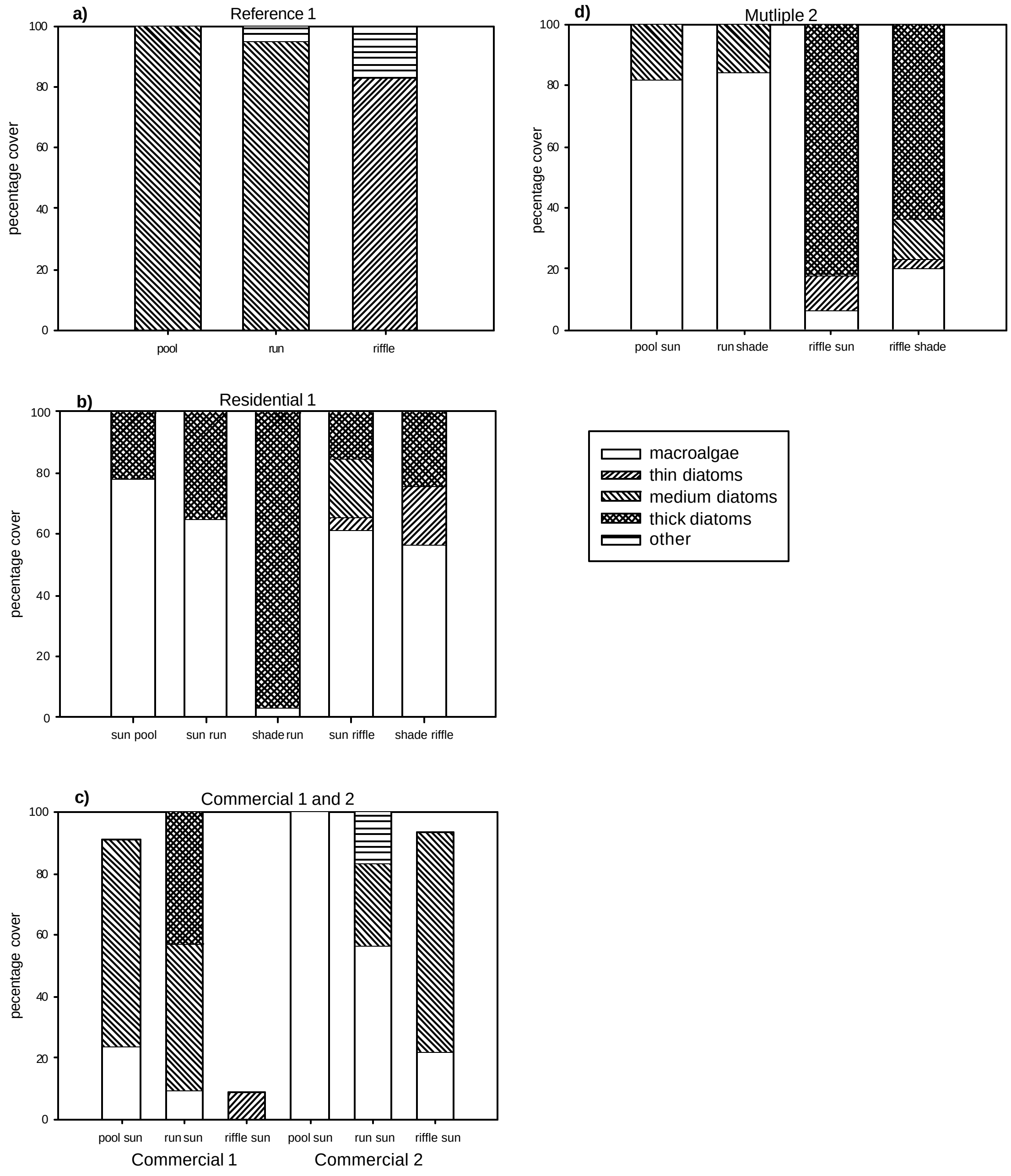

Fig. 5. Percent cover of different algal types (macroalgae; thin, medium, and thick diatoms films; other algae) at the sampled sites in the Malibu Creek watershed, June 2002. Data represent average of habitat transects, n=1-9, see Appendix A.

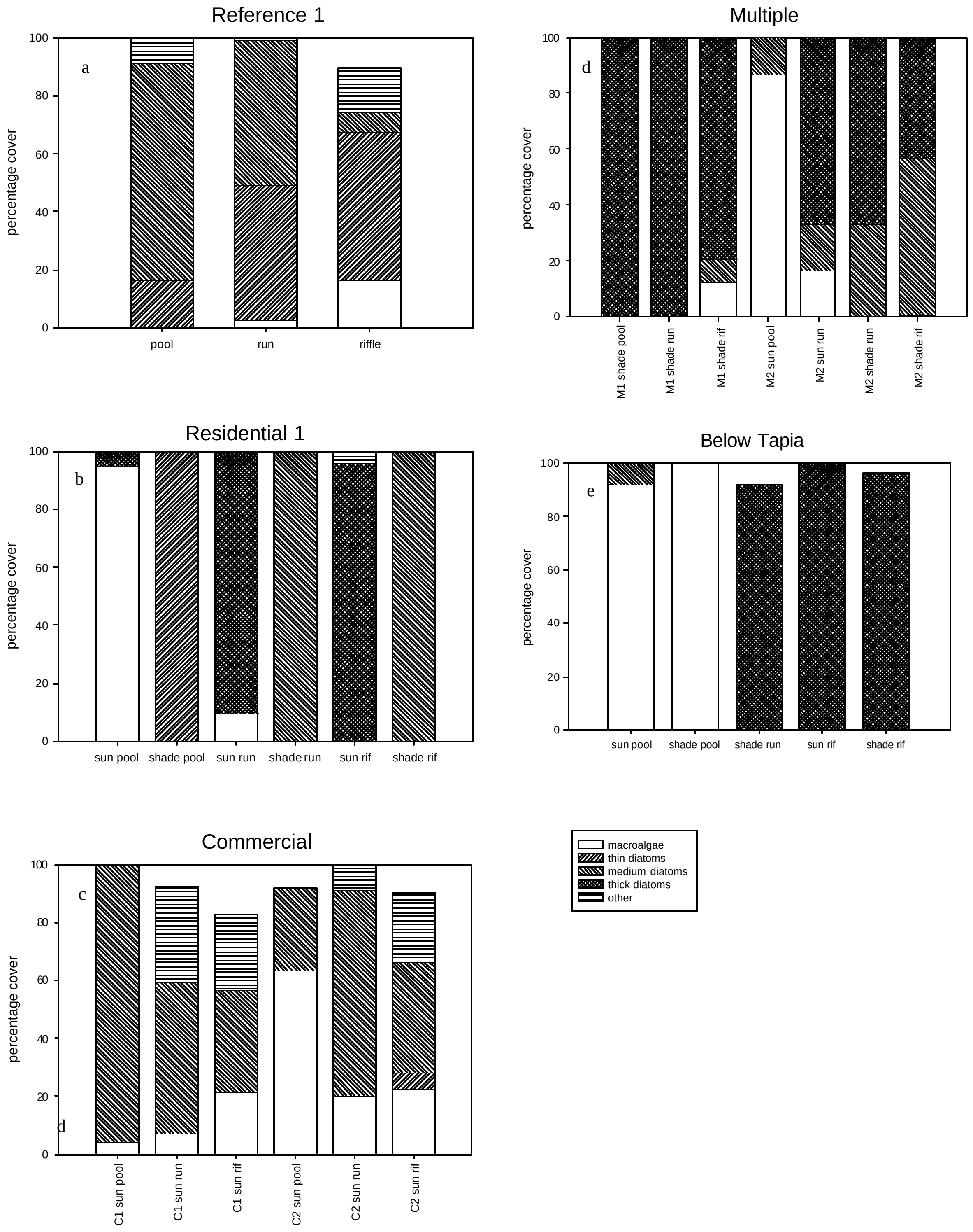

Fig. 6: Percent cover of different algal types (macroalgae; thin, medium, and thick diatom films; other algae) at the sampled sites in the Malibu Creek watershed, August 2002. Data represent average of habitat transects, n=1-9, see Appendix A.

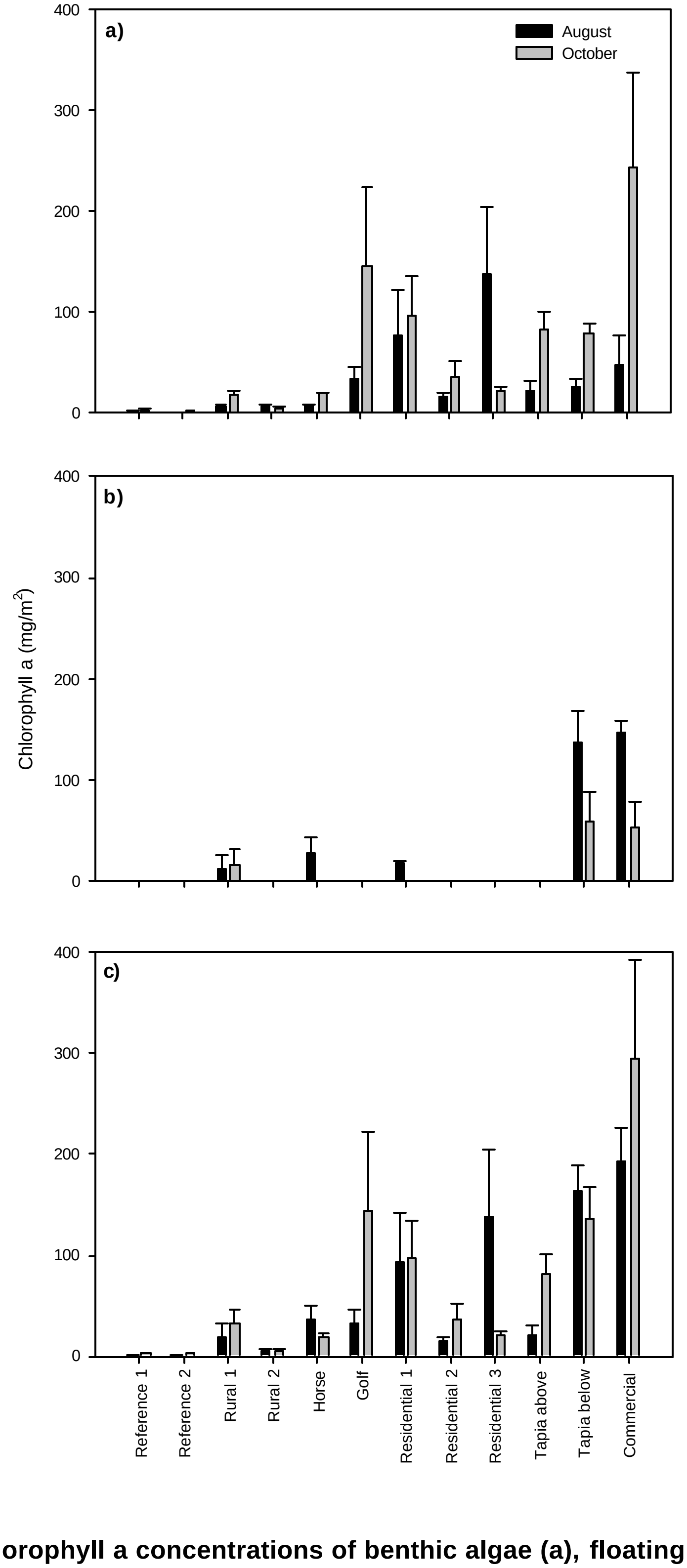

Fig. 7. Mean chlorophyll a concentrations of benthic algae (a), floating algae (b), total algae (c) at the sampled sites in the Malibu Creek watershed, August and October, 2001 (error bars = + 1 SE).

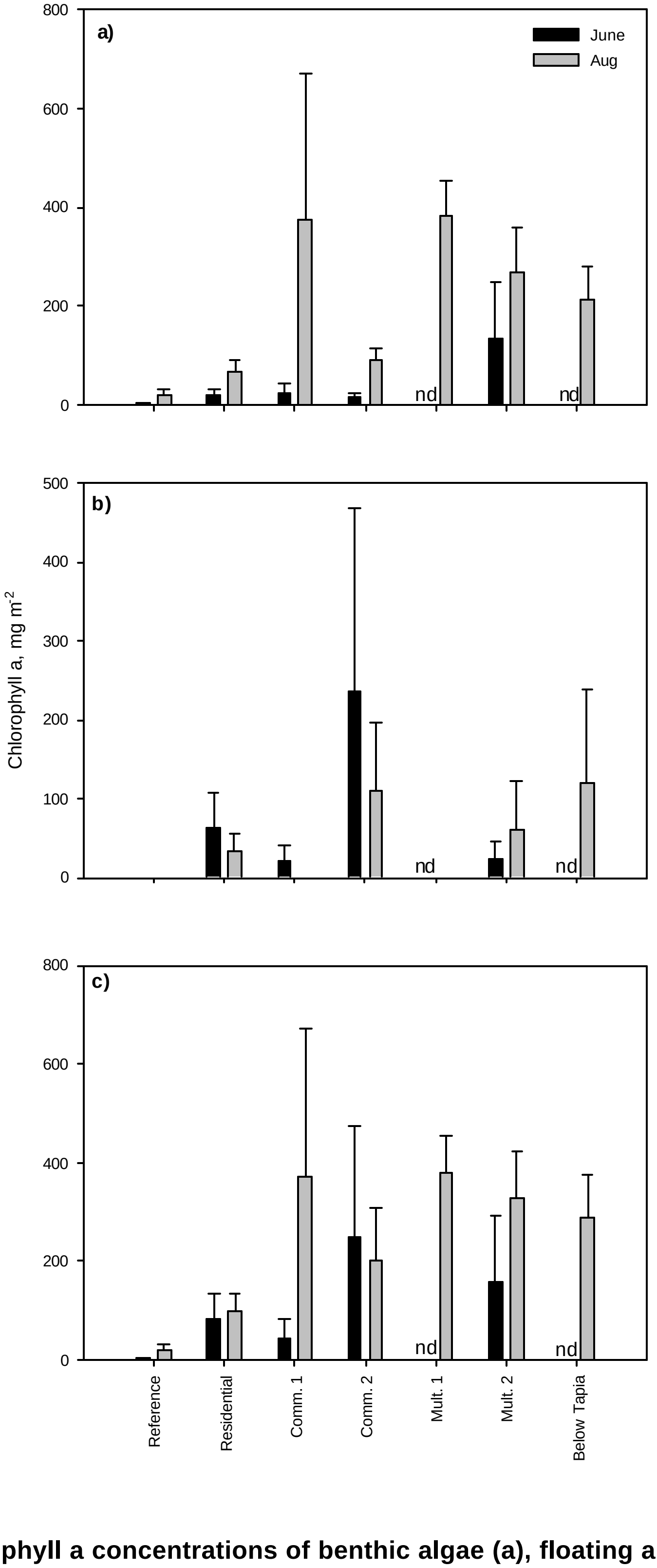

Fig. 8. Mean chlorophyll a concentrations of benthic algae (a), floating algae (b), and total algae (c) at the sampled sites in the Malibu Creek watershed, June and August, 2002 (error bars = + 1 SE). Note different y axes.

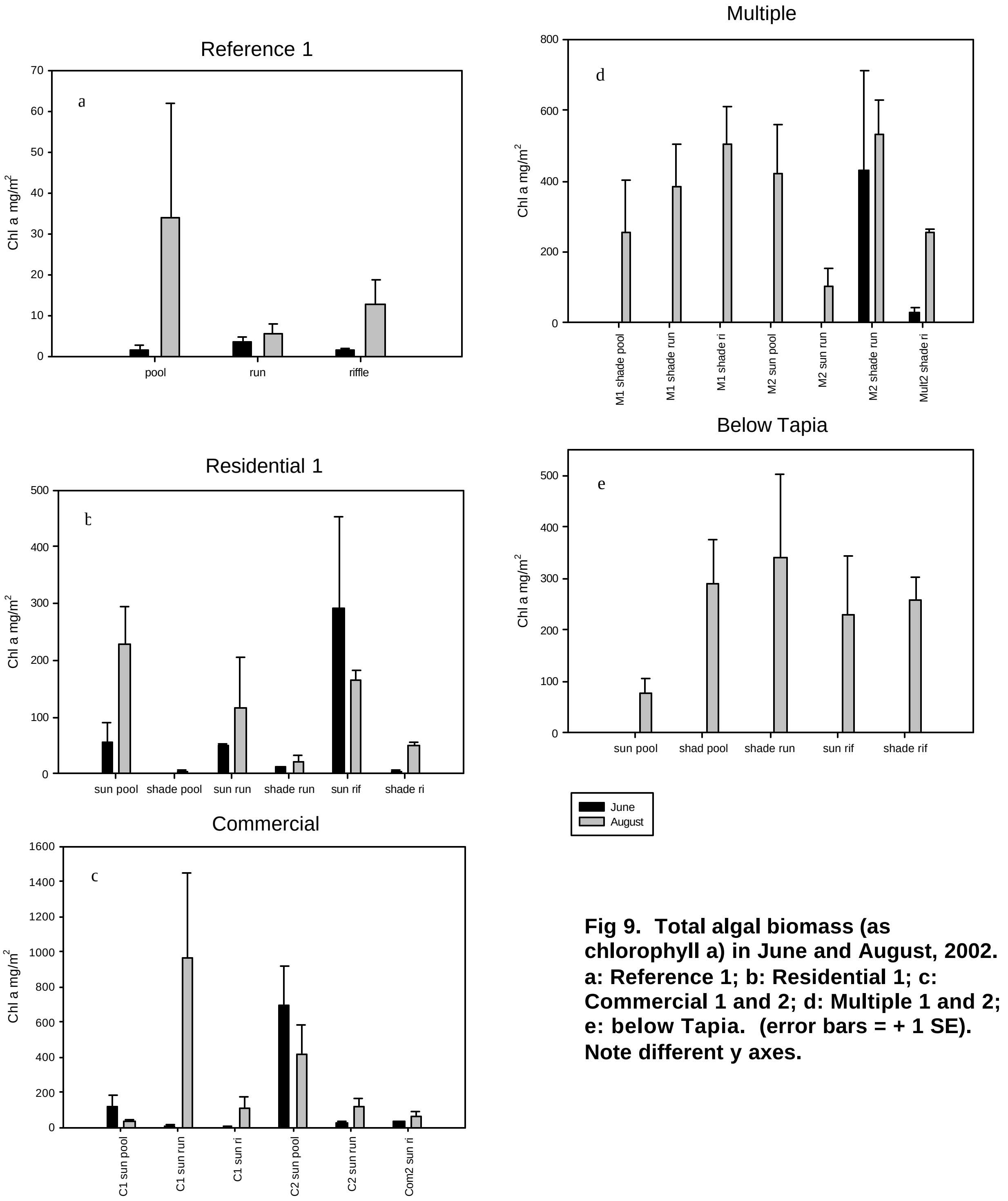

Fig 9. Total algal biomass (as chlorophyll a) in June and August, 2002. a: Reference 1; b: Residential 1; c: Commercial 1 and 2; d: Multiple 1 and 2; e: below Tapia. (error bars = + 1 SE). Note different y axes.

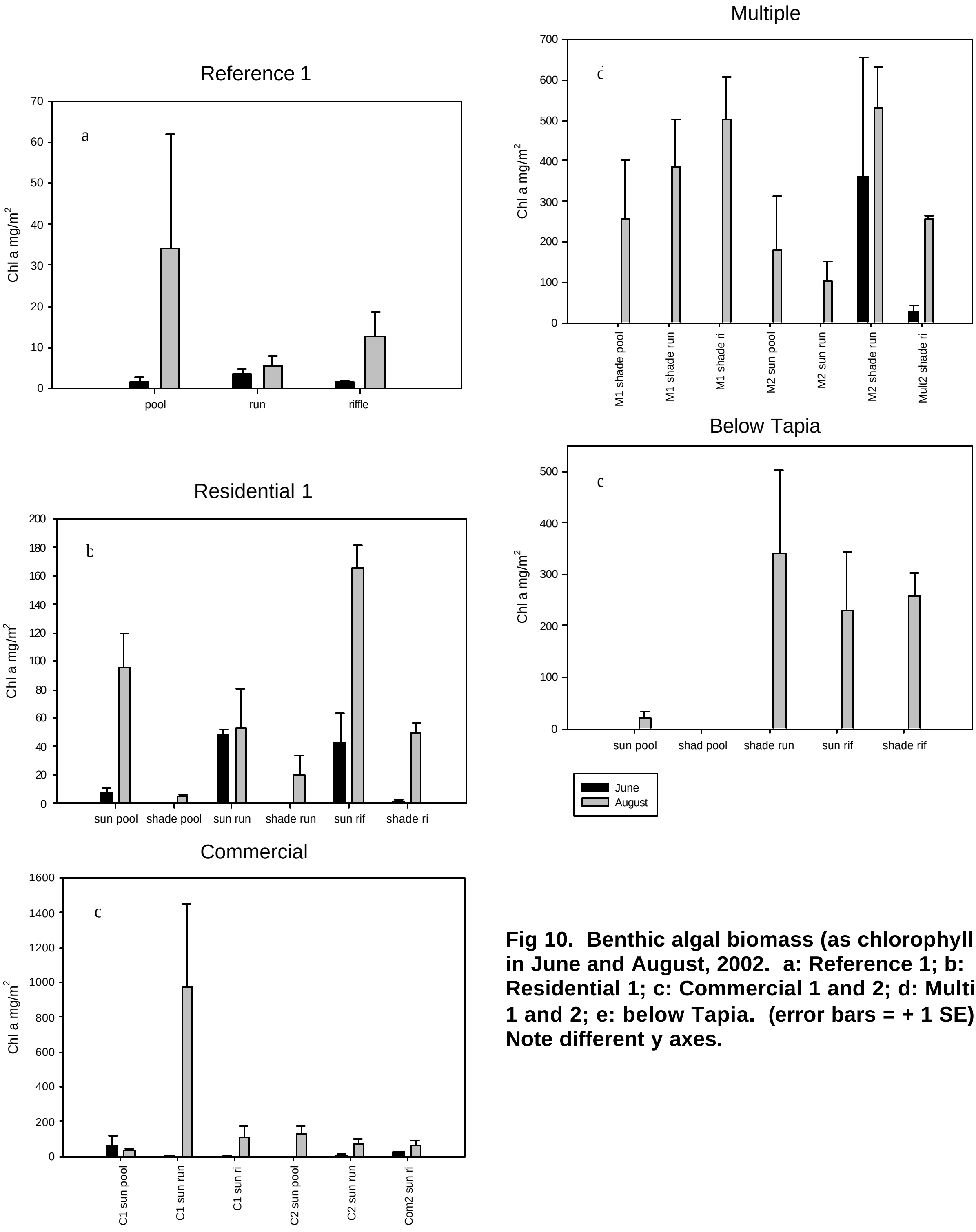

Fig 10. Benthic algal biomass (as chlorophyll a) in June and August, 2002. a: Reference 1; b: Residential 1; c: Commercial 1 and 2; d: Multiple 1 and 2; e: below Tapia. (error bars = + 1 SE). Note different y axes.

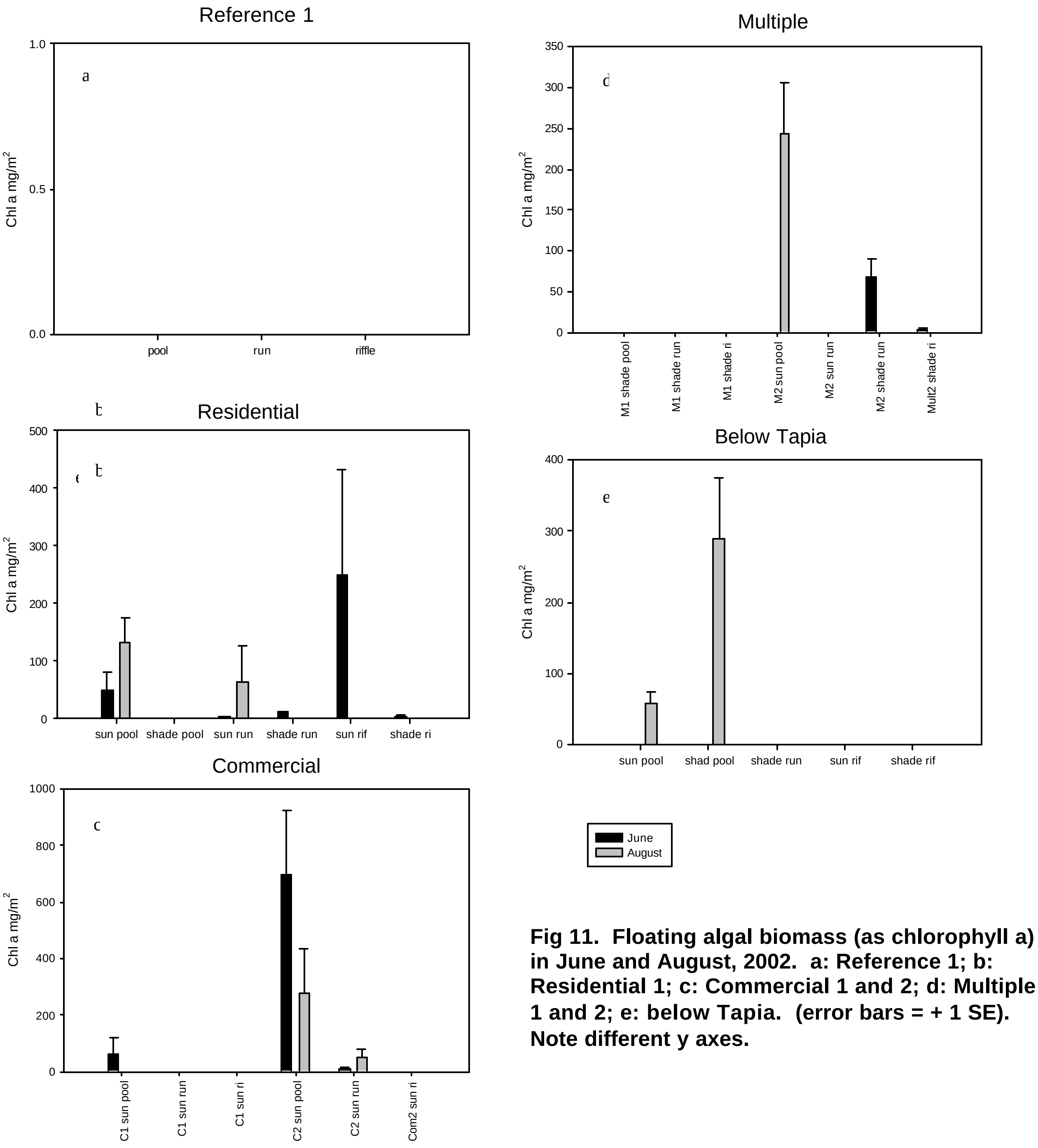

Fig 11. Floating algal biomass (as chlorophyll a) in June and August, 2002. a: Reference 1; b: Residential 1; c: Commercial 1 and 2; d: Multiple 1 and 2; e: below Tapia. (error bars = + 1 SE). Note different y axes.

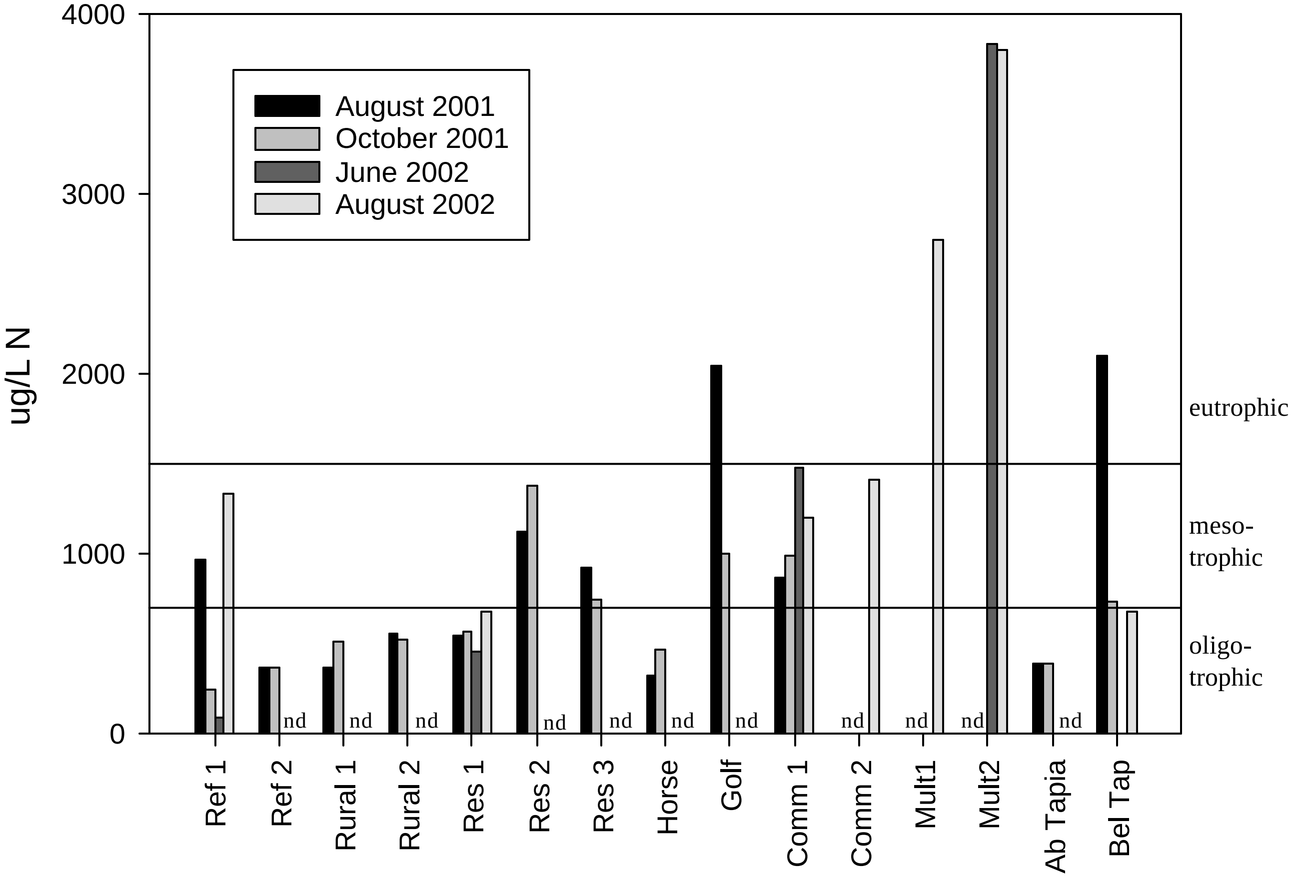

Fig. 12. Total nitrogen concentrations at stream sites in the Malibu Creek watershed, August and October, 2001, and June and August, 2002. Oligotrophic, mesotrophic, and eutrophic designations are according to Dodds et al. (1998) (see text). Note: not all sites were sampled on all dates (nd = no data, site not sampled on this date).

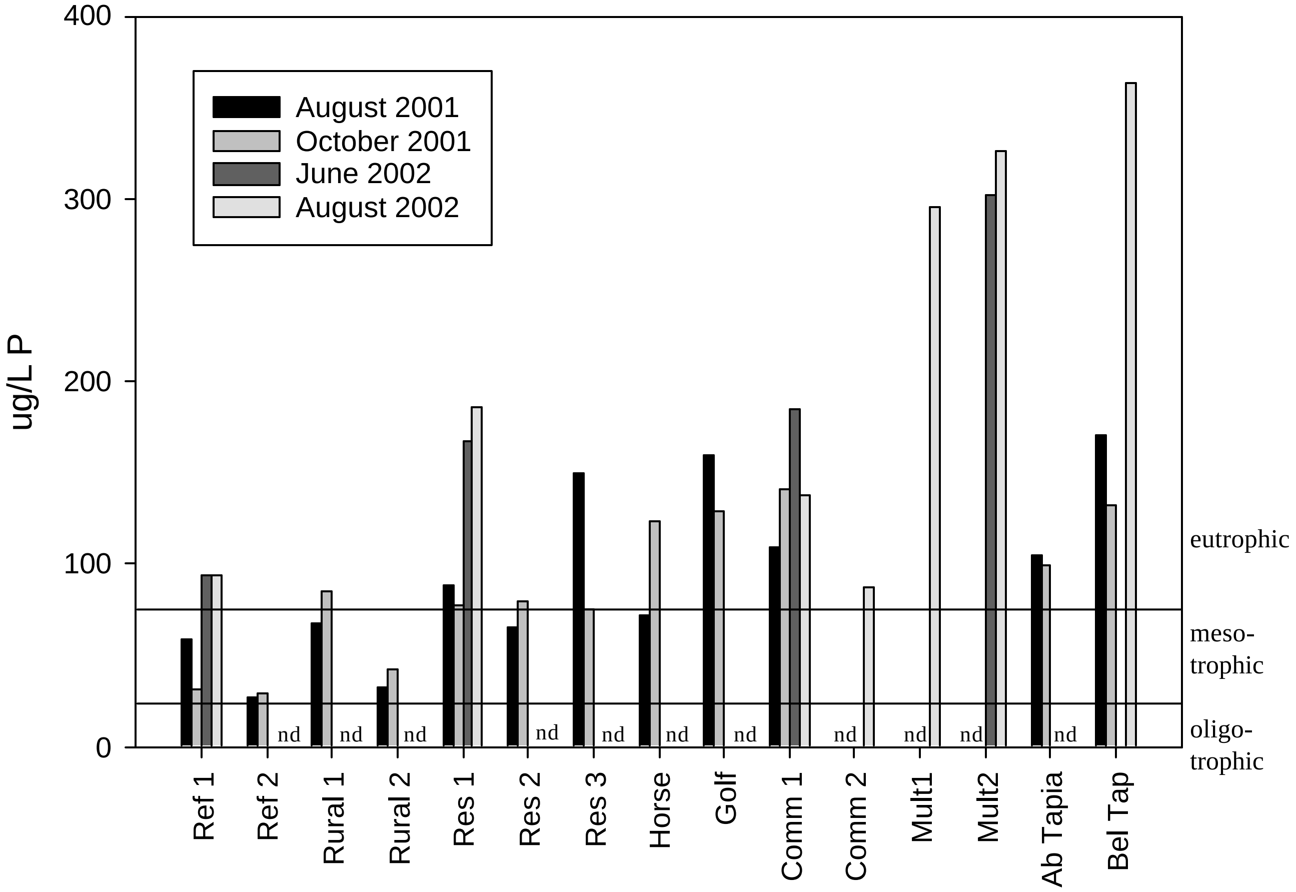

Fig 13. Total phosphorus concentrations at stream sites in the Malibu Creek watershed, August and October, 2001, and June and August, 2002. Oligotrophic, mesotrophic, and eutrophic designations are according to Dodds et al. (1998) (see text). Note: not all sites were sampled on all dates (nd = no data, site not sampled on this date).

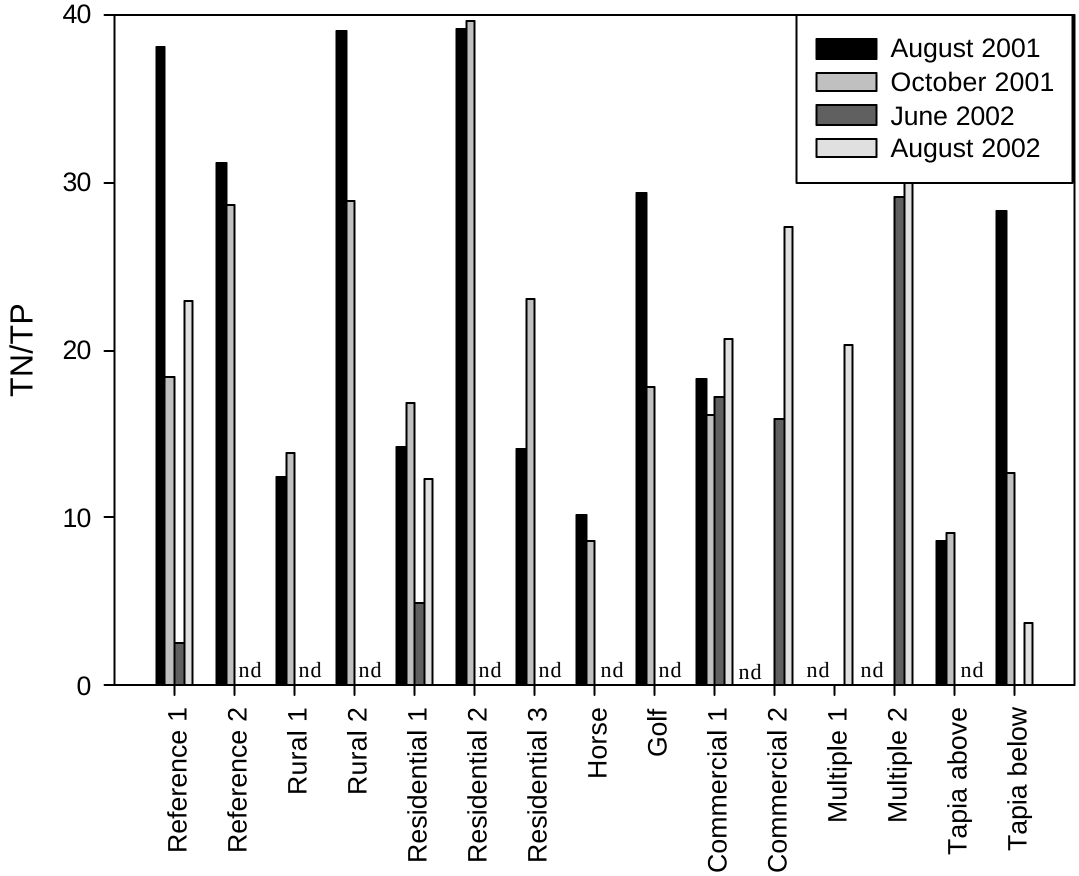

Fig 14. Molar TN/TP ratios at stream sites in the Malibu Creek watershed, August and Octo and June and August, 2002.

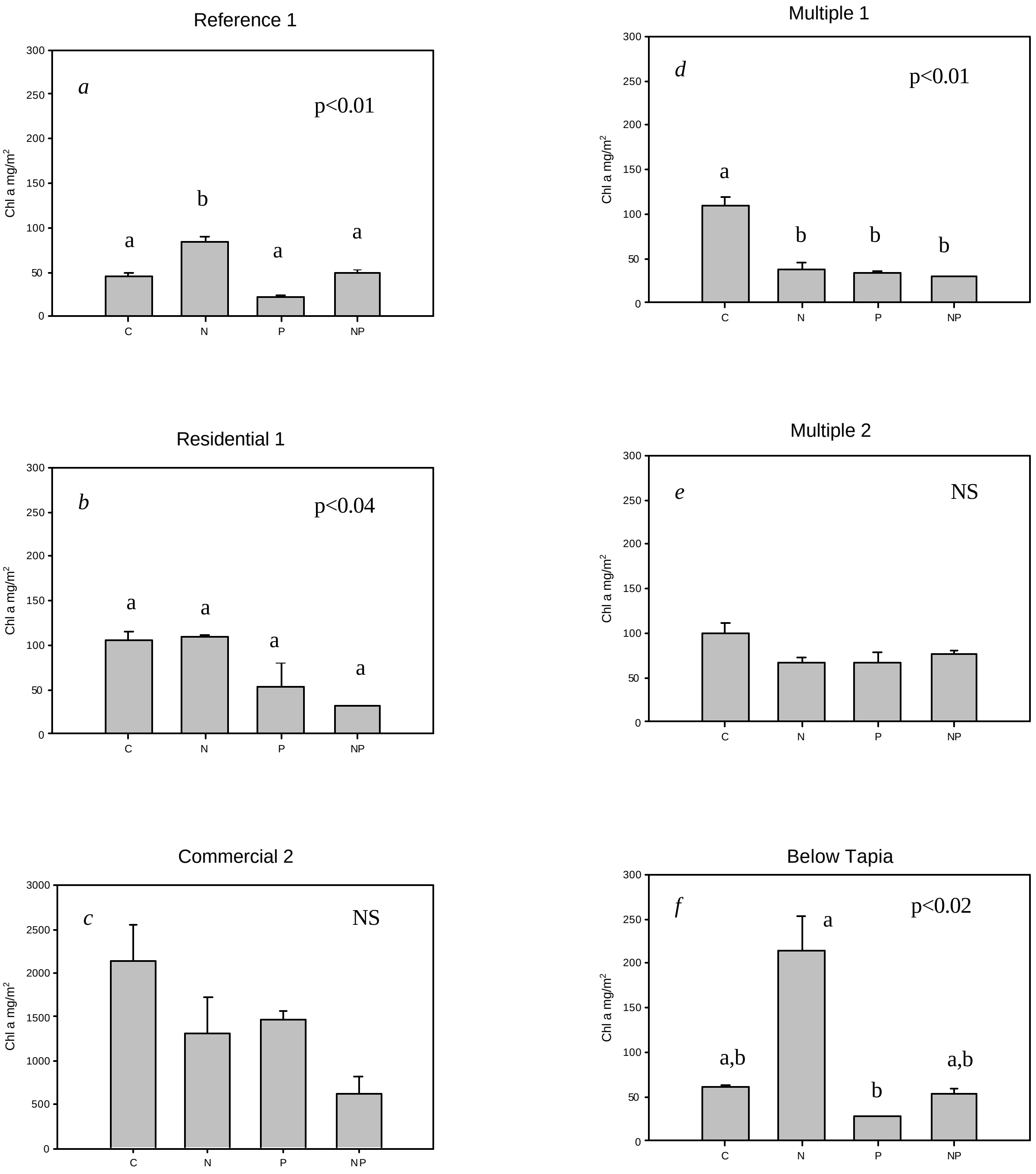

Fig. 15. Chlorophyll a levels on Nitex and agar substrata on NDS's at stream sites within the Malibu Creek watershed, September, 2002. p values represent the results of one-way ANOVAs testing for the effects of nutrient treatments on chlorophyll levels (NS = not significant, p>0.04). For sites showing significant effects of treatments on chlorophyll levels, Scheffe's multiple range test was performed to determine which treatments were different from each other. Treatments marked with the same letter are not significantly different (p>0.05). Note different scale of y-axis in 7c. Chlorophyll a levels on NDS from the below Tapia site should be compared to levels from other sites only with caution, because NDS from this site were deployed for a shorter time period than NDS from other sites (see text).

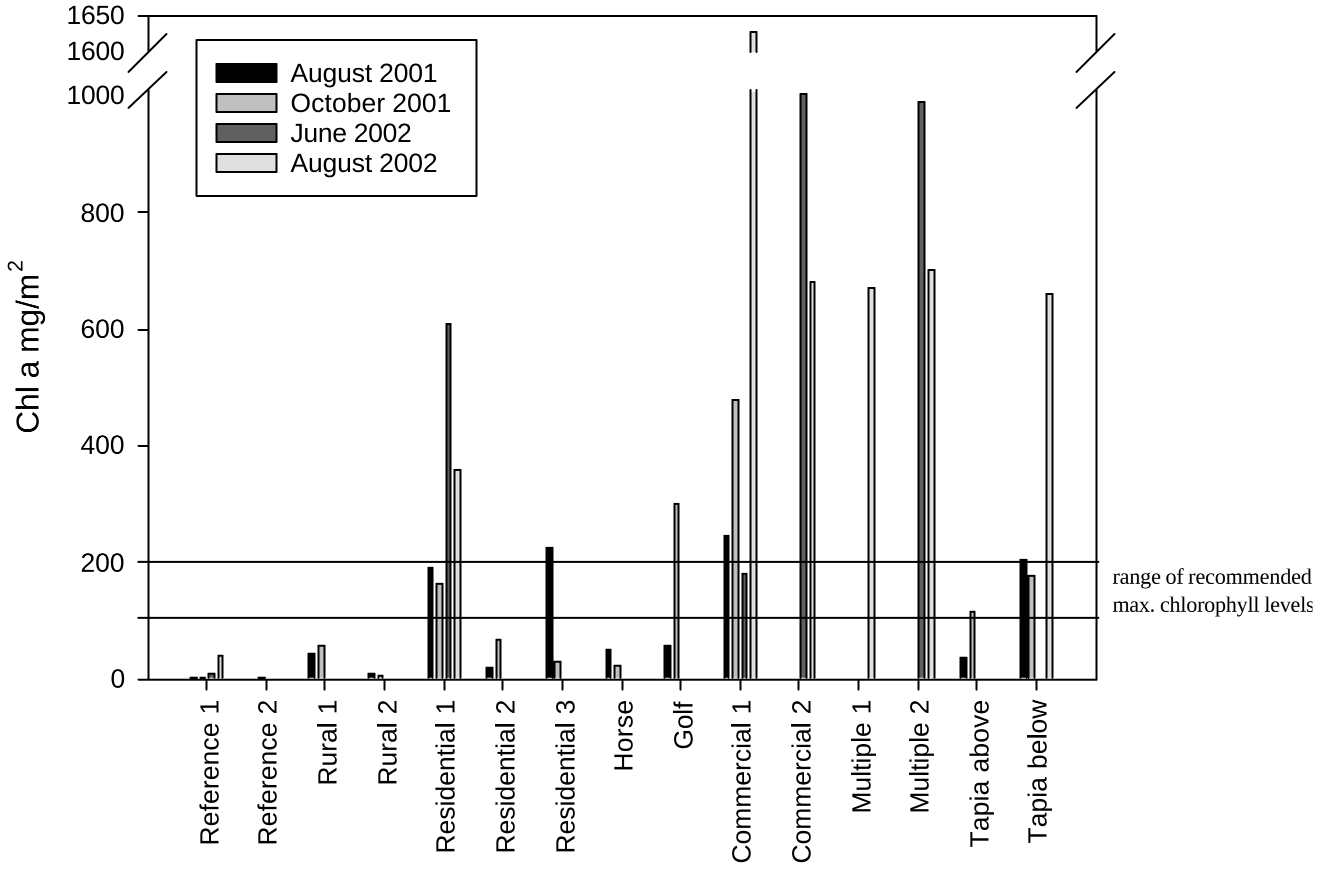

Fig. 16. Maximum total algal chlorophyll a concentrations measured at stream sites in the Malibu Creek watershed in August and October, 2001, and June and August, 2002. Note the break in y-axis. Reference lines indicate the range of recommended maximum levels of chlorophyll a required to protect the recreational and aesthetic values of streams (see Table 4).

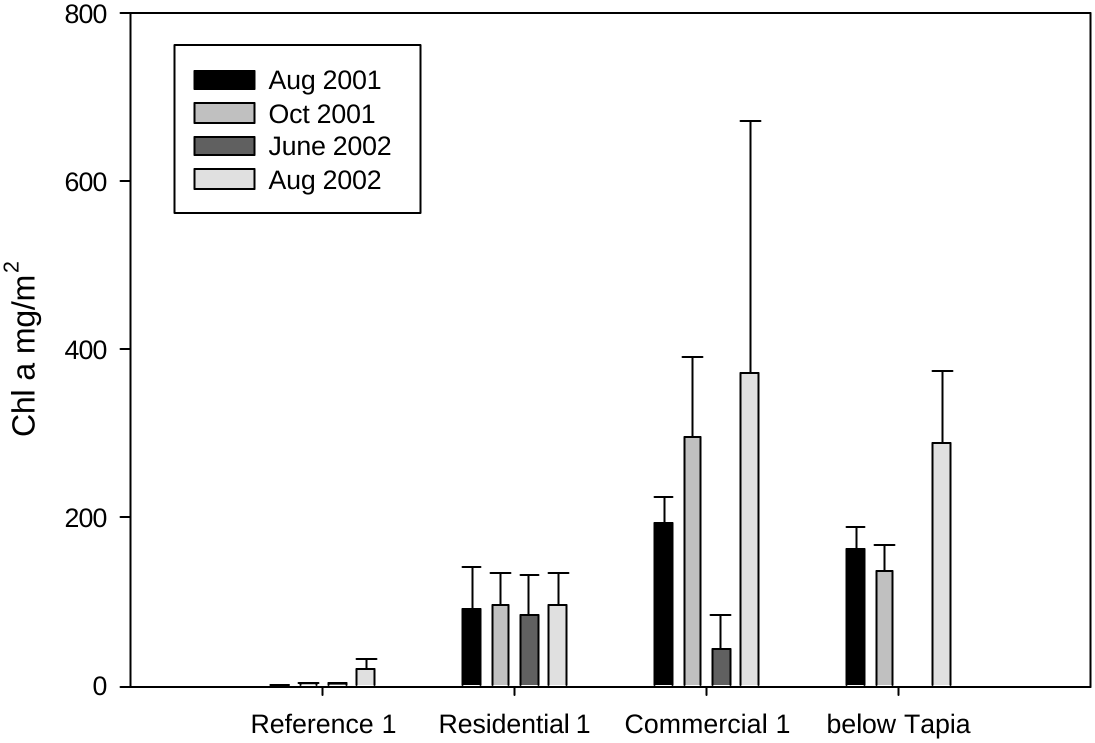

Fig. 17. Total algal chlorophyll a concentrations in the Malibu Creek watershed at sites sampled in both 2001 and 2002.

APPENDIX A.

TABLES

Table A.1. Longitude and latitude of our sampling sites in the Malibu Creek watershed. GPS data obtained from Garmin eMap, version 2.75.

Site	Latitude	Longitude
Open Space 1	W118.64719	N34.09257
Open Space 2	W118.74671	N34.19653
Rural 1	W118.70061	N34.07917
Rural 2	W118.68085	N34.09009
Horse	W118.78686	N34.11969
Golf	W118.79091	N34.15534
Residential 1	W118.76282	N34.17122
Residential 2	W118.79015	N34.18633
Residential 3	W118.82021	N34.18007
Above Tapia	W118.72922	N34.09662
Below Tapia	W118.70159	N34.07820
Commercial 1	W118.75773	N34.14968
Commercial 2	W118.75879	N34.14213

Table A.2. Percentage cover of macroalgal species at stream sites in the Malibu Creek watershed, August 2001. Values presented are mean ± standard error, n = number of samples.

Site	Macroalgae				*n*
	Cladophora	*Rhizoclonium*	*Enteromorpha*	*Spirogyra*	
Open Space 1	0	0	0	0	3
Open Space 2	0	0	0	0	4
Rural 1	0	40.0 ± 24.5	0	0	4
Rural 2	0	0	0	0	5
Golf	0	0	0	0	7
Horse	0	0	0	37.3 ± 15.3	5
Residential 1	0	39.6 ± 11.9	0.2 ± 0.2	1.4 ± 1.4	9
Residential 2	0	0	0	0	4
Residential 3	0	0	0	0	8
Above Tapia	0.4± 0.4	0	0	0	9
Below Tapia	22.2 ± 14.7	28.2 ± 12.1	13.1 ± 6.5	0	9
Commercial 1	0	53.6 ± 9.1	23.8 ± 7.4	0	9

Table A.3. Percentage cover of macroalgal species at stream sites in the Malibu Creek watershed, October 2001. Values presented are mean ± standard error, n = number of samples.

Site	Macroalgae				*n*
	Cladophora	*Rhizoclonium*	*Enteromorpha*	*Spirogyra*	
Open Space 1	0	0	0	0	3
Open Space 2	0	0	0	0	3
Rural 1	0	30.0 ± 19.1	0	0	6
Rural 2	0	0	0	0	7
Golf	0	0	0	0	7
Horse	0	0	0	33.3 ± 8.3	9
Residential 1	0	0	0	0.9 ± 0.6	9
Residential 2	0	0	0	0	4
Residential 3	0	0	0	0	7
Above Tapia	0	0	0	0	9
Below Tapia	9.3 ± 6.9	5.6 ± 5.6	2.8 ± 2.8	0	9
Commercial 1	0	0	48.9 ± 14.3	0	9

Table A.4. Percentage cover of macroalgal species at stream sites in the Malibu Creek watershed, June 2002. Values presented are mean ± standard error, n = number of samples. n.d. = no data available

Algal species by habitat	Open Space 1	Residential 1	Commercial 1	Commercial 2	Multiple 2
Sun pool, *n*=	*1*	*9*	*9*	*7*	*3*
Cladophora	0	0	0	0	0
Rhizoclonium floating	0	18.4 ± 10.1	0	89.1 ± 8.0	0
Rhizoclonium benthic	0	21.8 ± 8.0	0	10.9 ± 8.0	0
Enteromorpha floating	0	32.2 ± 13.9	24.0 ± 15.4	0	62.7 ± 31.5
Enteromorpha benthic	0	0	0	0	19.3 ± 13.8
Spirogyra	0	0	0	0	0
Unknown filamentous	0	0	0	0	0
Sun run, *n*=	*2*	*8*	*9*	*3*	*0*
Cladophora	0	0	0	0	n.d.
Rhizoclonium floating	0	0	0	3.3 ± 3.3	n.d.
Rhizoclonium benthic	0	34.0 ± 5.8	0	52.7 ± 20.3	n.d.
Enteromorpha floating	0	22.3 ± 13.1	9.6 ± 5.6	0.7 ± 0.7	n.d.
Enteromorpha benthic	0	4.0 ± 2.1	0	0	n.d.
Spirogyra	0	0	0	0	n.d.
Unknown filamentous	0	0	0	0	n.d.
Sun riffle, *n*=	*8*	*7*	*9*	*3*	*5*
Cladophora	0	20.6 ± 9.7	0	19.3 ± 19.3	0
Rhizoclonium floating	0	28.6 ± 18.4	0	0	0
Rhizoclonium benthic	0	13.1 ± 8.5	0	2.7 ± 1.3	0
Enteromorpha floating	0	0	0	0	3.6 ± 2.4
Enteromorpha benthic	0	0	0	0	0
Spirogyra	0	0	0	0	0
Unknown filamentous	0	0	0	0	0
Shade pool, *n*=	*0*	*0*	*0*	*0*	*0*
Cladophora	n.d.	n.d.	n.d.	n.d.	n.d.
Rhizoclonium floating	n.d.	n.d.	n.d.	n.d.	n.d.
Rhizoclonium benthic	n.d.	n.d.	n.d.	n.d.	n.d.
Enteromorpha floating	n.d.	n.d.	n.d.	n.d.	n.d.
Enteromorpha benthic	n.d.	n.d.	n.d.	n.d.	n.d.
Spirogyra	n.d.	n.d.	n.d.	n.d.	n.d.
Unknown filamentous	n.d.	n.d.	n.d.	n.d.	n.d.
Shade run, *n*=	*0*	*3*	*0*	*0*	*9*
Cladophora	n.d.	0	n.d.	n.d.	0
Rhizoclonium floating	n.d.	0	n.d.	n.d.	3.3 ± 3.3
Rhizoclonium benthic	n.d.	0	n.d.	n.d.	25.6 ± 8.2
Enteromorpha floating	n.d.	0	n.d.	n.d.	27.8 ± 11.8
Enteromorpha benthic	n.d.	0	n.d.	n.d.	1.6 ± 1.1
Spirogyra	n.d.	3.3 ± 3.3	n.d.	n.d.	10.0 ± 6.6
Unknown filamentous	n.d.	0	n.d.	n.d.	0
Shade riffle, *n*=	*0*	*3*	*0*	*0*	*3*
Cladophora	n.d.	0	n.d.	n.d.	0
Rhizoclonium floating	n.d.	0	n.d.	n.d.	0
Rhizoclonium benthic	n.d.	23.3 ± 11.7	n.d.	n.d.	13.3 ± 13.3
Enteromorpha floating	n.d.	33.3 ± 29.3	n.d.	n.d.	6.7 ± 6.7
Enteromorpha benthic	n.d.	0	n.d.	n.d.	0
Spirogyra	n.d.	0	n.d.	n.d.	0
Unknown filamentous	n.d.	0	n.d.	n.d.	0

Table A.5. Percentage cover of macroalgal species at stream sites in the Malibu Creek watershed, August 2002. Values presented are mean ± standard error, n = number of samples. n.d. = no data available

Algal species by habitat	Open Space 1	Residential 1	Commercial 1	Commercial 2	Multiple 1	Multiple 2	Below Tapia
Sun pool, *n*=	*3*	*9*	*9*	*9*	*0*	*7*	*9*
Cladophora	0	0	0	0	n.d.	0	0
Rhizoclonium floating	0	27.8 ± 8.8	1.1 ± 0.5	0	n.d.	0	0
Rhizoclonium benthic	0	0	0	0	n.d.	0	0
Enteromorpha floating	0	0.4 ± 0.4	3.3 ± 1.5	63.7 ± 16.7	n.d.	79.4 ± 14.0	0
Enteromorpha benthic	0	0	0	0	n.d.	4.6 ± 4.6	0
Spirogyra	0	66.4 ± 8.4	0	0	n.d.	0	91.6 ± 6.7
Unknown filamentous	0	0	0	0	n.d.	0	0
Sun run, ***n*****=**	*7*	*3*	*3*	*9*	*0*	*9*	*0*
Cladophora	2.9 ± 2.9	0	7.3 ± 4.6	1.2 ± 1.2	n.d.	0	n.d.
Rhizoclonium floating	0	9.3 ± 9.3	0	0	n.d.	0	n.d.
Rhizoclonium benthic	0	0	0	0	n.d.	16.7 ± 8.3	n.d.
Enteromorpha floating	0	0	0	18.0 ± 10.9	n.d.	0	n.d.
Enteromorpha benthic	0	0	0	3	n.d.	0	n.d.
Spirogyra	0	0	0	0	n.d.	0	n.d.
Unknown filamentous	0	0	0	0	n.d.	0	n.d.
Sun riffle, *n*=	*6*	*7*	*9*		*0*	*0*	*3*
Cladophora	16.0 ± 8.7	0	17.3 ± 5.2	10.3 ± 4.7	n.d.	n.d.	0
Rhizoclonium floating	0	0	0	0	n.d.	n.d.	0
Rhizoclonium benthic	0	0	0	0	n.d.	n.d.	0
Enteromorpha floating	0	0	3.6 ± 2.4	11.8 ± 4.6	n.d.	n.d.	0
Enteromorpha benthic	0	0	0.4 ± 0.4	0	n.d.	n.d.	0
Spirogyra	0	0	0	0	n.d.	n.d.	0
Unknown filamentous	0	0	0	0	n.d.	n.d.	0
Shade pool, *n*=	*0*	*9*	*0*	*0*	*3*	*0*	*3*
Cladophora	n.d.	0	n.d.	n.d.	0	n.d.	0
Rhizoclonium floating	n.d.	0	n.d.	n.d.	0	n.d.	0
Rhizoclonium benthic	n.d.	0	n.d.	n.d.	0	n.d.	0
Enteromorpha floating	n.d.	0	n.d.	n.d.	0	n.d.	0
Enteromorpha benthic	n.d.	0	n.d.	n.d.	0	n.d.	0
Spirogyra	n.d.	0	n.d.	n.d.	0	n.d.	100 ± 0
Unknown filamentous	n.d.	0	n.d.	n.d.	0	n.d.	0
Shade run, *n*=	*0*	*3*	*0*	*0*	*3*	*9*	*3*
Cladophora	n.d.	0	n.d.	n.d.	0	0	0
Rhizoclonium floating	n.d.	0	n.d.	n.d.	0	0	0
Rhizoclonium benthic	n.d.	0	n.d.	n.d.	0	0	0
Enteromorpha floating	n.d.	0	n.d.	n.d.	0	0	0
Enteromorpha benthic	n.d.	0	n.d.	n.d.	0	0	0
Spirogyra	n.d.	0	n.d.	n.d.	0	0	0
Unknown filamentous	n.d.	0	n.d.	n.d.	0	0	0
Shade riffle, *n*=	*0*	*3*	*0*	*0*	*4*	*7*	*3*
Cladophora	n.d.	0	n.d.	n.d.	0	0	0
Rhizoclonium floating	n.d.	0	n.d.	n.d.	0	0	0
Rhizoclonium benthic	n.d.	0	n.d.	n.d.	12.5 ± 12.5	0	0
Enteromorpha floating	n.d.	0	n.d.	n.d.	0	0	0
Enteromorpha benthic	n.d.	0	n.d.	n.d.	0	0	0
Spirogyra	n.d.	0	n.d.	n.d.	0	0	0
Unknown filamentous	n.d.	0	n.d.	n.d.	0	0	0

Table A.6. Average chlorophyll a concentrations ± standard error by site, August and October 2001. n=3 except n=1 at Reference 2 in October.

Site	August			October		
	Benthic	Float	Total	Benthic	Float	Total
Open Space 1	1.6±0.1	0.0	1.6±0.1	2.8±0.8	0.0	2.8±0.8
Open Space 2	0.5±0.2	0.0	0.5±0.2	3.2	0.0	3.2
Rural 1	6.5±1.9	12.7	19.2±12.5	17.3±4.3	15.7	33.0±13.0
Rural 2	4.9±2.4	0.0	4.9±2.4	3.2±1.9	0.0	4.9±1.8
Horse	7.5±0.6	28.2±15.5	35.7±14.8	19.8±0.7	0.0	19.8±2.5
Golf	32.9±12.6	0.0	32.9±12.6	144.3±78.2	0.0	144.3±78.2
High density 1	75.7±46.5	17.1±2.9	92.8±49.3	96.5±37.9	0.6	97.1±37.9
High density 2	15.9±2.9	0.2	16.1±2.9	36.2±15.8	0.0	36.2±15.8
High density 3	137.3±66.4	0.0	137.3±66.4	21.2±4.5	0.0	21.2±4.5
Tapia above	21.3±9.1	0.3	21.7±8.9	82.3±18.6	0.0	82.3±18.6
Tapia below	24.9±9.3	137.8±30.6	162.7±26.0	77.7±11.0	58.1±29.4	135.8±32.2
Commercial 1	46.9±30.3	146.5±12.2	193.4±32.5	242.5±95.0	52.8±24.8	295.3±97.0

Table A.7. Average chlorophyll a concentrations ± standard error (n=3) by habitat, June 2002.

Site	Habitat	Light	Benthic	Floating	Total
Open Space 1	pool	shade	1.5±1.2	0.0	1.5±1.2
	riffle	sun	2.3±0.3	0.0	2.3±0.3
	riffle	shade	0.6±0.1	0.0	0.6±0.1
	run	sun	2.1±0.6	0.0	2.1±0.6
	run	shade	5.2±1.7	0.0	5.2±1.7
Residential 1	pool	sun	6.7±4.2	48.9±30.5	55.6±34.4
	riffle	sun	42.2±21.6	249.9±183.4	292.2±161.8
	riffle	shade	1.6±1.1	3.5±3.0	5.1±2.2
	run	sun	48.5±3.9	2.6±2.1	51.1±1.8
	run	shade	0.0	12.9	12.9
Commercial 1	pool	sun	62.9±58.2	60.2±60.2	123.1±56.7
	riffle	sun	2.7±0.9	0.0	2.7±0.9
	run	sun	9.1±3.6	0.0	9.1±3.6
Commercial 2	pool	sun	0.0	698.4±224.9	698.4±224.9
	riffle	sun	30.8	0.0	30.8
	run	sun	12.3±8.8	9.7±5.7	22.0±13.6
Multiple 2	riffle	sun	13.7±7.1	0.0	13.7±7.1
	riffle	shade	28.0±14.4	2.8±2.8	30.8±12.2
	run	shade	362.6±294.7	68.1±21.0	430.6±280.9

Table A.8. Average chlorophyll a concentrations ± standard error (n=3) by habitat, August 2002.

Site	Habitat	Light	Benthic	Floating	Total
Open Space 1	pool	sun	75.0 ±70.3	0.0	75.0 ±70.3
	pool	shade	6.5 ±2.1	0.0	6.5 ±2.1
	run	sun	8.3 ±4.2	0.0	8.3 ±4.2
	run	shade	3.2 ±1.6	0.0	3.2 ±1.6
	riffle	sun	9.6 ±1.4	0.0	9.6 ±1.4
	riffle	shade	16.2 ±12.5	0.0	16.2 ±12.5
Residential 1	pool	sun	95.7 ±24.1	133.2 ±42.0	228.9 ±65.4
	pool	shade	4.8 ±1.1	0.0	4.8 ±1.1
	run	sun	52.8 ±27.5	63.6 ±63.6	116.4 ±89.3
	run	shade	19.8 ±13.9	0.0	19.8 ±13.9
	riffle	sun	165.1 ±16.5	0.0	165.1 ±16.5
	riffle	shade	50.0 ±6.7	0.0	50.0 ±6.7
Commercial 1	pool	sun	39.5 ±1.9	0.0	39.5 ±1.9
	run	sun	969.2 ±482.5	0.0	969.2 ±482.5
	riffle	sun	110.9 ±66.6	0.0	110.9 ±66.6
Commercial 2	pool	sun	133.1 ±44.4	279.9 ±153.7	413.0 ±169.2
	run	sun	73.0 ±31.8	50.5 ±29.8	123.5 ±46.1
	riffle	sun	66.9 ±26.5	0.0	66.9 ±26.5
Multiple 1	pool	shade	255.2 ±146.9	0.0	255.2 ±146.9
	run	shade	383.9 ±120.7	0.0	383.9 ±120.7
	riffle	shade	504.0 ±104.7	0.0	504.0 ±104.7
Multiple 2	pool	sun	178.9 ±135.9	242.8 ±64.0	421.8 ±139.9
	run	sun	102.6 ±49.3	0.0	102.6 ±49.3
	run	shade	531.1 ±100.2	0.0	531.1 ±100.2
	riffle	shade	255.9 ±8.5	0.0	255.9 ±8.5
Below Tapia	pool	sun	19.7 ±13.8	58.1 ±15.2	77.8 ±28.1
	pool	shade	0.0	543.6±75.1	543.6±75.1
	run	shade	341.3 ±161.1	0.0	341.3 ±161.1
	riffle	sun	230.3 ±112.6	0.0	230.3 ±112.6
	riffle	shade	258.1 ±44.2	0.0	258.1 ±44.2