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Substratum-associated microbiota

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METHODS

Epstein and Rossel (1995) tested three methods for dislodging attached bacteria from sediment particles as a prelude to bacterial counts, and found an ultrasonic cell disrupter was most effective. These authors then developed a protocol for bacterial enumeration that was reportedly superior to existing published protocols. A modification of a fluorochrome cyanodiotoly tetrazolium chloride (CTC) technique used for direct counts of respiring (i.e. viable) bacterial cells with epifluorescence microscopy was described by Pyle *et al.* (1995); the composition of the CTC-containing medium is apparently critical to obtaining quick, reliable bacterial counts from aquatic samples. Line-transect, point-intercept, and quadrat methods for quantifying percent coverage of macroalgal aggregates on stream bedrock were compared by Necchi *et al.* (1995a) and the pros and cons of these methods were discussed. Battley (1995) cautioned that ash-free dry mass can inaccurately estimate microbial cell mass because oxides and salts of phosphorus and sulfur contribute a greater percentage of ash than these elements contribute to cellular constituents.

Several alternative methods to direct microscopic cell counts for quantifying microbial colonization of solid surfaces in aquatic systems were described in 1995. Sonak and Bhosle (1995) demonstrated that staining of bacteria attached to metal (aluminum, stainless steel, and copper) or non-metal (polystyrene) surfaces with crystal violet, followed by spectrophotometric absorbance measures provided a simple, sensitive, and less time-consuming alternative to viable direct cell counts. Various fluorescently labelled lectins were employed by Michael and Smith (1995) to detect and describe the distribution of glycoconjugates laid down early (1–3 d) in microbial colonization of glass and marine macrophyte surfaces by marine microbes. This technique revealed spatial and chemical heterogeneity in early stages of biofouling that the authors surmise may lead to identification of microscale cues for biofouling. Bermingham *et al.* (1995) detected hyphae of the aquatic hyphomycete, *Angulospora longissima*, on leaves by using monoclonal antibodies to this fungus produced by mice. A nested Polymerase

Chain Reaction (PCR) technique developed by Arias *et al.* (1995) proved sensitive enough to detect 10 fg of DNA, or 12–120 cells, of the pathogenic bacterium *Vibrio vulnificus*.

Underwood *et al.* (1995) compared the efficiency with which microbial extracellular polymeric substances (EPS) could be extracted from several types of estuarine-sediment microbial assemblages using the phenol-sulfuric acid assay under varying storage and processing conditions. Estimates of the amount and type of carbohydrates within sediments varied with the taxonomic content of microbial assemblages, but also with storage conditions, sample size, extraction media, and time of extraction. The effects of microbial extracellular enzymes on decomposition rate of polysaccharides (cellulose and arabinoxylan) in sediment samples were estimated by using toluene to inhibit microbial uptake of the simple-carbohydrate products of decomposition without affecting extracellular enzyme activity (Boschker *et al.*, 1995). Leff *et al.* (1995) compared the efficiencies of three published methods (the Ogram, Tsai, and Jacobson methods) for extracting DNA from stream sediments, discussed the benefits and drawbacks of each, and identified circumstances under which each would be most appropriately used.

Several methods for examining the functional properties of benthic microbial communities were detailed. Jackson *et al.* (1995) used extracellular enzyme activity to infer organic-matter processing rates in a Lake Erie *Typha* wetland, as an alternative to the more conventional "litter-bag" technique. This method allowed assessment of *in situ* decomposition rates, particularly for fine particles, that cannot be estimated with litter bags. Microalgal and bacterial production in periphyton communities were measured simultaneously using ^{14}C -bicarbonate and ^3H -leucine incorporation, under a range of light intensities, and were found to be significantly and positively correlated (Neely and Wetzel, 1995). Responses to exposure of microbial communities containing both algae and bacteria, or bacteria alone, to a photosystem II inhibitor suggested that bacterial production and algal photosynthetic activity were coupled. Thomaz and Wetzel (1995) modified the [^3H]leucine incorporation method of quantifying bacterial biomass production (BBP) for use with epiphytic bacterial biofilms. Disruption of mat integrity in thicker biofilms increased ratios of BBP/biomass, a result not observed with thin, early successional biofilms. Kerner and Gramm (1995) designed a laboratory device that allowed them to study the microbial processes within settled layers of seston at sediment-water interfaces in lentic systems. They observed significant spatial and temporal heterogeneity in patterns of oxygen con-

sumption and nitrification within these 1-mm layers, and suggested that seasonal variation in these processes may influence benthic/pelagic coupling. Oxygen microsensors, which are often employed to examine microspatial heterogeneity in photosynthetic activity within attached microbial mats, can alter the properties of the diffusive boundary layer at the mat surface (Lorenzen *et al.*, 1995), but these disruptions had no effect on photosynthesis estimates, unless the mat surface being probed was very smooth. Leser (1995) designed three-phase (sediment/water/air) microcosms to study the fate, functioning, and ecological impact of microorganisms released into aquatic systems. By comparing similarities in microbial DNA between microcosms and a natural lake system before and after introduction of a specific bacterial strain into the microcosms, Leser was able to assess the time required for microbial communities to recovery to pre-introduction structure.

A number of authors employed benthic microbiota to assess changes in environmental quality. Kelly and Whitton (1995) introduced a diatom-based index that proved useful for assessing changes in trophic status of lotic systems. Five types of benthic-diatom indices (4 quantitative, 1 zonation based) were used to evaluate temporal and spatial variation in water quality in several rivers in England and Scotland (Kelly *et al.*, 1995). Evaluation of the results lead the authors to suggest that a generic level of taxonomic specificity is adequate for routine monitoring. Wångberg (1995) used a Pollution-Induced Community Tolerance (PICT) method to detect a gradient of heavy-metal impact on algal communities in a series of lakes located increasing distances from a smelter discharging these pollutants into the atmosphere. Non-metric multidimensional scaling (MDS) and the BIOENV procedure were employed by Rundle and Attrill (1995) to detect effects of pH changes on freshwater lotic meiobenthic crustacean communities. These techniques were effective at detecting pH effects, particularly when species-level data was used, but their effectiveness was reduced in circumstances where systems being compared exhibited large differences in stream physicochemistry.

ECOLOGY

Colonization and community development. The role of exopolysaccharides (EPS) in microbial colonization and growth on solid surfaces was investigated by a number of authors. A bevy of chemical tests and manipulative experiments conducted by Quintero and Weiner (1995) showed that the EPS capsule produced by a strain of marine *Hypomonas* was involved in the attachment of this bacterium to surfaces. Bhosle *et al.* (1995) described the chemical makeup and timing of production of the EPS produced by the marine fouling diatom, *Navicula subinflata*. An elegant series of tests conducted by Johnson *et al.* (1995) revealed that adhesion and stalk production by the marine fouling diatom, *Achnanthes longipes*, was stimulated by bromide and sulfate, and inhibited by iodide. Varying concentration of these elements in culture media resulted in varying EPS morphologies, ranging from pads, to stalk-pads, to stalks, to no EPS production.

Abarzua and Jakubowski (1995) published a review of the state of knowledge on the biochemical and biological methods for prevention of biofouling. They suggested that isolation of biogenic agents produced by some micro- and macroalgal species and marine invertebrates hold the greatest promise for developing effective antifouling substances. The propensity for green mussels to remain relatively free of epibiotic microorganisms was investigated by Becker (1995). Among the possible mechanisms examined to explain this phenomenon, shell extracts were found to have some

anti-bacterial and anti-fungal activity, while grazing of mussel shells by gastropods and filtration activity of the mussels themselves also reduced microbial fouling. Wieczorek *et al.* (1995) conducted laboratory experiments showing that colonization by larvae of the barnacle, *Balanus amphitrite* was inhibited by thin, early successional microbial biofilms, but that as these biofilms developed they facilitated larvae attachment. Gatenholm *et al.* (1995) noted that colonization of solid surfaces by barnacle larvae was inhibited if those surfaces were covered with 3–5% polyacrylamide gel containing immobilized marine gram-negative bacteria. The red macroalga, *Delisea pulchra*, produces halogenated furanones that strongly inhibit the colonization of barnacle larvae, marine bacteria, and green algal zoospores (Denys *et al.*, 1995).

Field and flume studies conducted by Harvey *et al.* (1995) showed that patterns of recruitment by bivalve larvae onto filamentous structures (simulating filamentous benthic algae and hydroids) could be explained by passive colonization mechanisms and were influenced by branch size and branching pattern on these benthic substrata. Differences in diatom colonization among two different species of seagrass (*Enhalus acoroides* and *Thalassia hemprichii*) and suspended glass microscope slides were examined by Sterrenburg *et al.* (1995). The taxonomic structure of colonization assemblages was influenced less by substratum type than by location, suggesting random colonization that was strongly influenced by transport of "old diatom assemblages" carried among substratum types on decaying seagrass leaves. Railkin (1995) reported that heterotrophic flagellates colonizing artificial substrata suspended in the White Sea comprised >40% of microbial species encountered, and that flagellate densities varied with depth (greater at 1 m than 5), substratum orientation (greater on vertical than horizontal surfaces), and intensity of longitudinal current. The ability of bdellovibrio bacteria to attach to various substratum types and to resist mechanical displacement from those surfaces was studied by Williams *et al.* (1995a). Bdellovibrios colonized quickly, varied in colonization rates among substratum types (oyster shells, glass, titanium, and steel), and proved to be relatively resistant to removal by physical agitation. Wellnitz and Sheldon (1995) investigated the mechanisms behind low algal colonization rates observed in stream habitats dominated by blooms of ferromanganese-depositing bacteria. Diatom abundance in experimental treatments receiving iron increased over time, but was considerably lower than in control or manganese treatments.

Development, glucose uptake, and enzymatic activity of epixylic biofilms was studied in four forested streams of varying pH within a New Zealand river catchment (Tank and Winterbourn, 1995). Microbial biomass was dominated by fungi and filamentous heterotrophs at all sites, pH appeared to have little influence on microbial activity, and results of radiotracer experiments indicated that epixylic biomass was assimilated by grazing amphipods. Turner *et al.* (1995a) used measurements of photosynthetic capacity to assess formation of midsummer blooms of metaphytic filamentous green algae (*Mougeotia* and *Zygonium*) in the littoral zone of an experimentally acidified lake. Photosynthetic rates during bloom initiation were high, despite lower water-column nutrient concentrations, and were controlled by algal crowding, irradiance, dissolved inorganic carbon, and water temperature. Heterotrophic biofilms developing in water-supply lines of dental air-water syringes displayed distinct successional changes in bacterial species composition and physiology during a 180-day period of community development observed by Tall *et al.* (1995).

Temporal and spatial distribution. Seasonal variation in microbiota. Changes in microphytobenthic chlorophyll *a* concen-

trations and primary production over a 2-yr period in an estuary in the Netherlands were studied by de Jonge and de Jonge (1995). Chlorophyll-*a* peaks in estuarine sediments, though variable among sites, were noted in early summer and autumn, and it was reported that sediment-inhabiting microalgae accounted for >17% of the total primary productivity in the system. Brotas *et al.* (1995) studied spatial heterogeneity and seasonal change in benthic algae in a Portuguese estuary, and reported that 62% of the variation in sediment chlorophyll concentration could be explained by sediment composition and tidal height. Clear seasonal patterns were not evident, primary because of variation induced by among-site differences in tidal influence. Changes in percent coverage and taxonomic composition of periphyton colonizing fibreglass panels placed in intertidal areas of Botany Bay, Australia were examined with respect to colonization time, season of exposure, and herbivory by grazing gastropods (Anderson, 1995). This study, which employed a computer-image analysis technique to quantify percent cover, demonstrated distinct yet complex patterns of seasonal variation in taxonomic structure and microspatial heterogeneity. Delille (1995), in an intensive >3-yr study of seasonal changes in heterotrophic bacterial populations in nearshore marine sediments off Antarctica, concluded that the large seasonal fluctuations in microbial communities that he observed were induced more by periodic organic enrichments than variation in temperature.

Changes in biomass and taxonomic composition of epiphyton growing on *Cladophora* and on the vascular macrophyte, *Ranunculus*, were monitored over an 18 month period in the River Itchen, U.K. (Shamsudin and Sleight, 1995). Diatoms dominated these assemblages in all seasons, but the identity of dominant species varied among habitats (vegetation types, drift, epilithon); production estimates made from colonization data indicated that epiphytic algae were the principal primary producers in this system. Seasonal changes in the vertical distribution of epiphytic microalgal community structure, chlorophyll biomass, and primary productivity on the emergent macrophyte, *Phragmites australis*, were detailed by Müller (1995). Vymazal and Richardson (1995) measured seasonal changes in epiphyton biomass, species composition, and nutrient content on three macrophyte species in the Florida Everglades. Epiphyton, which was dominated by cyanobacteria in summer-autumn and diatoms in winter-spring, contained high levels of calcium and very high nitrogen:phosphorus ratios. Griffith and Perry (1995) examined inter-annual variation of mid-winter/spring periphyton community structure in two small mountain streams in West Virginia in three consecutive years. Algal cell densities within the periphyton, which was dominated by the cyanobacterium, *Chae-maesisiphon*, were inversely correlated with inter-annual variation in the frequency of high stream discharge. Meiofaunal assemblages in a tidal freshwater marsh in Virginia changed seasonally in taxonomic composition, density of individuals, and spatial variability; these assemblages represent an understudied, but potentially important, trophic link to fish production in freshwater wetlands (Yozzo and Smith, 1995).

The influences of temperature and photoperiod on germination patterns of benthic resting stages of several marine diatoms species were investigated, in culture, by McQuoid and Hobson (1995) to better understand the role of these factors in generating commonly observed patterns of seasonal succession in marine phytoplankton. Agbeti and Smol (1995) examined connections between variation in several physical, chemical, and biological variables and encystment, and subsequent settling to the benthos, in freshwater chryso-phytes. Encystment varied among species in timing and rate, and was relatively uncommon, leading the authors to suggest that,

within a given lake, encystment activity may vary from year to year. Harris *et al.* (1995) collected water-column and sediment samples from a Scottish sea-loch during the spring diatom bloom in two consecutive years and reported on variation in species composition, which was dominated by *Thalassiosira*. A key for the 18 taxa encountered was provided.

Spatial variation within systems. Bergey *et al.* (1995) transferred *Cladophora*-bearing cobbles among current-velocity regimes in a northern California river and found that *Cladophora* from fast-, moderate-, and slow-current habitats did not differ in branching patterns, but supported different epiphyte densities and species compositions. *Cladophora* transferred from fast- to slow-current habitats exhibited greatest fragmentation. Densities of most benthic microcrustacea were inversely related to flow velocity among three stream reaches studied by Robertson *et al.* (1995). These authors suggested that some reach types may serve as flow refugia for these organisms during disturbance by spates. Filamentous algae on wave-exposed shores of a Danish lake provided refugia from wave disturbance to a suite of macroinvertebrate taxa, and was key in determining benthic invertebrate distribution in this system (Brodersen, 1995). Both salinity and degree of exposure to wave activity influenced cell densities and species composition in epiphytic diatom assemblages on the filamentous brown macroalgae, *Pilayella littoralis*, in the Baltic Sea (Snoeijs, 1995). Salinity was the major factor dictating diatom distribution, with significant inter-specific variation in salinity tolerance and optima noted, but species diversity was more influence by wave exposure.

Lowe and Pillsbury (1995) hypothesized that increases in light availability induced by zebra-mussel filtering activity in Lake Huron were responsible for large shifts in benthic algal community structure and biomass observed in that system from pre- to post-invasion of zebra mussels. Following proliferation of zebra mussels, benthic algal biomass, chlorophyll concentrations, and primary production rates have increased, and algal community structure has shifted from dominance by diatoms to dominance by Zygnematalean green algae.

An analysis of benthic diatom and dinoflagellate spatial distribution at three spatial scales in the Russian White Sea revealed the existence of several orders of aggregation likely reflecting effects of inter-species interactions at smaller scales and sediment composition and emersion regimes at larger scales (Saburova *et al.*, 1995). Surficial sediments collected from 60 sites across a tidal flat in the Yellow Sea, Korea, yielded 371 taxa and could be grouped into 8 taxonomically distinct clusters that correlated to differences in sediment composition (Oh and Koh, 1995). Williams *et al.* (1995b) studied the distribution of bdellovibrios on different substrata over a wide geographic area of Chesapeake Bay, over a range of temperatures and salinities. All samples taken from biofilms growing on oyster shells yielded bdellovibrios, even at temperatures below 10°C, with recovery from water-column samples and sediments occurring in 79% and 44% of these sampling areas, respectively. Reay *et al.* (1995) measured benthic-community metabolism, chlorophyll content, and exchanges of oxygen, dissolved organic nitrogen, and dissolved organic phosphorus across the sediment-water interface in sandy and silt-clay sediments in a Chesapeake Bay inlet over one year. Productivity was higher in sandy sediments, but estimates indicated that nutrient flux from both sediment types could supply 6–14% of annual phytoplankton nutrient requirements. Benthic bacterial abundance, bacterial production, and activity of 5 different hydrolytic enzymes were measured in surficial sediments, and in the overlying bottom water, along a depth gradient in the Celtic Sea (Poremba and Hoppe, 1995). Glycosidase activity

changed considerably with depth, suggesting differences in microbial population structure and/or availability and degradability of specific compounds on the sea floor. Helmke and Weyland (1995) noted that bacterial distribution in water underlying sea ice in Antarctica's Weddell Sea was homogenous, and bacterioplankton exhibited low metabolic activity, whereas within sea ice, bacteria were much more heterogeneously distributed, varying significantly in density and metabolic activity among ice of different consistencies.

Spatial heterogeneity in meiofaunal assemblages was studied by a number of authors. In a survey of meiofaunal assemblages in 5 mangrove areas off Zanzibar, emphasizing free-living nematodes, Ólafsson (1995) observed considerable variation in species representation among sites that differed in salinity, sediment grain size, and emersion regime. Benthic rotifers comprised between 2–20% of the meiofaunal community in a rainfill pool on the flood plain of Australia's River Murray, with significant spatial variation associated with distribution of macrophytes (Pontin and Shiel, 1995). Saunders-Davies (1995) examined rotifer distribution within a large macro-tidal lagoon on the coast of the United Kingdom, described a new species from these collections, and reported significant negative correlations between rotifer abundances and species richness and salinity. The distribution and taxonomic structure of metazoan meiofauna assemblages from deep-sea sediments (211–2080 m) in the Antarctic Weddell Sea was reported by Vanhove *et al.* (1995).

Spatial variation among systems. Douglas and Smol (1995) sampled epiphytic, epilithic, and surficial-sediment diatom assemblage from 35 clear, oligotrophic, high-arctic ponds, all of which freeze completely for 10 months of the year. Variation in taxonomic structure among these samples was best explained by differences in habitat type and alkalinity. Connections between the taxonomic structure and diversity of benthic algal and cyanobacterial assemblages and the chemical environment of six freshwater streams in Antarctica were studied by Pandey *et al.* (1995). Nitrogen-fixing cyanobacteria dominated assemblages at most sites, reaching highest abundances in mid-channel where dissolved nitrogen concentrations were lowest. Cazabon *et al.* (1995) sampled periphyton in a diversity of streams in the french mediterranean that varied in degree of permanence, degree of anthropogenic perturbation, discharge, and water source. Results suggested that periphyton communities were extremely sensitive to changes in environmental conditions. Necchi *et al.* (1995b) surveyed distribution and abundance of macroalgae in 44 stream segments in southeastern Brazil. Macroalgae distribution at all sites was patchy and diversity within assemblages was low, a pattern suggested to typify stream macroalgal assemblages.

Variation in benthic, periphytic, and planktonic rotifer assemblages collected from 60 sampling sites in high-altitude alpine habitats in the Austrian Alps was best explained by density and diversity of submerged vegetation, pH, conductivity, and temperature (Jersabek, 1995). Green (1995) investigated variation in periphytic and planktonic rotifer assemblages along a salinity gradient in a Malaysian estuary and in 2 nearby saline ponds. In the estuary, changes in rotifer species composition were tied to changes in salinity, but the taxonomic structure of the estuarine assemblage differed considerably from that of the nearby ponds. Meiofauna samples from five European estuaries, spanning a wide range of salinities and sediment types, were analyzed by Soetaert *et al.* (1995) for differences in overall meiofaunal community structure and nematode diversity. Salinity and sediment type proved much more influential than longitudinal proximity in determining similarities among samples.

Four studies examined the influence of catchment characteristics, including geology, land use, and disturbance history, on differences in periphyton characteristics among streams. Minshall *et al.* (1995) observed significant differences in taxonomic structure of both periphyton and macroinvertebrate assemblages, and in chemical characteristics in two adjacent headwater streams in Yellowstone National Park, one located in a catchment burned by the 1988 Yellowstone wildfires, and one not. Maier (1995) reported that differences in periphyton community structure between two fast-flowing, Austrian mountain streams were generated, primarily, by differences in catchment geology. A more detailed study of seasonal changes in one of these systems showed that variation in discharge played a strong role in generating annual variation in benthic-algal species composition and biomass. Biggs (1995) analyzed periphyton and water-chemistry data collected monthly over one year from 16 New Zealand streams, and used these data to develop a predictive model relating the interactive effects of disturbance frequency, land-use characteristics, and basin geology to periphyton biomass in lotic systems. An extensive study of periphyton communities within 34 stream reaches of the Yakima River Basin, Washington State, demonstrated that the physical/chemical factors that influence benthic algal biomass and structure depend strongly on land-use practices within a given drainage basin (Leland, 1995).

Effects of physical/chemical disturbance. The dynamics of phytoplankton communities in a shallow, subtropical, hypereutrophic lake were found to be strongly influenced by wind-induced resuspension of previously settled planktonic species and meroplankton from the benthos (Schelske *et al.*, 1995). These authors reported strong correlations between planktonic chlorophyll *a* concentrations and wind speed, and noted that cell resuspension is one mechanism by which dormant resting stages of many phytoplanktonic taxa are induced into physiological activity. de Jonge and van Beusekom (1995) investigated the importance of estuarine tidal flats as a source and sink for suspended mud and microphytobenthos, and determined the influence of wind-induced wave activity on these dynamics. Resuspension of benthic microalgae and mud could be described as a linear function of "effective windspeed" (windspeed averaged over 3 high-water periods preceding sampling), but the authors cautioned that relatively large areas must be considered to properly quantify the magnitude of exchange between benthos and water column in estuarine systems. Storm-induced suspension from the benthos significantly decreased concentrations of neutral lipids in male benthic harpacticoid copepods from the Gulf of Mexico, after only 2 d of resuspension; energy reserves in females were unaffected (Thistle *et al.*, 1995).

The effects variation in discharge and/or current speed on microbiota in lotic systems was the topic of several studies. Blinn *et al.* (1995) conducted *in situ* experiments in the tailwaters of the Colorado River below Glen Canyon Dam, AZ, to examine influences of emersion frequency, timing, and duration, and exposure to freezing during emersion on benthic algae (primarily *Cladophora* and its diatom epiphytes), and the implications of these effects on energy transfer from algae to primary consumers and, eventually, trout. Spatial and temporal heterogeneity of benthic rotifers in surficial sediments and interstitial hyporheic habitats in a gravel-bed stream, and the response of these assemblages to a spring spate, were discussed by Schmid-Araya (1995). The five common species varied in distribution, but all persisted through the disturbance due to protection within low-flow refugia or deeper dispersal into the hyporheic zone. Biggs and Thomsen (1995) employed a recirculating laboratory flow tank to quantify the shear stress required to dislodge periphyton communities of different

biomass, taxonomic composition, and physiognomy. Their results demonstrated that the same magnitude of shear-stress increases can have widely different effects depending on periphyton community characteristics. This same experimental flow tank was used by Hawes and Smith (1995) to determine the increases in water velocity and drag needed to dislodge the foliose green alga, *Ulva lactuca*, from benthic substrata. From their results, empirical relationships between drag coefficients and Reynold's number were developed that allowed estimation of the mean water velocity at which macroalgae of a given thallus size should detach. Momo (1995) developed a logistic model for biofilm growth that incorporated biofilm detachment and thresholds of resistance and illustrated that, above a critical current velocity, periphyton development is not stable.

Effects of acidification on periphyton communities were examined in two systems, one artificial, the other natural. Genter (1995) conducted a manipulative, artificial stream experiment that examined the individual and interactive effects of elevated aluminum concentrations and acidity on periphyton. Different suites of algal species responded under different treatment conditions, leading Genter to suggest that such changes may have consequences for food-web relationships in acid-stressed aquatic ecosystems. Acidification of a system within Ontario's Experimental Lakes Area increased respiration/photosynthesis ratios in epilithic assemblages, reduced net photosynthetic rates in the epilithon, and induced blooms of metaphytic filamentous green algae, which differed from the epilithon in physiological response to acidification (Turner *et al.*, 1995b).

Activity of attached or sediment-associated bacteria. A number of publications examined variation in microbial enzyme activities in benthic environments. Sinsabaugh and Findlay (1995) measured biomass and production of both fungi and bacteria, and activities of seven extracellular enzymes involved in organic matter decomposition in surface sediments, from four contrasting sites, to better understanding of linkages between microbial variables and ecosystem processes. Considerable variation in all of these factors was associated with variation in particle size of organic matter. Differences among streams of different pH in rates of microbial decomposition of leaf litter from three different vegetative sources were reported by Griffith *et al.* (1995). Performance of various microbial exoenzymes varied with pH, and these differences altered leaf-litter processing rates among streams. Variation in rates of leaf-litter processing along a habitat continuum from a high-gradient non-tidal stream down to a tidal, freshwater marsh was ascribed to differences in microbial respiration rates, physical abrasion, and activity of macroinvertebrate shredders (Hill and Perrotte, 1995). An analysis of electron transport system (ETS) activity within sediments from four beaver ponds lead Songster-Alpin and Klotz (1995) to suggest that beaver ponds can greatly increase microbial activity in stream reaches below them, and likely strongly affect some biogeochemical cycles in those systems. Lopez *et al.* (1995) tested the hypothesis that metabolic activity of bacteria within the sediments of seagrass beds depends on seagrass growth and availability of inorganic nutrients. Their results indicated that, on annual time scales, bacterial activity was directly related to seagrass production, but on seasonal time scales, bacteria and seagrass metabolism were inversely related because of competition for inorganic nutrients.

Linkages between surface and subsurface components of lotic system, as they relate to bacterial activity within stream sediments, were investigated by several authors. Through a variety of manipulative experiments and *in situ* measurements, Jones *et al.* (1995) concluded the microbial respiration within the hyporheic zone of

a desert stream was tightly coupled with primary production in the surface stream, and that spatial heterogeneity in hyporheic respiration rates reflects spatial heterogeneity in the distribution of zones of hydrologic downwelling that supply sediment-associated bacteria with dissolved organic carbon from the surface. The mechanisms behind spatial heterogeneity in hyporheic respiration rates in this system were detailed by Jones (1995). Enzymatic activities of hyporheic bacteria in downwelling zones within the Rhône River, greatly contribute to the ability of such areas to serve as efficient filters for biodegradable dissolved organic matter (Marmonier *et al.*, 1995). Temporal changes in microbial respiration rates in sediments of a prealpine river in Switzerland were tied to the occurrence of periodic high discharge events that flush particulate organic matter from stream sediments Naegeli *et al.* (1995).

Kairesalo *et al.* (1995) conducted experiments in flow-through chambers containing "live" and formaldehyde-"killed" sediments to determine the role of bacterial activity in controlling exchange of nutrients between sediments and the overlying water. Bacteria increased retention efficiency of both phosphorus and nitrogen. The release of phosphorus from sediments to overlying lake water was monitored in sediments from a hypereutrophic lake after settlement of *Microcystis* colonies obtained from different stages of bloom development (Brunberg, 1995). *Microcystis* colonies from benthic environments, or pelagic colonies from mid-bloom periods, were not readily decomposed and retained cellular phosphorus; colonies collected in October, during declines of pelagic *Microcystis* populations, were degraded more rapidly and released phosphorus that was subsequently taken up by heterotrophic bacteria within colonial mucilage. Burke (1995) reported that photosynthetic activity of benthic species of *Cyanothece*, *Spirulina*, and *Oscillatoria*, in a hypersaline lake was responsible for maintaining oxygen supersaturation in the hypolimnion of that system for up to six months. Over the course of a spring phytoplanktonic diatom bloom in a eutrophic lake, Middelboe *et al.* (1995) reported a shift from high bacterioplankton activity during early bloom stages, presumably fed by algal release of dissolved polymeric compounds, to high enzymatic activity of attached bacteria. Stehr *et al.* (1995) described variation in production of exopolymeric substances by an ammonium-oxidizing species of *Nitromonas* from the lower River Elbe, typically found attached to flocs, and discussed possible adaptive advantages of these exopolymers.

The role of substratum-associated microbiota in degrading or modifying chemicals added to sediments in aquatic systems was the topic of six studies. Kazumi *et al.* (1995) found a strain of the iron-reducing bacterium, *Geobacter metallireducens*, was able to degrade benzoate and phenol, but not the chlorinated isomers of these chemicals; these compounds were degraded, however, in their sediment-enrichment experiments, suggesting the presence of other, perhaps novel, Fe-reducing microbes. Kazumi and Capone (1995) showed that the carbamate pesticide, aldicarb, can be transformed in lake sediments under anoxic conditions by microbial consortia to yield products of direct benefit to methanogens within these sediments. Microorganisms indigenous to anaerobic coastal sediments in the German North Sea were able to reduce nitrated diphenylamine derivatives (Drzyzga *et al.*, 1995). Poly-beta-hydroxyalkanoate (PHA) was found to serve as a carbon source and electron donor for sulfate-reducing microorganisms in lake sediments (Urmeneta *et al.*, 1995). Chemical manipulation of river sediments taken from mercury-contaminated and non-contaminated sites by Oremland *et al.* (1995) revealed the importance of sulfate-reducing and methanogenic bacteria in oxidative demethylation of MeHg in anoxic environments. Rates of biodegradation of the

herbicide, atrazine, in wetland sediments receiving wastewater from a sugar mill were enhanced by varying degrees, by amending the sediments with several simple organic compounds (Chung *et al.*, 1995).

Roy and Knowles (1995) documented the effects of a suite of chemicals (nitrapyrin, allylthiourea, C_2H_2 , CH_3F , dicyandiamide, allylsulfide) on nitrification and methane-oxidation ability of freshwater, sediment-inhabiting microbes. They noted that allylsulfide provides a promising tool for investigating interactions between methanotrophs and nitrifying microbes in natural aquatic systems.

Patterns and processes within biofilms. Physical, chemical and biological processes within mature biofilms were investigated by several researchers. Freeman *et al.* (1995) demonstrated how the affinity of a given ion for entrapment within river biofilms can be altered by manipulating the ionic composition of the overlying water, and made an analogy between river biofilms and ion chromatography. Freeman and Lock (1995) found no change in bacterial densities within a thick biofilm when they removed all sources of dissolved organic substrates from the overlying water, and suggested that the polysaccharide matrix acts as a reserve source of organic C for microbiota within biofilms. The rate and stoichiometry of sulfate reduction by *Desulfovibrio desulfuricans* in biofilms varied considerably from that measured in suspended *D. desulfuricans* cells; the authors caution against the incorporation of kinetic and stoichiometric data derived from suspended cells into biofilm accumulation models (Okabe *et al.*, 1995).

Cyanobacterial mats covering intertidal stromatolites at Stocking Island, Exuma Cays, Bahamas exhibited zonation in mat consistency, from soft in near-shore areas, to crusty, and then hard at more offshore sites (Pinckney *et al.*, 1995a). These visually distinct mat types were composed of distinct phototrophic assemblages; under reduced irradiance, diatoms photoacclimated by increasing accessory photopigments, and cyanobacteria reduced the photoprotective carotenoid echinenone. Pentecost (1995) described the temperature optima of thermophilic cyanobacteria at three of Britain's four thermal springs that are exposed to light.

Interactions between nutrients and microbenthos. Based on responses of benthic diatom assemblages to experimental manipulation of nitrogen supply, Stevenson (1995) suggested that there is little evidence for the existence of tradeoffs between optimal reproductive and dispersal strategies in benthic diatoms, nor is there evidence for coadapted traits; the high species diversity within diatom communities may be due to the high diversity of niches available. Mulholland *et al.* (1995) used indoor artificial stream channels to test the hypothesis that upstream-downstream linkages produce longitudinal patterns in nutrient cycling and periphyton characteristics in stream ecosystems. Nutrient recycling supported a greater fraction of the algae downstream than upstream, while upstream algae depended more on stream-water nutrients; this increased nutrient cycling may compensate for longitudinal declines in nutrient concentrations in stream water, preventing large longitudinal changes in periphyton biomass and productivity. Samples collected from the inlet and outlet of a remote, high elevation (3593 m) wetland located in Front Range, Colorado demonstrated the capability of that system to retain nutrients (Toetz, 1995). Periphyton colonization in this systems was slow, probably because of low temperatures (6.8°C) and high UV exposure. Large-scale variation of intertidal nutrient concentrations, primary production, and consumer biomass were measured in the benthos around the South African coast (Bustamante *et al.*, 1995). Primary and secondary production directly correlated with nutrient concentrations, which were highest on the west coast, intermediate on the

south, and lowest on the east coast. A temperate intertidal cyanobacterial mat community was sampled monthly for 1 year and periodically enriched with nutrients to determine seasonal and nutrient-related impacts on community composition, growth, and N-fixation rates (Pinckney *et al.*, 1995b). Changes in mat biomass and community composition corresponded with seasonal shifts in N-fixation. Mats were N-limited, and the addition of N increased diatoms, while P increases stimulated N-fixing cyanobacteria. Pinckney *et al.*, (1995c) investigated the effects of decreasing salinity and increasing nutrients on production and N-fixation rates of cyanobacterial mats from hypersaline habitats. When salinity-induced osmotic stress was relieved, mats significantly increased their CO_2 and N-fixation rates; addition of nutrients had no effect. The diversity of nitrogenase genes in a marine cyanobacterial mat was investigated through amplification of a gene fragment to estimate the diversity of heterotrophic nitrogen fixation genes in such mats (Zehr *et al.*, 1995). Phylogenetic analysis showed that similar organisms clustered together, and numerous clusters indicate that there is a high diversity of heterotrophic N-fixing organisms in marine cyanobacterial mats.

Effects of nutrient enrichment on benthic microflora and microfauna were investigated in several studies. Microfauna of an arctic tundra stream did not respond to phosphorus enrichment alone, but their biomass doubled when both phosphorus and nitrogen were added (Ruble and Partusch-Talley, 1995). In stream reaches where insect grazer densities are high, microfauna may be regulated by grazers. Pan and Lowe (1995) tested the hypothesis that indirect effects of hydropsychid colonization onto nutrient-leaching clay pots would be greater than the direct effect of nutrient enrichment on the growth of benthic algal communities on these substrata in a small northern Michigan stream. They found a significant interactive effect of hydropsychid colonization and P enrichment on algal chlorophyll *a*, but not on algal biovolume or carbon fixation rate. In a Mediterranean stream, summer nutrient enrichment enhanced periphytic algal biomass, net and gross primary production, and respiration, however, photosynthetic capacity decreased, possibly due to self-shading (Guasch *et al.*, 1995). Nutrient-diffusing clay pots were used to assess nutrient limitation on epiphytic algal community structure and productivity in an eelgrass meadow (Coleman and Burkholder, 1995). While epiphyte productivities in enriched and non-enriched treatments did not differ, N-enrichment stimulated densities of the diatom *Cocconeis placentula*, and inhibited the growth of dinoflagellates and the diatom *Melosira* sp. Nitrogen uptake kinetics differ substantially among algae of different size (Hein *et al.*, 1995). Microalgae take up nitrogen much faster per unit of biomass than macroalgae at both high and low substrate concentrations because of the differences in the relative surface area to volume ratios of the two.

When nutrients and insecticides were applied to macrophyte (*Elodea*)-dominated laboratory drainage ditches, macrophyte biomass increased in response to the nutrient additions, and periphyton increased initially in response to both nutrient input and the loss of arthropod grazers, but then decreased as non-arthropod grazers began to increase (Brock *et al.*, 1995). Schuldts and Hershey (1995) demonstrated that carcasses of chinook salmon that remain in tributaries of Lake Superior following spawning runs can significantly elevate total phosphorus, SRP, and periphyton biomass. Salmon-derived nitrogen also appears to be incorporated into some mayflies and caddisflies, suggesting that these carcasses can be an important source of nutrients in streams even when the runs are relatively small.

A few studies focused on the effects of pollutants on periphytic biofilms. Using multivariate analyses and pollution indices, Lobo *et al.* (1995) demonstrated the structural changes in epilithic diatom assemblages in response to organic pollution and eutrophication in 28 rivers in the Tokyo metropolitan area. Water chemistry of 16 soft-water streams in the Netherlands was analyzed in 1990 and these data were compared with data collected in 1974 and 1981 to determine long-term changes in diatom assemblages and chemistry of streams polluted by atmospheric deposition of sulfur and nitrogen (van Dam and Mertens, 1995). While pH and sulfate did not change, nitrogen increased nearly 10-fold and alkalinity decreased by 30%. Tate *et al.* (1995) found benthic-algal species richness in a Rocky-Mountain stream influenced by acid mine drainage to be very low, due in part to abundant iron oxide deposits that sorbed phosphate. Injection of $^{32}\text{PO}_4$ into this stream showed that algal uptake and sorption on iron oxides were significant in removing phosphate, and that exposure to light can cause photoreduction of the P-iron oxide complex, releasing P back into the water.

Photosynthesis and the effects of irradiance. Several studies examined the effects of UV radiation on benthic algae. Bebout and Garciapichel (1995) found that moderate exposure to UV-B radiation caused cells at the surface of a cyanobacterial mat to bleach in color, and their photosynthetic rate to plummet. These authors suggested that migration of cyanobacteria into the deeper layers of the mat limits UV exposure. Schofield *et al.* (1995) indicated that UV-B radiation may target photosystem II and inhibit the carbon fixation rates for Antarctic frazil ice-algal communities. Another ice-algae study revealed that, while UV-B radiation inhibits the growth rate of a mat-forming cyanobacterium (*Phormidium murayi*), inhibition depends on the ratio of UV-B to UV-A as growth rates increased linearly with increasing UV-A (Quesada *et al.*, 1995). This supports the view that UV-B inhibition represents a balance between damage and repair processes controlled by separate wavebands. Banaszak and Trench (1995) observed the effects of UV radiation on the symbiotic relationships between two marine dinoflagellates and their anemone hosts. Exposure to UV depressed the synthesis of chlorophyll *a* and *c* in one dinoflagellate (*Symbiodinium microadriaticum*), while the second species (*S. californium*) developed multiple-layered cell walls after 4-wk exposure to UV. Seasonal variations in photosynthesis-irradiance responses by biofilms in two undisturbed Mediterranean streams, one shaded and one open, were studied over an annual cycle (Guasch and Sabater 1995). While the carotenoid/chlorophyll ratio indicated adaptation to high light regimes for algal communities in the open stream, and higher photosynthetic efficiency at lower light saturation suggested algae in the shaded stream were adapted to low light, additional environmental factors and algal community structure appear to exert a strong influence the community photosynthesis-irradiance parameters.

The effects of temperature and irradiance on benthic algae was addressed by several authors. The migratory patterns of lentic algae from sediment into open water appear to be related to more than light-dark cycles. Hansson (1995) suggests that some algal species may have receptors able to detect several environmental variables, including those associated with thermal stratification. O'Neal and Lembi (1995) described a preference for high light conditions by two filamentous mat-forming green algae (*Pithophora oedogonia* and *Spirogyra* sp.), that differed in temperature optima—*P. oedogonia* was a cold stenotherm, and *Spirogyra* was eurythermal (15 to 35°C). In a similar study, Graham *et al.* (1995) tested the optimal temperature and light conditions for net photosynthesis of *Spirogyra* by exposing this alga to 58 combinations of light and temperature

under controlled laboratory conditions. Optimum conditions were 25°C and 1500 $\mu\text{mol photon} \cdot \text{m}^{-2} \cdot \text{Sec}^{-1}$, and while *Spirogyra* can tolerate cool water and high irradiances, it cannot maintain positive net photosynthesis under conditions of high temperature and low light (e.g. when exposed to self-shading). Robinson *et al.* (1995) found that Antarctic under-ice algae employ complementary pigmentation (e.g. high fucoxanthin:chlorophyll *a* ratios in benthic algae produced enhanced green light absorption) and maximize absorption efficiency as adaptive strategies to low-light stress.

Vertical distributions of chlorophyll concentrations and photosynthetic parameters of sediment-associated microalgae were measured with a resolution of 1 mm in sandy sediments of Corpus Christi Bay, Texas (Macintyre and Cullen, 1995). A floe in the upper-most millimeter of all sediments contained highest proportions of benthic chlorophyll, yet photosynthetically competent algae were found well below the depth to which light penetrates the sediment. Nickel sorption by periphyton is positively related to light intensity, suggesting an important relationship between nickel sorption and photosynthesis which may be a result of active uptake, adsorption through cation exchange, or nickel precipitation (Gray and Hill, 1995).

Herbivory and Predation. Feminella and Hawkins (1995) quantitatively analyzed the results of 89 experimental studies published between 1972 and 1993 to compile a review summarizing the state of knowledge on effects of herbivory on periphyton in stream ecosystems. They reported that in 70–81% of the studies, ambient densities of grazers reduce periphyton biomass and altered community structure, while having little effect on periphyton productivity. Further, when periphyton biomasses are manipulated, grazer production and density are typically affected. These analyses suggest that stream herbivores regulate their food resources as much or more frequently than herbivores in other ecosystems, which, they suggest, contradicts the common view that stream communities are regulated primarily by abiotic factors. Another review, by Cattaneo and Mousseau (1995), summarized data from 27 publications on the removal rate of periphyton by grazers. These authors report that periphyton removal rate increased significantly with grazer body mass and food availability, and that a large portion of removal can be attributed to the physical activity of the grazers rather than by direct ingestion.

Several authors investigated the effects of grazers on periphyton. A comprehensive study by Lamberti *et al.* (1995) demonstrated negative effects of grazing on algal standing crop, export, and gross primary production. These effects were strongest for the caddisfly *Dicosmoecus gilvipes*, intermediate with *Juga silicula* snails, and weakest with *Baetis* mayflies but, at high grazer densities, responses in most algal parameters converged, suggesting that high grazing pressure, regardless of taxon, similarly affected periphyton. A study of grazing by *Dicosmoecus gilvipes* on periphyton under different levels of soluble reactive phosphorus, showed that grazing rates increased with increasing nutrient concentrations, and that, regardless of nutrient input, *D. gilvipes* tended to select stalked diatoms over filamentous blue-green algae (Walton *et al.*, 1995). Steinman *et al.* (1995) addressed the influence of periphyton biomass, irradiance, and herbivory by snails on phosphorus turnover in stream periphyton communities at the spatial scale of the mat and its boundary layer. Their results suggest that internal cycling may provide an important source of P in high biomass periphyton communities, and that grazing promotes nutrient turnover within the mat. Densities of periphytic algae found in the cleared zones around a sedentary grazer (*Petrophila confusalis*) were significantly lower than densities just outside these clearly demarcated grazing scars

(Bergey, 1995). Grazing by third-instar larvae altered diatom community composition, but fifth instar larvae had no effect on algal community structure, because they did not feed selectively. Herbivory by the caddisfly, *Agapetus boulderensis*, removed filamentous green and blue-green algae, and arrested algal succession at "early successional stages" in both high- (40 cm/sec) and low-flow (20 cm/sec) habitats in an open-canopy mountain stream (Poff and Ward, 1995). The survival of the spores of fecal microbes (e.g. fecal coliform, fecal streptococci, and *Clostridium perfringens*) in freshwater and marine sediments near sewage outfalls remained high throughout a 68 day experiment, however, these spores experienced a net die-off when cultured in the presence of predatory protozoans (Davies *et al.*, 1995). In the late 1970s eutrophication in the Dutch Wadden Sea may have been the cause of fouling of seagrass stands on tidal flats. Since then, densities of the mudsnail (*Hydrobia ulvae*) have increased, and field enclosure experiments verify that increases in the mudsnail cause significant decreases in epiphyton, which may positively effect the seagrass (Philippart, 1995).

A number of studies focused on the interaction between food quality and quantity on grazer/predator abundance. Kornijów *et al.* (1995) found that when three invertebrates (a snail, an isopod, and a chironomid) were offered partially decomposed and fresh *Mougeotia* (a filamentous green alga) and *Elodea nuttallii* (a macrophyte), all three preferred the decomposed materials; decomposed algae and macrophytes were more palatable, and had higher nutritional value than their fresh counterparts. In an enclosure study, Gresens (1995) demonstrated that chironomids, snails, and chydorid Cladocerans had qualitatively different effects on littoral periphyton, and that competitive interactions among grazers (at ambient densities) decreased grazer growth and development. The effects of spatial heterogeneity (grooves on the substratum) on the relationship between a trichopteran herbivore (*Agapetus monticolus*) and the epilithon on which it feeds was investigated in three colonization experiments in an upland stream (Gawne and Lake, 1995). While grooves on the substratum may increase food abundance for this grazer, this effect appears to vary with season. In an Arctic sea-ice microbial community, a protozoan grazer appeared to change grazing preference from bacteria to algae during algal blooms (Laurion *et al.*, 1995). When organic material was added to marine sediments in controlled experiments (Bak *et al.*, 1995), bacterial densities increased initially, followed by a 4–5 fold increase in flagellate densities, but when macrofauna were present, the flagellates tended to disperse deeper into the sediments. The diets of two polyphagous insect predators (*Plectrocnemia conspersa* and *Sialis fuliginosa*) were investigated in an English stream using gut analyses (Lancaster and Robertson, 1995). *Sialis fuliginosa* preferred ostracods over Cyclopoids, Harpacticoids, and Chydoridae, but *P. conspersa* did not feed selectively.

The interactions between meiofaunal grazers and their food sources were addressed. In non-vegetated intertidal habitats on the southwest coast of France, Montagna *et al.* (1995) demonstrated meiofaunal functional responses to changes in food (microphytobenthos) quality and quantity. While total meiofaunal community grazing rates increased in response to increased chlorophyll concentrations in the top 1 cm of sediment, only harpacticoids (and not ostracods or nematodes) increased in density. In a similar study, Borchardt and Bott (1995) measured the rate at which meiofauna in a small Pennsylvania stream grazed epilithic diatoms and bacteria. Their results suggested that meiofauna in this stream probably have little influence on bacterial production, but may have significant effects on diatom production when meiofaunal densities are high.

Austen and Warwick (1995) conducted a comparative mesocosm experiment to determine the effects of different qualities and quantities of natural foods on the structure of the meiobenthic communities from a polluted and an undisturbed estuary. While they found no significant treatment effects, the abundance of diatom-feeding nematodes declined over time in the undisturbed estuary, possibly because diatoms were not among the sources of food added to the mesocosms.

Isotopes were used to trace carbon through benthic food webs. Hall (1995) traced bacterial carbon through a stream food web and concluded that bacteria were more important in the diets of benthic shredders, scrapers, and collectors than predators. The mayfly, *Stenonema*, a biofilm scraper, was the most highly labeled of all invertebrate taxa. The relative importance of benthic and planktonic algae to lake food webs was elucidated by comparing carbon and nitrogen stable-isotope ratios of the constituent organisms (Hecky and Hesslein, 1995). When benthic primary productivity is light limited due to turbidity, phytoplankton carbon appears to dominate the diets of the primary consumers. Nitrogen and phosphorus were added to mesocosms to stimulate phytoplankton production and ultimately accrue fresh radio-labeled phytodetritus in the sediments (Widbom and Frithsen, 1995). Although polychaetes and mud anemones increased 37-fold and 12-fold, respectively, in response to the phytodetrital input, the authors estimate that 75% of the labeled organic carbon remained available for consumption indicating that food was not the limiting factor to these meiofauna.

Ecological and Taxonomic Surveys. A morphometric analysis of *Batrachospermum* sect. *Batrachospermum* was conducted, and revised descriptions and a new synoptic key of the species were provided (Vis *et al.*, 1995). The benthic brackish-marine diatom *Biremis lucens* was analyzed morphometrically, an SEM description of specimens from different localities in Europe, Africa, and Australasia was given, and aspects of taxonomy and ecology of this species were discussed (Sabbe *et al.*, 1995). Sabbe and Vyverman (1995) detailed the taxonomy, morphology, and ecology of some widespread representatives of the diatom genus, *Opephora*. Bakker *et al.* (1995) described phylogeographic relationships from nuclear rDNA internal-transcribed-spacer sequences among ten biogeographic isolates of the cosmopolitan green alga, *Cladophora vagabunda*. They concluded that *C. vagabunda* represents the predicted intermediate case between ancient tropical species that exhibit strong vicariance imprints, and recent cold-temperate to boreal lineages that do not. Genetic variation was examined within and among North Atlantic, North Sea, and Baltic populations of the benthic red alga, *Phycodrys rubens*, using allozymes and random amplified polymorphic DNA (RAPD) markers (Vanoppen *et al.*, 1995). While some distinct genetic groups were found, within-population RAPD variation was similar to or greater than between-population variation, reflecting a great deal of biological variability. Summer periphyton of some lotic and lentic habitats in Antarctica was surveyed, and 31 new records for the Antarctic continent were described and illustrated (Vinocur and Pizarro, 1995). Wilken *et al.* (1995) found 14 taxa of silica-scaled Chrysophytes from the peninsula of Nuussuaq, West Greenland; four of the taxa are new to Greenland. Faust (1995) described sand-dwelling dinoflagellate communities from South Water Cay and Carrie Bow Cay, Belize, and included descriptions of two new species. In a review article summarizing the ecology of the filamentous cyanobacteria, *Nostoc*, Dodds *et al.* (1995) underscored the many ecological adaptations of the genus that allow it to exploit a variety of terrestrial and aquatic habitats.

Several taxonomic contributions and distributional surveys of aquatic fungi were published in 1995. Taxonomic contributions included descriptions of six new epiphytic species from North Carolina saltmarshes (Kohlmeyer *et al.*, 1995a, b), a new epixylic species within the ascomycetes from tropical streams in Australia and Brunei (Hyde, 1995a), three new ascomycetes genera and six new species from an Australian tropic river system (Hyde, 1995b), and a new freshwater genus and species within the lophiostomataceae from submerged wood substrata in northern Queensland, Australia (Hyde, 1995c). Iqbal *et al.* (1995) surveyed freshwater hyphomycetes that were endophytic within the roots of three tree species growing on the banks of a canal in Pakistan. A survey of Ingolidian fungi within stream foam in the Gredos and Bejar mountains of central Spain yielded 66 species, 52 of which were strictly aquatic (Decscals *et al.*, 1995a) and 112 spore forms, 20 of which likely belong to undescribed taxa (Decscals *et al.*, 1995b).

Distribution and ecology of aquatic fungi. Several contributions to the proceedings to a symposium on mangrove ecosystems focused on various aspects of fungal ecology. Hyde and Lee (1995) reviewed the state of knowledge on mangrove fungi, with emphasis on biogeography and biodiversity, host specificity, spatial distribution across environmental gradients and on plant-specific scales, and the role of these organisms in nutrient cycling and detritus processing. Growth and ascocarp formation of three fungal species was investigated in mixed and single cultures on wood from three different sources (Tan *et al.*, 1995). Time required for ascocarp formation varied both interspecifically and with substratum type, and was delayed in mixed cultures, suggesting a role of interference competition. Alias *et al.* (1995) reported on the specificity of fungal species for particular types of mangrove wood, and compared taxonomic structure of fungal assemblages in three mangrove ecosystems in Malaysia. Distinct patterns of vertical zonation in taxonomic structure of fungal assemblages growing on stems of an herbaceous mangrove were attributed to variation in the nature of the substratum and degree of emersion due to the influence of tides (Sadaba *et al.*, 1995). Labyrinthulomycetean fungi were found to colonize leaf discs immersed in mangrove swamps within 24 h. Data from *in vitro* lab experiments and observations by scanning electron microscopy, suggested that these fungi played a key role in leaf decay in these systems (Bremer, 1995).

The role of aquatic fungi in leaf decay was examined in a number of other systems, as well. Suberkropp and Chauvet (1995) demonstrated, through reciprocal transfer experiments between a hardwater, nutrient-rich stream and a softwater nutrient-poor stream, that fungal activity and consequent rates of decay of yellow polar leaves were very sensitive to concentration of water-column nutrients and pH. The findings of a study on the relative influence of bacteria and fungi in the breakdown of three types of leaf material in a large river indicated that, as with small headwater streams, fungi play an eminently important role in this biological process (Baldy *et al.*, 1995). Microbial assemblages on leaf blades of the emergent sedge, *Carex*, in varying states of decay (i.e. standing-senescent, standing-dead, and recently fallen), were examined to study changes in productivities of microbial decomposers at different stages of decomposition (Newell *et al.*, 1995). It was suggested that fungi partially degrade plant lignocellulose during standing decay, followed by bacterial decomposition of this material after leaf fall and breakup. Fungal colonization of alder leaves was 1–2 wks more rapid than colonization of *Eucalyptus* leaves in a Portuguese stream, but this difference was greatly reduced if eucalypt leaves were first extracted with acetone to lower phenolic and tannin content (Bärlocher *et al.*, 1995).

Pattee and Chergui (1995) used existing knowledge of aquatic fungal ecology to assess which of two hypotheses about the spatial and temporal organization of lotic systems (the river habitat template [RHT] and patch dynamics concept [PDC]) was supported. Of the few fungal traits that could be employed in these tests, all were consistent with the RHT hypothesis. Mishra (1995) described the distribution of microfungi, in connection with physicochemical measurements, among various habitat types within a subtropical, eutrophic lake in India. Lecampionsumard *et al.* (1995a) described an unusual, possibly pathogen/host, interaction between a group of marine fungi and live coral, *Porites lobata*. Invasion of fungal hyphae into coral tissue induces deposition of new skeletal tissue by the coral.

Miscellaneous. Lecampionsumard *et al.* (1995b) provided detailed descriptions of the sequence of colonization and successional changes within a diverse assemblage of euendolithic microbiota that bore into the coral, *Porites lobata*. Variation in the reproductive life-history characteristics (i.e. occurrence of sexual larvae, colony size, number of statoblasts, and number of zooids) of a common freshwater bryozoan, *Cristatella mucedo*, sampled from both lotic and lentic habitats in central Finland was described by Uotila *et al.* (1995). Life-history data on age-specific life expectancy for a marine meiobenthic harpacticoid copepod, *Amphiascus tenuiremis*, was reported (Green *et al.*, 1995); maximum longevity was 21.5 wks. The propensity for some caddisfly larvae to incorporate any of 13 species of live freshwater red algae into their cases was documented by Sheath *et al.* (1995) using light and scanning-electron microscopy.

Doolittle *et al.* (1995) documented the ability of bacteriophage T4 to infect *Escherichia coli* when these bacteria are growing within a biofilm; previous assumptions held that such cells were protected from infection by the biofilm exopolymeric matrix. The different mechanisms by which diatom species form flocculent aggregates, or are incorporated into such aggregates, were studied in the laboratory by Crocker and Passow (1995). These authors discussed the implications of such aggregations on diatom settlement to the benthos following phytoplanktonic blooms. Moyer *et al.* (1995) characterized the phylogenetic diversity of bacteria within microbial mats associated with a hydrothermal vent system off Hawaii, and identified 11 genetically distinct bacteria strains from this assemblage.

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Effects of chemicals on microorganisms

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Microbial responses to chemicals manifest themselves in a variety of forms depending on the chemical, the type of microorganism, the concentration, the exposure time, and other chemical, physical, biological, and environmental factors. Barriers to quantifying the effects of chemicals on microorganisms are frequently related to methodological or analytical limitations. Recent developments in methodologies used to evaluate chemical-microbial interactions are summarized in this paper. A brief overview of recent studies on microbial responses to specific chemicals is provided in tabular form categorized by chemical and microorganism.

MEASUREMENT METHODS

A summary of methodologies used to evaluate the effects of chemicals on microorganisms is given in Table 1. The tests vary in terms of the organism used, the analytical techniques, the types of contaminants, sensitivity, and time required.

EFFECTS OF ORGANIC CHEMICALS ON MICROORGANISMS

Studies in which the effects of organic chemicals on microorganisms were quantified are summarized in Table 2. The table is organized alphabetically by type of organism and grouped alphabetically by the chemical name. The majority of the studies were conducted using bacteria, with some studies based on algae as a test organism, and some studies based on fungi and protozoa.

EFFECTS OF INORGANIC CHEMICALS ON MICROORGANISMS

A summary of studies that focused on the effects of inorganic chemicals on microorganisms is given in Table 3. Table 3 is organized alphabetically by chemical name and for each chemical studies are grouped by organism type to facilitate comparison of study results for a given chemical on different types and species of microorganisms. Studies that were based on mixtures of chemicals are summarized at the end of the table and typically were based on mixtures of heavy metals.

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