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## Substratum-Associated Microbiota

Christopher G. Peterson

Nancy Tuchman

Loyola University Chicago, [ntuchma@luc.edu](mailto:ntuchma@luc.edu)

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292. Masetti, D., *et al.*, "Deep-water Asymmetric Cycles and Progradation of Carbonate Platforms Governed by High-frequency Eustatic Oscillations (Triassic of the Dolomites, Italy)." *Geology*, **19**, 336 (1991).
293. MacLeod, N., and Keller, G., "Hiatus Distributions and Mass Extinctions at the Cretaceous/Tertiary Boundary." *Geology*, **19**, 497 (1991).
294. Carpenter, S. R., and Leavitt, P. R., "Temporal Variation in a Paleolimnological Record Arising from a Trophic Cascade." *Ecology*, **72**, 277 (1991).
295. MacDonald, G. M., *et al.*, "Radiocarbon Dating of Limnic Sediments: A Comparative Analysis and Discussion." *Ecology*, **72**, 1150 (1991).

## Substratum-associated microbiota

Christopher G. Peterson, Nancy C. Tuchman

### METHODS

Several new methods were introduced for the quantitative and qualitative assessment of bacteria on natural substrata. Poglazova *et al.*<sup>1</sup> introduced a rapid sensitive spectrofluorimetric method for quantifying bacterial cell densities on substrata that uses the fluorescent dye, fluorescamine, which reacts specifically with microbial amino acids and proteins. This same group of authors<sup>2</sup> devised a sensitive bacterial counting method specifically for soft sediment-associated bacteria, which entailed separation of microorganisms from sediments, followed by staining with fluorescamine and subsequent counting using microscopy. Another numerical-quantification method for sessile bacteria on submerged surfaces using DAPI stain and counting cells via epillumination fluorescence microscopy was reported to be highly specific and sensitive, yielding higher bacterial counts than standard plating techniques.<sup>3</sup> A method for separating bacteria from meiofauna (namely marine nematodes and foraminifera) in soft sediments and determining biomass of both groups using semi-automatic image analysis was introduced.<sup>4</sup> Ford *et al.*<sup>5</sup> proposed an image analysis system to quantify chemotactic movement of bacteria along an artificially constructed chemical gradient in a stopped-flow diffusion chamber. Brandl and Hanseimann<sup>6</sup> compared five methods for extracting porewater from sediments for chemical evaluation of microbial metabolic processes and suggested that the equilibrium diffusion technique works most satisfactorily. A pyrolysis-mass spectrometry method was used to characterize exopolymers from a diverse collection of aquatic bacteria isolated from marine and freshwater habitats.<sup>7</sup> Newell and Fallon<sup>8</sup> described a method to estimate instantaneous growth rates for ergosterol-containing fungi on dead aquatic grasses by measuring rates of radiolabeled acetate incorporation into ergosterol.

Some methods for measuring algal abundance and productivity have been recently published. Voltolina<sup>9</sup> compared three methods commonly used to detach diatoms from culture flasks and homogenized the samples. He reported that sonication is

significantly more effective at removing and homogenizing cells with minimal damage to cell frustules than other methods. Cattaneo and Roberge<sup>10</sup> discussed the inefficiency of using a brushing syringe sampler to completely remove natural periphyton from hard surfaces in streams. They suggested that relative abundance of tightly adhering algal species increase with increases in flow rate, rendering the sampler less effective in fast flowing waters than in lake systems. A method for separating and concentrating living dinoflagellate resting cysts from marine sediments using density-gradient centrifugation was proposed.<sup>11</sup>

Fuller and Bucher<sup>12</sup> described chambers for measuring algal primary production in streams in which natural algal assemblages grown on tiles are rotated through a chamber containing filtered stream water during incubation with  $\text{NaH}^{14}\text{CO}_3$ . Carpenter *et al.*<sup>13</sup> analyzed the artifacts created by measuring primary productivity and nitrogenase activity of coral reef algal turfs in enclosure chambers. They found that both primary productivity and nitrogenase activity changed under different flow rates and between oscillatory and vortex flow, suggesting that these processes depend on ambient flow speeds and boundary-layer dynamics. A paper described a  $^{14}\text{C}$  percolation technique for measuring primary productivity of microalgae in intact sediment cores and compared results of this method with the slurry and unpercolated techniques.<sup>14</sup> The use of gravity cores in sediments of high porosity can account for major compression within the top 15 cm of sediment, according to Crusius and Anderson,<sup>15</sup> while freeze coring eliminates this artifact. Boland and Rowe<sup>16</sup> detailed the construction of the GOMEX (Gulf of Mexico) box sediment corer and described its advantages over the Reineck spade corer.

### ECOLOGY

**Community development and structure.** Stevenson and Peterson<sup>17</sup> demonstrated that both immigration and emigration of cells influence the dynamics of lotic diatom assemblages and proposed a method for estimating emigration rates. In a series of flume experiments, algae immigrated more proficiently into communities of intermediate age than into communities at early or late stages of development.<sup>18</sup> Several papers described movement patterns of microbiota within and between substrata. Lauffenburger<sup>19</sup> provided an overview of research on bacterial chemotaxis and concluded that cell motility and chemotaxis can strongly influence bacterial population dynamics. Malmcrona-Friberg<sup>20</sup> documented chemotaxis of a marine bacterium (*Vibrio alginolyticus*) along a gradient of breakdown products generated by metabolic activity of a substratum-associated *Flavobacterium* species. The marine bacterium *Deleya* (formerly *Pseudomonas*) *marina* switched randomly from gliding motility on benthic substrata to swimming flagella-driven motility.<sup>21</sup> A previously unrecorded type of diatom motility was observed in the araphid marine diatom, *Ardissonea* (formerly *Synedra*) *crystallina*,<sup>22</sup> indicating that some presumed nonmotile diatom taxa may have locomotory abilities.

Substratum characteristics were found to affect the rate of development and character of periphyton communities. Substrata with surface-free energies of 31–43 mN/m were initially more heavily colonized by all major groups of microbiota than substrata with lower free energies, but these differences diminished as communities developed.<sup>23</sup> Goldsborough and Hickman<sup>24</sup> noted that inert cylinders supported higher algal

biomass than morphologically similar culms of the aquatic macrophyte *Scirpus* and conducted an experiment that suggested the cuticle on actively growing *Scirpus* culms retarded periphyton establishment. Similarly, epiphytic bacteria colonized senescent areas of *Ceratophyllum* leaves more readily than healthy non-senescent areas.<sup>25</sup> A comparison of biofilm development on glass (epilithic) and wood (epixylic)<sup>26</sup> showed that epilithic biofilms contained more chlorophyll but epixylic biofilms exhibited greater enzymatic activity, owing to bacterial utilization of the wood as a supplemental carbon source. Wood substrata also supported more microbial biomass than leaf surfaces; current velocity had little influence on biomass or exoenzyme activity in biofilms on either wood or leaves.<sup>27</sup>

McCormick and Stevenson<sup>28</sup> concluded that both passive and active tolerance mechanisms generated successional changes in lotic periphyton communities and that early- and late-successional species differed considerably in autecological characteristics. Similarly, Stevenson *et al.*<sup>29</sup> noted that early-successional diatom species were typically fast immigrants but could not sustain rapid population growth in dense late-successional communities. The rate of size reduction after cell division differed among 19 diatom species, and cell volume was inversely related to maximal growth rate.<sup>30</sup> Primary succession of protistan communities in isolated aquatic systems was found to be influenced most by species dispersal abilities, but in systems that were less isolated (that is, those with higher species invasion rates), biotic interactions became more important in driving successional change.<sup>31</sup>

The rate and extent of biofilm development was affected by current. Ghosh and Gaur<sup>32</sup> observed that algal biomass accrued on artificial substrata over 5 weeks in an Indian spring was lowest in a pool habitat but was inversely related to current velocity in three riffle habitats (ranging from 10–15 cm·s<sup>-1</sup> to 37–41 cm·s<sup>-1</sup>). *Pseudomonas fluorescens* biofilms developed in a 2.5 m·s<sup>-1</sup> current were more compact and thinner than those developed in 0.5 m·s<sup>-1</sup> current.<sup>33</sup> Gantzer *et al.*<sup>34</sup> demonstrated that heterotrophic biofilms supported greater biomass when acclimated in a 18.3 cm·s<sup>-1</sup> current than at a velocity of 9.5 cm·s<sup>-1</sup> and that biofilm metabolic activity was positively related to current. Thus, streambed biofilm activity was a function of both present current velocity (that is, that controlling mass transport) and the acclimation velocities that determined biofilm biomass.

Other factors reported to influence development of microbial communities included production of allelochemicals and viral infection. Gross *et al.*<sup>35</sup> characterized a secondary metabolite (fischerellin), produced by the benthic cyanobacterium *Fischerella muscicola*, that inhibited growth of other cyanobacteria as well as members of the Chlorophyceae. Kokjohn *et al.*<sup>36</sup> found that *Pseudomonas aeruginosa* bacteriophages readily attached and replicated when host cells were physiologically competent to allow phage growth, even at host-cell densities lower than those typically found in nature, but bacteriophage replication was much reduced when *Pseudomonas* cells were starved.

Structure of attached microbial assemblages was reported to vary with age and habitat. Mir *et al.*<sup>37</sup> observed that microbial mats growing on a marine sandflat increased in the degree of structural and functional stratification with age. Stock and Ward<sup>38</sup> described the structure of thick (2 cm), highly productive, cohesive cyanobacterial mats in an Alabama stream as consisting of a thin (less than 1 mm) upper layer of biologically active

filaments overlying a laminae of *Oscillatoria* filaments and sediment. Colonies of the cyanobacterium *Rivularia* were varied in degree of calcification and community physiognomy based on water chemistry, degree of exposure to desiccation, and flow characteristics.<sup>39</sup> Seeler and Golubić<sup>40</sup> described a new endolithic stigonematalean cyanobacterium (*Iyengariella endolithica* sp. nova) from carbonate deposits in a spring-fed lake in north-eastern Mexico. The environmental requirements, morphology, and variability of *Synechococcus elongatus*, another endolithic cyanobacterium found in streams, were described by Büdel *et al.*<sup>41</sup> Differences in morphological properties of three species of *Hyella*, a cyanobacterium that bores into tropical mollusc shells, were discussed by Campion-Alsumard.<sup>42</sup>

Autogenic processes within developing microbial communities were found to alter the microenvironmental conditions within those communities. Dodds<sup>43</sup> used microelectrodes to document differences in oxygen, current velocity, pH, and water chemistry outside and within a floating *Cladophora glomerata* mat and concluded that filamentous algae in flowing freshwaters can provide a distinct subhabitat for epiphytic diatoms. Stal<sup>44</sup> and Castenholz *et al.*<sup>45</sup> discussed the ability of cyanobacteria to shift between oxygenic and anoxygenic photosynthesis in response to diel fluctuations in the physicochemical environment within benthic mats. Aggregation of *Anabaena flos-aquae* filaments enable this cyanobacterium to alter microenvironmental conditions to facilitate nitrogenase activity.<sup>46</sup> Examination of cell-bound and extracellular phosphatase activities of 50 cyanobacterial strains, comprising 10 genera, showed large variation in ability to use organic phosphorus.<sup>47</sup> Epilithic biofilms from a large river were found to accumulate carbohydase enzymes, a condition thought to contribute to the metabolic resistance of these biofilms to fluctuation in dissolved organic matter.<sup>48</sup> Blenkinsopp *et al.*<sup>49</sup> reported that concentrations of biofilm storage products (for example, glycogen, poly-beta-hydroxyalkanoate) changed seasonally, with highest levels occurring in spring; accumulation of these compounds occurred irrespective of river water chemistry and was thought to influence the value of the biofilm as an invertebrate food source.

**Temporal and spatial variation in community distribution.** Sinsabaugh *et al.*<sup>50</sup> analyzed patchiness of epilithon in different flow regimes of a boreal river and determined that patch length was smaller than cobble or boulder substrata; thus epilithon patch structure emerged from small-scale processes such as turbulence and macroinvertebrate activity. Between-patch variation in structural and functional community properties varied with habitat type and season. Sand-Jensen and Borum<sup>51</sup> summarized how differences in water movements, diffusive boundary layers, nutrient demands, carbon and oxygen dynamics, and light conditions might vary to favor dominance of phytoplankton, periphyton, or macrophytes in aquatic systems. Takamura and Iwakuma<sup>52</sup> measured uptake rates of ammonium, nitrate, and urea of epiphytic and planktonic algae in a hypereutrophic lake and concluded that epiphytic algae were competitively inferior to phytoplankton with respect to utilization of nitrogen.

Several papers reported how physical and/or chemical variables influenced seasonal or spatial variation within groups of microbiota. Algal communities in a Nevada river changed in community structure along a dissolved-nitrogen gradient below an influx of treated wastewater.<sup>53</sup> Dodds<sup>54</sup> collected *Cladophora glomerata* from six Montana river sites over 5 months and found that low-flow high-ammonium concentrations and low epiphyte



densities were all strongly correlated with high biomass of this alga. A laboratory light-gradient experiment showed that *C. glomerata* exhibited negligible growth at photon-flux densities less than  $29 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ; this light limitation threshold was corroborated by field observations in Lake Erie.<sup>55</sup> Hall and Walmsley<sup>56</sup> reported that formation of akinetes and zoospores of another filamentous chlorophyte, *Rhizoclonium riparium*, could be induced by exposing aging cultures to high temperature (40°C) and that germination of these reproductive structures was stimulated at temperatures of 15–20°C.

Lalonde and Downing<sup>57</sup> examined the relationship between epiphyte biomass on macrophytes and water-column total phosphorus (TP) content of 11 lakes and found that season, sampling depth, and macrophyte architecture accounted for more variation in epiphyte biomass than TP. Edsall *et al.*<sup>58</sup> observed dense periphyton mats on isolated shoals in Lake Superior and suggested that they may be important in the food web of that system. Oppenheim<sup>59</sup> reported that in different seasons, different combinations of environmental variables influenced diatom assemblages along a saltmarsh, sandflat, and mudflat of an estuarine intertidal shore; salinity and organic matter concentration appeared most influential in winter, whereas diatom species distributions in spring and autumn were most affected by chemistry of interstitial water. Density of sediment bacteria in a tropical oxbow lake varied between dry and rainy seasons in concert with changes in electrode potential of the sediment surface.<sup>60</sup> Smorzewski and Schmidt<sup>61</sup> documented seasonal changes in ammonia-oxidizing bacteria and their activity in sediments of a eutrophic freshwater lake and found that cell-specific ammonia-oxidation potential and diversity of ammonia oxidizers decreased as sediments became deoxygenated during summer stratification.

A ciliated protozoan biotope, similar to that found in reservoir sediments, developed in association with floating mats of the macrophyte *Lemna gibba*.<sup>62</sup> Anoxia in both *Lemna* mats and sediments likely caused this development. Karlson<sup>63</sup> studied recruitment and persistence of a stream bryozoan population over 2 years and concluded that sessoblast persistence was essential for promoting future recruitment and local population growth. Vuille<sup>64</sup> examined the abundance and production of planktonic and substratum-associated microcrustacean populations in a lake littoral zone and found that benthic communities reached abundance maxima after late-summer senescence of aquatic macrophytes. Microcrustaceans consumed 26 and 18% of littoral-zone net primary production in successive years. Boulton *et al.*<sup>65</sup> demonstrated that movement of meiofauna within the hyporheic zone of a Sonoran Desert stream occurred most frequently in a downstream direction and no correlation existed between direction of movement and taxonomic group. Shiozawa<sup>66</sup> described distribution and abundance of microcrustacea from nine low-order streams in Minnesota.

Effects of disturbance on spatial and temporal variation of substratum-associated microbial communities were addressed in a number of studies. Delgado *et al.*<sup>67</sup> noted that estuarine diatom communities that contained a little detritus were less likely to be disrupted by turbulence than communities with high detrital content. Disturbance experiments on diatom cultures showed that sand movement affected diatom species differently and that such differences in susceptibility might affect dynamics of natural estuarine diatom communities.<sup>68</sup> Wave-induced suspension of benthic material from a shallow freshwater lake re-

duced light penetration and lowered productivity of remaining benthic algae by 15%.<sup>69</sup>

Substratum type and stability was important in regulating algal biomass at two sites (one channelized and one not) in a Danish lowland stream.<sup>70</sup> Uehlinger<sup>71</sup> monitored periphyton biomass in a prealpine river and observed that time since last flood was the best predictor of algal biomass. Resistance of periphyton to severe floods appeared to depend on substratum size. Ács and Kiss<sup>72</sup> observed consistent seasonal change in periphytic algae in the River Danube over 2 years but noted that spates displaced assemblage structure to that characteristic of early colonization. Establishment of *Cladophora* and the colonial cyanobacterium *Nostoc* in streams, and the resistance of these algae to scour and grazing, was facilitated by substratum heterogeneity.<sup>73</sup> Applegate and Bryers<sup>74</sup> developed monospecific *Pseudomonas putida* biofilms under oxygen-limited and carbon-limited conditions and found that oxygen-limited biofilms were most resistant to removal by scour but had a greater propensity to experience catastrophic sloughing.

**Effects of variation of nutrient supplies.** Periphyton accrual and productivity in mesocosms suspended in a small reservoir were inhibited by exposure to montmorillonite and kaolinite clays but increased beyond levels reached in phosphate-enriched treatments when clay and phosphate were added simultaneously.<sup>75</sup>

Enrichment experiments in outdoor experimental channels in both a coastal shallow-water sediment system<sup>76</sup> and a freshwater stream<sup>79</sup> showed that nitrogen and phosphorus enrichment enhanced algal biomass accrual and increased the rate of microalgal succession. In the stream study,<sup>79</sup> shading of communities during late stages of succession reduced algal standing crops. Nilsson and Sündback<sup>77</sup> observed that nitrogen and phosphorus enrichment of microalgal communities grown on sand/agar substrata enhanced algal biomass and productivity and altered community composition in a manner similar to that observed on natural enriched sediments. Nutrient bioassays conducted during low flow periods in an Ozark stream showed periphyton to be nitrogen limited; measurement of nitrogen:phosphorus ratios at 16 sites in 10 streams indicated that nitrogen limitation of periphyton may be common in this region.<sup>78</sup> Phosphorus enrichment of stream-side mesocosms drawing water from a British Columbian stream enhanced algal biomass and increased insect densities and emergence.<sup>79</sup>

Paul *et al.*<sup>80</sup> monitored incorporation, release, and subsequent downstream reincorporation of radiolabeled phosphorus and carbon by lotic periphyton to demonstrate nutrient spiralling in these communities and provided evidence that successional change resulted from interspecific differences in abilities to sequester and recycle nutrients from the water column. A series of four laboratory-stream studies<sup>81–84</sup> examined the relative importance of nutrient cycling and herbivory by snails in controlling periphyton dynamics. In each study, nutrients were manipulated through recirculation of stream water, and periphyton grown under recirculated or nonrecirculated conditions were either exposed to snail grazing or left ungrazed. Recirculation reduced nutrients in stream water, had no effect on algal biomass or carbon fixation rates, but altered community properties associated with nutrient recycling (for example, phosphatase activity, algal nutrient content). Herbivory reduced or eliminated most differences attributable to recirculation and greatly reduced algal biomass.<sup>81</sup> The nitrogen-fixing diatom, *Epithemia*, was most

abundant in recirculated nongrazed channels; grazing increased dominance of prostrate algae and greatly reduced biovolume of algal taxa with upright growth forms.<sup>82</sup> In the absence of grazers, communities in nonrecirculated streams recovered more rapidly from a light-elimination disturbance than those in recirculated channels, but snails, when present, constrained recovery regardless of nutrient regime.<sup>83</sup> Scour affected snail-grazed communities less than nongrazed communities, and recovery in grazed communities was inhibited in recirculated channels relative to channels with higher nutrient supply rates.<sup>84</sup> In contrast, recovery rates were unaffected by nutrient regime in ungrazed channels, suggesting that nutrient recycling helped maintain productivity in these habitats despite low nutrient input. McCormick and Stevenson<sup>85</sup> also examined interactive effects of nutrients and grazing and demonstrated that activity of grazing snails could mediate the response of algal communities to enrichment, depending on the relative susceptibility to ingestion of different components of the community.

**Herbivory.** Several papers examined interactions between invertebrate grazers and benthic algal assemblages. One study described the grazing pressures exerted by two common caddisflies on the benthic algae in Big Sulphur Creek.<sup>86</sup> In this stream, *Helicopsyche borealis* selected epilithic diatoms and bluegreen algae, whereas *Gumaga nigricula* grazed mainly on the filamentous green alga, *Cladophora*. Dodds<sup>87</sup> examined the influence of insect grazers on *Cladophora glomerata* and its epiphytes and discussed nutrient transfers between *Cladophora* and its epiphytes, as well as shading and current velocity effects of epiphytes on *Cladophora*. Martin *et al.*<sup>88</sup> demonstrated that grazing by two caddisfly species reduced benthic algal ash-free dry mass but had no effect on chlorophyll *a*, suggesting that algal quality could be improved by grazing of senescent cells. Grazing by two different invertebrate guilds (microcrustaceans and chironomids/oligochaetes) had different effects on periphytic algal biomass and diversity in a eutrophic marsh pond.<sup>89</sup>

The impact of snail grazing on phyto-benthos was explored by several authors. Tuchman and Stevenson<sup>90</sup> found that selective removal of overstory algal species by *Elimia livescens* effectively altered the rate and direction of algal succession in two lake systems. Whether succession was accelerated or arrested depended on the autecologies and growth forms of the colonizing algae in a particular lake. An experiment on the effects of snail size and hunger level on periphyton removal by *Elimia clavaeformis* suggested that neither size nor degree of starvation had a significant effect on loss of total periphyton ash-free dry mass; however, erect forms of algae were removed by all snails, and adnate growth forms were removed only by starved snails.<sup>91</sup> Lane<sup>92</sup> found nutritional quality of periphyton communities changed with age, which subsequently affected grazing rates and growth rates of the snail *Neritina reclinata*. A study of seasonal and spatial variation of epilithic microalgal distribution and abundance and the effect of limpet (*Patella vulgata*) grazing showed that diatom and filamentous algae differed in microdistribution and that limpets fed on rarer algal taxa.<sup>93</sup> The diatom community of the Mitchell River exhibited spatial (from riffles to pools) and seasonal variation; however, grazing by three different snail species was random, and gut contents reflected diatom assemblages on the substratum rather than a selective preference for various growth forms.<sup>94</sup> A patchy physical environment for algal community development was experimentally produced by altering light and current regimes within experi-

mental streams wherein periphyton succession and grazing behavior of the snail *Juga silicula* was measured.<sup>95</sup> Another study on habitat patchiness examined colonization rates by epiphytic algae onto both natural and artificial plants and subsequent attraction of the epiphytic community to epifaunal grazers.<sup>96</sup>

Selective herbivory of benthic algal assemblages by three algalivorous protozoa was found to substantially impact the benthic algal assemblage in stream-side channels.<sup>97</sup> Nematode and harpacticoid copepod grazing rates on sediment-associated microphyton slightly exceeded rates of primary production.<sup>98</sup> Perlmutter and Meyer<sup>99</sup> found that harpacticoid copepods reduced density and biomass of detritally associated bacteria in a stream while increasing the cell-specific production. Organic matter loading from a freshwater tributary to an estuary appeared to stimulate grazing rates of harpacticoid copepods, nematodes, and juvenile molluscs on both microalgae and bacteria.<sup>100</sup>

Invertebrates were found to affect benthic algal assemblages in ways other than herbivory. Scrimgeour *et al.*<sup>101</sup> examined the relative importance of consumptive and nonconsumptive removal of algae from substrata by three mayfly grazers and found that at low algal biomass levels, consumptive removal was more important than nonconsumptive removal; at high algal biomass, the reverse was true. Tuft-weaving chironomid larvae inhabiting the filamentous alga *Cladophora glomerata* had negative effects on the alga when algal tufts were new and had positive effects on algal biomass in older tufts due to cell removal and nutrient recycling dynamics.<sup>102</sup>

**Primary production.** Falkowski and LaRoche<sup>103</sup> compiled a minireview of physiological acclimation to spectral irradiance in algae. Boston and Hill<sup>104</sup> measured photoassimilation of <sup>14</sup>C at six light levels for 10 different natural periphyton communities grown under differing ambient light, nutrient, and grazer regimes and found that self-shading may be as important as the light environment in determining periphyton photosynthesis-irradiance relationships.<sup>105</sup> A study conducted on the effects of very low light intensities on cyanophyte and chlorophyte cell ultrastructure revealed that cyanophytes responded by increasing sheath thickness and reducing glycogen granules, whereas chlorophytes did not exhibit ultrastructural changes.<sup>106</sup> An investigation of the effects of tidal stage and irradiance on benthic microalgal productivity in intertidal sediments found that productivity at low tide was twice that at high tide.<sup>107</sup>

Davison<sup>108</sup> assembled a minireview on environmental parameters effecting algal photosynthesis with emphasis on temperature. Lamberti *et al.*<sup>109</sup> examined the recovery of a stream ecosystem after a catastrophic debris flow and suggested that high light levels and reduced grazing pressure contributed to the rapid accrual of benthic algae after disturbance.

**Microbial production in sediments.** Cammen<sup>110</sup> found that bacterial biomass, bacterial production, and sediment organic carbon were four to five times greater in a intertidal mudflat than on a sandflat, despite similar microalgal biomass and production in the two habitats. Schwinghamer *et al.*<sup>111</sup> experimentally manipulated illumination and detritus content of salt-marsh sediments in mesocosms to better understand the factors controlling oxygen flux in natural sediments. They employed two commonly used oxygen-flux measurement techniques (gradient and stirred-core flux) and cautioned that knowledge of community dynamics is necessary to obtain useful information from such measurements. Oxygen- and inorganic-nutrient flux at the sediment-water interface in subtidal sediments was found to be



mediated by the activity of photosynthetic microphytobenthic organisms.<sup>112</sup> Sweerts *et al.*<sup>113</sup> determined that oxidation of methane, ammonium, iron, and sulfide accounted for approximately 75 and 15% of oxygen consumed in profundal and littoral sediments, respectively, and that oxygen-consumption rates were greater in profundal sediments than in littoral sediments, regardless of season. Fiebig and Lock<sup>114</sup> concluded that microbiota present on stream beds can immobilize large amounts of dissolved organic carbon from groundwater supplies, and thus, make this energy source available to the stream ecosystem.

**Fungal distribution and function.** Several studies examined distribution of aquatic hyphomycete fungi in lake and stream ecosystems. Shearer and Webster<sup>115</sup> placed twigs of alder and oak at five sites along a gradient of stream order and pH and described the longitudinal distribution patterns of colonized fungal conidia. Another study described the 43 species of fungi inhabiting the river Pisa and its tributary.<sup>116</sup> Thomas *et al.*<sup>117</sup> described changes in concentration of aquatic hyphomycete spores in an Australian creek relative to the quality of riparian vegetation at five sites and developed a continuous systems model describing the dynamics of spore density changes with stream distance.<sup>118</sup>

An investigation of the intraspecific hyphal interactions of aquatic fungi isolated from widely separated geographic locations showed that growth of both strains generally slowed as they approached each other on the substratum.<sup>119</sup> The rate of fungal colonization onto fresh autumn-shed alder leaves was slower than onto dried alder leaves in the River Teign,<sup>120</sup> although the rate of leaching of soluble substances was greater in dried leaves. Gessner and Schwoerbel<sup>121</sup> used an ergosterol:biomass conversion factor to estimate that peak fungal mass accounted for 10.2% of alder leaf dry mass during autumn in a softwater stream. Chergui and Pattee<sup>122</sup> inoculated leaf litter with four fungal species, and leaf weight loss increased with time but varied according to the fungal species. Invertebrate consumption of the fungal-colonized leaves increased with time of fungal conditioning.

**Miscellaneous.** Christian and Wetzel<sup>123</sup> discussed the benefits of using field research in conjunction with mathematical simulation models to decipher complex dynamics of microbial food webs in estuaries. Lane *et al.*<sup>124</sup> analyzed 16S rRNA nucleotide sequences from 37 strains of iron- and/or sulfur-oxidizing bacteria to suggest potential evolutionary relationships among members of this phylogenetically diverse group. Rahat<sup>125</sup> reviewed data showing the role of colonization, competition, and territoriality in establishing host/symbiont specificity in algae/hydra endosymbioses. Neither prokaryotic nor eukaryotic microorganisms were able to completely degrade mucus produced by three coral reef Anthozoa over 21 days of incubation, suggesting this substance likely functions in defense and does not serve as a significant microbial carbon source.<sup>126</sup> Uriz *et al.*<sup>127</sup> tested eight groups of benthic marine organisms for presence of antibacterial, antifungal, antiviral, cytotoxic, and antimutagenic materials and found these antifouling substances to be widespread, particularly among the Porifera, Bryozoa, and Tunicata.

*Christopher G. Peterson and Nancy C. Tuchman are assistant professors in the Natural Science Department and Biology Department, respectively, at Loyola University of Chicago. Correspondence should be addressed to C. G. Peterson, Natural Science Department, Loyola University of Chicago, 6525 N. Sheridan Rd., Chicago, IL 60626.*

## REFERENCES

1. Poglazova, M. N., *et al.*, "A Spectrofluorimetric Method for the Determination of Total Bacterial Counts in Natural Substrata." *Mikrobiologiya* (USSR), **60**, 176 (1991).
2. Kuzhinovskii, V. A., *et al.*, "A Method for Counting Microorganisms in Marine Bottom Sediments." *Mikrobiologiya* (USSR), **60**, 377 (1991).
3. Wolfaardt, G. M., *et al.*, "The Use of DAPI in the Quantification of Sessile Bacteria on Submerged Surfaces." *Biofouling* (G. B.), **4**, 265 (1991).
4. Thomsen, L., "Treatment and Splitting of Samples for Bacteria and Meiofauna Biomass Determinations by Means of a Semi-automatic Image Analysis System." *Mar. Ecol. Prog. Ser.* (Ger.), **71**, 301 (1991).
5. Ford, R. M., *et al.*, "Stopped-flow Chamber and Image Analysis System for Quantitative Characterization of Bacterial Population Migration: Motility and Chemotaxis of *Escherichia coli* K12 to Fucose." *Microbiol. Ecol.*, **22**, 127 (1991).
6. Brandl, H., and Hanselmann, K. W., "Evaluation and Application of Dialysis Porewater Samplers for Microbiological Studies at Sediment-Water Interfaces." *Aquat. Sci.* (Switz.), **53**, 55 (1991).
7. Ford, T., *et al.*, "Characterization of Exopolymers of Aquatic Bacteria by Pyrolysis-Mass Spectrometry." *Appl. Environ. Microbiol.*, **57**, 1595 (1991).
8. Newell, S. Y., and Fallon, R. D., "Toward a Method for Measuring Instantaneous Fungal Growth Rates in Field Samples." *Ecology*, **72**, 1547 (1991).
9. Voltolina, D., "A Comparison of Methods for the Dispersion of Cultures of Benthic Diatoms." *Cryptogam. Algal.* (Fr.), **12**, 183 (1991).
10. Cattaneo, A., and Roberge, G., "Efficiency of a Brush Sampler to Measure Periphyton in Streams and Lakes." *Can. J. Fish Aquat. Sci.*, **48**, 1877 (1991).
11. Schwinghamer, P., *et al.*, "Separation and Concentration of Living Dinoflagellate Resting Cysts From Marine Sediment via Density-gradient Centrifugation." *Limnol. Oceanogr.*, **36**, 588 (1991).
12. Fuller, R. L., and Bucher, J. B., "A Portable Chamber for Measuring Algal Primary Production in Streams." *Hydrobiologia* (Neth.), **209**, 155 (1991).
13. Carpenter, R. C., *et al.*, "Measurement of Primary Productivity and Nitrogenase Activity of Coral Reef Algae in a Chamber Incorporating Oscillatory Flow." *Limnol. Oceanogr.*, **36**, 40 (1991).
14. Jönsson, B., "A <sup>14</sup>C-Incubation Technique for Measuring Microphytobenthic Primary Productivity in Intact Sediment Cores." *Limnol. Oceanogr.*, **36**, 1485 (1991).
15. Crusius, J., and Anderson, R. F., "Core Compression and Surficial Sediment Loss of Lake Sediments of High Porosity Caused by Gravity Coring." *Limnol. Oceanogr.*, **36**, 1021 (1991).
16. Boland, G. S., and Rowe, G. T., "Deep-sea Benthic Sampling with the GOMEX Box Corer." *Limnol. Oceanogr.*, **36**, 1015 (1991).
17. Stevenson, R. J., and Peterson, C. G., "Emigration and Immigration Can Be Important Determinants of Benthic Diatom Assemblages in Streams." *Freshwater Biol.* (G. B.), **26**, 279 (1991).
18. Reiter, M. A., "Preliminary Experiments Concerning the Potential for Hydrodynamic Isolation in Benthic Algal Assemblages." *J. Freshwater Ecol.*, **6**, 103 (1991).
19. Lauffenburger, D. A., "Quantitative Studies of Bacterial Chemotaxis and Microbial Population Dynamics." *Microbiol. Ecol.*, **22**, 175 (1991).
20. Malmcrona-Friberg, K., *et al.*, "Chemotactic Response of a Marine Bacterium to Breakdown Products of an Insoluble Substrate." *FEMS Microbiol. Ecol.* (Den.), **85**, 199 (1991).
21. Shea, C., *et al.*, "Variable Expression of Gliding and Swimming Motility in *Deleya marina*." *Can. J. Microbiol.*, **37**, 808 (1991).
22. Pickett-Heaps, I., *et al.*, "Active Gliding Motility in an Araphid

- Marine Diatom, *Ardissonea* (Formerly *Synedra*) *crystallina*." *J. Phycol.*, **27**, 718 (1991).
23. Becker, K., and Wahl, M., "Influence of Substratum Surface Tension on Biofouling of Artificial Substrata in Kiel Bay (Western Baltic): *In situ* Studies." *Biofouling* (G. B.), **4**, 275 (1991).
  24. Goldsborough, L. G., and Hickman, M., "A Comparison of Periphytic Algal Biomass and Community Structure on *Scirpus validus* and on a Morphologically Similar Artificial Substratum." *J. Phycol.*, **27**, 196 (1991).
  25. Underwood, G. J. C., "Note: Colonization and Invasion of Leaves of the Aquatic Macrophyte *Ceratophyllum demersum* L. by Epiphytic Bacteria." *Microbiol. Ecol.*, **21**, 267 (1991).
  26. Sinsabaugh, R. L., et al., "Comparison of Epilithic and Epixytic Biofilm Development in a Boreal River." *Freshwater Biol.* (G. B.), **25**, 179 (1991).
  27. Golladay, S. W., and Sinsabaugh, R. L., "Biofilm Development on Leaf and Wood Surfaces in a Boreal River." *Freshwater Biol.* (G. B.), **25**, 437 (1991).
  28. McCormick, P. V., and Stevenson, R. J., "Mechanisms of Benthic Algal Succession in Lotic Environments." *Ecology*, **72**, 1835 (1991).
  29. Stevenson, R. J., et al., "Density-dependent Growth, Ecological Strategies, and Effects of Nutrients and Shading on Benthic Diatom Succession in Streams." *J. Phycol.*, **27**, 59 (1991).
  30. Mizuno, M., "Influence of Cell Volume on the Growth and Size Reduction of Marine and Estuarine Diatoms." *J. Phycol.*, **27**, 473 (1991).
  31. McCormick, P. V., et al., "The Relative Importance of Population Versus Community Processes in Microbial Primary Succession." *Hydrobiologia* (Neth.), **213**, 83 (1991).
  32. Ghosh, M., and Gaur, J. P., "Regulatory Influence of Water Current on Algal Colonization in an Unshaded Stream at Shillong (Meghalaya, India)." *Aquat. Bot.* (Den.), **40**, 37 (1991).
  33. Santos, R., et al., "The Structure of *Pseudomonas fluorescens* Biofilms in Contact with Flowing Systems." *Biofouling* (G. B.), **4**, 319 (1991).
  34. Gantzer, C. J., et al., "Effect of Long-term Water Velocity Changes on Streambed Biofilm Activity." *Water Res.* (G. B.), **25**, 15 (1991).
  35. Gross, E. M., et al., "Fischerellin, a New Allelochemical from the Freshwater Cyanobacterium *Fischerella muscicola*." *J. Phycol.*, **27**, 686 (1991).
  36. Kokjohn, T. A., et al., "Attachment and Replication of *Pseudomonas aeruginosa* Bacteriophages Under Conditions Simulating Aquatic Environments." *J. Gen. Microbiol.* (G. B.), **137**, 661 (1991).
  37. Mir, J., et al., "Vertical Stratification and Microbial Assemblage of a Microbial Mat in the Ebro Delta (Spain)." *FEMS Microbiol. Ecol.* (Den.), **86**, 59 (1991).
  38. Stock, M. S., and Ward, A. K., "Blue-Green Algal Mats in a Small Stream." *J. Phycol.*, **27**, 692 (1991).
  39. Obenlünenschloss, J., and Schneider, J., "Ecology and Calcification Patterns of *Rivularia* (Cyanobacteria)." *Arch. Hydrobiol. Algal Stud.* (Ger.), **64**, 489 (1991).
  40. Seeler, J.-S., and Golubić, S., "*Iyengariella endolithica* sp. nova, a Carbonate Boring Stigonematalean Cyanobacterium from a Warm Spring-fed Lake: Nature to Culture." *Arch. Hydrobiol. Algal Stud.* (Ger.), **64**, 399 (1991).
  41. Büdel, B., et al., "*Synechococcus elongatus*—Cryptoendolithic Growth Within Bleached Sandstone from Creeks in the Midland Area Spessart (Germany)." *Arch. Hydrobiol. Algal Studies* (Ger.), **64**, 357 (1991).
  42. Campion-Alsumard, T., "Three *Hyella* Taxa (Endolithic Cyanophytes) from Tropical Environments (Lizard Island, Great Barrier Reef)." *Arch. Hydrobiol. Algal Stud.* (Ger.), **64**, 159 (1991).
  43. Dodds, W. K., "Micro-environmental Characteristics of Filamentous Algal Communities in Flowing Freshwaters." *Freshwater Biol.* (G. B.), **25**, 199 (1991).
  44. Stal, L. J., "The Metabolic Versatility of the Mat-building Cyanobacteria *Microcoleus chthonoplastes* and *Oscillatoria limosa* and Its Ecological Significance." *Arch. Hydrobiol. Algal Stud.* (Ger.), **64**, 453 (1991).
  45. Castenholz, R. W., et al., "Photosynthetic and Behavioral Versatility of the Cyanobacterium *Oscillatoria boryana* in a Sulfide-rich Microbial Mat." *FEMS Microbiol. Ecol.* (Den.), **86**, 43 (1991).
  46. Kangatharalingam, N., et al., "Nitrogenase Activity, Photosynthesis, and the Degree of Heterocyst Aggregation in the Cyanobacterium *Anabaena flos-aquae*." *J. Phycol.*, **27**, 680 (1991).
  47. Whitton, B. A., et al., "Cell-bound and Extracellular Phosphatase Activities of Cyanobacterial Isolates." *Microbiol. Ecol.*, **21**, 85 (1991).
  48. Sinsabaugh, R. L., et al., "Exoenzyme Accumulation in Epilithic Biofilms." *Hydrobiologia* (Neth.), **222**, 29 (1991).
  49. Blenkinsopp, S. A., et al., "Seasonal Trends in River Biofilm Storage Products and Electron Transport System Activity." *Freshwater Biol.* (G. B.), **26**, 21 (1991).
  50. Sinsabaugh, R. L., et al., "Epilithon Patch Structure in a Boreal River." *J. North Am. Benthol. Soc.*, **10**, 419 (1991).
  51. Sand-Jensen, K., and Borum, J., "Interactions Among Phytoplankton, Periphyton, and Macrophytes in Temperate Freshwaters and Estuaries." *Aquat. Bot.* (Den.), **41**, 137 (1991).
  52. Takamura, N., and Iwakuma, T., "Nitrogen Uptake and C:N:P Ratio of Epiphytic Algae in the Littoral Zone of Lake Kasumigaura." *Arch. Hydrobiol.* (Ger.), **121**, 161 (1991).
  53. Rushforth, S. R., and Brock, J. T., "Attached Diatom Communities from the Lower Truckee River, Summer and Fall, 1986." *Hydrobiologia* (Neth.), **224**, 49 (1991).
  54. Dodds, W. K., "Factors Associated With Dominance of the Filamentous Green Alga *Cladophora glomerata*." *Water Res.* (G. B.), **25**, 1325 (1991).
  55. Lorenz, R. C., et al., "Minimum Light Requirements for Substrate Colonization by *Cladophora glomerata*." *J. Great Lakes Res.*, **17**, 536 (1991).
  56. Hall, D. J., and Walmsley, R. D., "Effect of Temperature on Germination of *Rhizoclonium riparium* (Siphonocladales, Chlorophyta) Akinetes and Zoospores." *J. Phycol.*, **27**, 537 (1991).
  57. Lalonde, S., and Downing, J. A., "Epiphyton Biomass is Related to Lake Trophic Status, Depth, and Macrophyte Architecture." *Can. J. Fish Aquat. Sci.*, **48**, 2285 (1991).
  58. Edsall, T. A., et al., "Periphyton Accumulation at Remote Reefs and Shoals in Lake Superior." *J. Great Lakes Res.*, **17**, 412 (1991).
  59. Oppenheim, D. R., "Seasonal Changes in Epipelagic Diatoms Along an Intertidal Shore, Berrow Flats, Somerset." *J. Mar. Biol. Assoc. U. K.* (G. B.), **71**, 579 (1991).
  60. Freitas, E. A. C., and Godinho-Orlandi, M. J. L., "Distribution of Bacteria in the Sediment of an Oxbow Tropical Lake (Lagoa do Infernao, SP, Brazil)." *Hydrobiologia* (Neth.), **211**, 33 (1991).
  61. Smorzewski, W. T., and Schmidt, E. L., "Numbers, Activities, and Diversity of Autotrophic Ammonia-oxidizing Bacteria in a Freshwater, Eutrophic Lake Sediment." *Can. J. Microbiol.*, **37**, 828 (1991).
  62. Salvado, H., and del Pilar Gracia, M., "Response of Ciliate Populations to Changing Environmental Conditions Along a Freshwater Reservoir." *Arch. Hydrobiol.* (Ger.), **123**, 239 (1991).
  63. Karlson, R. H., "Recruitment and Local Persistence of a Freshwater Bryozoan in Stream Riffles." *Hydrobiologia* (Neth.), **226**, 119 (1991).
  64. Vuille, T., "Abundance, Standing Crop and Production of Microcrustacean Populations (Cladocera, Copepoda) in the Littoral Zone of Lake Biel, Switzerland." *Arch. Hydrobiol.* (Ger.), **123**, 165 (1991).
  65. Boulton, A. J., et al., "Invertebrate Recolonization of Small Patches of Defaunated Hyporheic Sediment in a Sonoran Desert Stream." *Freshwater Biol.* (G. B.), **26**, 267 (1991).
  66. Shiozawa, D. K., "Microcrustacea From the Benthos of Nine Minnesota Streams." *J. North Am. Benthol. Soc.*, **10**, 286 (1991).

67. Delgado, M., et al., "Experiments on Resuspension of Natural Microphytobenthos Populations." *Mar. Biol. (Ger.)*, **108**, 321 (1991).
68. Delgado, M., et al., "Effect of Sand Movement on the Growth of Benthic Diatoms." *J. Exp. Mar. Biol. Ecol. (Neth.)*, **145**, 221 (1991).
69. Hellström, T., "The Effect of Resuspension on Algal Production in a Shallow Lake." *Hydrobiologia (Neth.)*, **213**, 183 (1991).
70. Iverson, T. M., et al., "Spring Bloom Development of Microbenthic Algae and Associated Invertebrates in Two Reaches of a Small Lowland Stream With Contrasting Sediment Stability." *Freshwater Biol. (G. B.)*, **26**, 189 (1991).
71. Uehlinger, U., "Spatial and Temporal Variability of the Periphyton Biomass in a Prealpine River (Necker, Switzerland)." *Arch. Hydrobiol. (Ger.)*, **123**, 219 (1991).
72. Acs, E., and Kiss, K. T., "Investigation of Periphytic Algae in the Danube at Göd (1669 km, Hungary)." *Arch. Hydrobiol. Algal Stud. (Ger.)*, **62**, 47 (1991).
73. Dudley, T. L., and D'Antonio, C. M., "The Effects of Substrate Texture, Grazing, and Disturbance on Macroalgal Establishment in Streams." *Ecology*, **72**, 297 (1991).
74. Applegate, D. H., and Bryers, J. D., "Effects of Carbon and Oxygen Limitations and Calcium Concentrations on Biofilm Removal Processes." *Biotechnol. Bioeng.*, **37**, 17 (1991).
75. Burkholder, J. M., and Cuker, B. E., "Response of Periphyton Communities to Clay and Phosphate Loading in a Shallow Reservoir." *J. Phycol.*, **27**, 373 (1991).
76. Sündback, K., and Snoeijs, P., "Effects of Nutrient Enrichment on Microalgal Community Composition in a Coastal Shallow-water Sediment System: An Experimental Study." *Bot. Mar. (Ger.)*, **34**, 341 (1991).
77. Nilsson, C., and Sündback, K., "Growth and Nutrient Uptake Studied in Sand-Agar Microphytobenthic Communities." *J. Exp. Mar. Biol. Ecol. (Neth.)*, **153**, 207 (1991).
78. Lohman, K., et al., "Experimental Evidence for Nitrogen Limitation in a Northern Ozark Stream." *J. North Am. Benthol. Soc.*, **10**, 14 (1991).
79. Mundie, J. H., et al., "Responses of Stream Periphyton and Benthic Insects to Increases in Dissolved Inorganic Phosphorus in a Mesocosm." *Can. J. Fish Aquat. Sci.*, **48**, 2061 (1991).
80. Paul, B. J., et al., "Nutrient Cycling by Biofilms in Running Waters of Differing Nutrient Status." *J. North Am. Benthol. Soc.*, **10**, 31 (1991).
81. Mulholland, P. J., et al., "Role of Nutrient Cycling and Herbivory in Regulating Periphyton Communities in Laboratory Streams." *Ecology*, **72**, 966 (1991).
82. Steinman, A. D., et al., "Interactive Effects of Nutrient Reduction and Herbivory on Biomass, Taxonomic Structure, and P Uptake in Lotic Periphyton Communities." *Can. J. Fish Aquat. Sci.*, **48**, 1951 (1991).
83. Steinman, A. D., et al., "Resilience of Lotic Ecosystems to a Light-Elimination Disturbance." *Ecology*, **72**, 1299 (1991).
84. Mulholland, P. J., et al., "Influence of Nutrients and Grazing on the Response of Stream Periphyton Communities to a Scour Disturbance." *J. North Am. Benthol. Soc.*, **10**, 127 (1991).
85. McCormick, P. V., and Stevenson, R. J., "Grazer Control of Nutrient Availability in the Periphyton." *Oecologia (Ger.)*, **86**, 287 (1991).
86. Feminella, J. W., and Resh, V. H., "Herbivorous Caddisflies, Macroalgae, and Epilithic Microalgae: Dynamic Interactions in a Stream Grazing System." *Oecologia (Ger.)*, **87**, 247 (1991).
87. Dodds, W. K., "Community Interactions Between the Filamentous Alga *Cladophora glomerata* (L.) Kuetzing, Its Epiphytes, and Epiphyte Grazers." *Oecologia (Ger.)*, **85**, 572 (1991).
88. Martin, I. D., et al., "Experimental Analysis of Density Dependent Effects on Two Caddisflies and Their Algal Food." *J. North Am. Benthol. Soc.*, **10**, 404 (1991).
89. Hann, B. J., "Invertebrate Grazer-Periphyton Interactions in a Eutrophic Marsh Pond." *Freshwater Biol. (G. B.)*, **26**, 87 (1991).
90. Tuchman, N. C., and Stevenson, R. J., "Effects of Selective Grazing by Snails on Benthic Algal Succession." *J. North Am. Benthol. Soc.*, **10**, 430 (1991).
91. Steinman, A. D., "Effects of Herbivore Size and Hunger Level on Periphyton Communities." *J. Phycol.*, **27**, 54 (1991).
92. Lane, J. M., "The Effect of Variation in Quality and Quantity of Periphyton on Feeding Rate and Absorption Efficiencies of the Snail  *Neritina relivata* (Say)." *J. Exp. Mar. Biol. Ecol. (Neth.)*, **150**, 117 (1991).
93. Hill, A. S., and Hawkins, S. J., "Seasonal and Spatial Variation of Epilithic Microalgal Distribution and Abundance and Its Ingestion by *Patella vulgata* on a Moderately Exposed Rocky Shore." *J. Mar. Biol. Assoc. U. K. (G. B.)*, **71**, 403 (1991).
94. Dillon, R. T., Jr., and Davis, K. B., "The Diatoms Ingested by Freshwater Snails: Temporal, Spatial, and Interspecific Variation." *Hydrobiologia (Neth.)*, **210**, 233 (1991).
95. DeNicola, D. M., and McIntire, C. D., "Effects of Hydraulic Refuge and Irradiance on Grazer-Periphyton Interactions in Laboratory Streams." *J. North Am. Benthol. Soc.*, **10**, 251 (1991).
96. Edgar, G. J., "Artificial Algae as Habitats for Mobile Epifauna: Factors Affecting Colonization in a Japanese *Sargassum* Bed." *Hydrobiologia (Neth.)*, **226**, 111 (1991).
97. McCormick, P. V., "Lotic Protistan Herbivore Selectivity and its Potential Impact on Benthic Algal Assemblages." *J. North Am. Benthol. Soc.*, **10**, 238 (1991).
98. Blanchard, G. F., "Measurement of Meiofauna Grazing Rates on Microphytobenthos: Is Primary Production a Limiting Factor?" *J. Exp. Mar. Biol. Ecol. (Neth.)*, **147**, 37 (1991).
99. Perlmutter, D. G., and Meyer, J. L., "The Impact of a Stream-dwelling Harpacticoid Copepod upon Detritally Associated Bacteria." *Ecology*, **72**, 2170 (1991).
100. Montagna, P. A., and Yoon, W. B., "The Effect of Freshwater Inflow on Meiofaunal Consumption of Sediment Bacteria and Microphytobenthos in San Antonio Bay, Texas, U. S. A." *Estuarine Coastal Shelf Sci.*, **33**, 529 (1991).
101. Scrimgeour, G. J., et al., "Mechanisms of Algal Patch Depletion: Importance of Consumptive and Non-consumptive Losses in Mayfly-Diatom Systems." *Oecologia (Ger.)*, **85**, 343 (1991).
102. Power, M. E., "Shifts in the Effects of Tuft-weaving Midges on Filamentous Algae." *Am. Midl. Nat.*, **125**, 275 (1991).
103. Falkowski, P. G., and LaRoche, J., "Acclimation to Spectral Irradiance in Algae." *J. Phycol.*, **27**, 8 (1991).
104. Boston, H. L., and Hill, W. R., "Photosynthesis-Light Relations of Stream Periphyton Communities." *Limnol. Oceanogr.*, **36**, 644 (1991).
105. Hill, W. R., and Boston, H. L., "Community Development Alters Photosynthesis-Irradiance Relations in Stream Periphyton." *Limnol. Oceanogr.*, **36**, 1375 (1991).
106. Albertano, P., et al., "Observations on Cell Structure of Microorganisms of an Epilithic Phototrophic Community Competing for Light." *Nova Hedwigia (Ger.)*, **53**, 369 (1991).
107. Pickney, J., and Zingmark, R. G., "Effects of Tidal Stage and Sun Angles on Intertidal Benthic Microalgal Productivity." *Mar. Ecol. Prog. Ser. (Ger.)*, **76**, 81 (1991).
108. Davison, I. R., "Environmental Effects on Algal Photosynthesis: Temperature." *J. Phycol.*, **27**, 2 (1991).
109. Lamberti, G. A., et al., "Stream Ecosystem Recovery Following a Catastrophic Debris Flow." *Can. J. Fish Aquat. Sci.*, **48**, 196 (1991).
110. Cammen, L. M., "Annual Bacterial Production in Relation to Benthic Microalgal Production and Sediment Oxygen Uptake in an Intertidal Sandflat and an Intertidal Mudflat." *Mar. Ecol. Prog. Ser. (Ger.)*, **71**, 13 (1991).
111. Schwingamer, P., et al., "Oxygen Flux and Community Biomass Structure Associated with Benthic Photosynthesis and Detritus Decomposition." *J. Exp. Mar. Biol. Ecol. (Neth.)*, **147**, 9 (1991).



112. Sundbäck, K., *et al.*, "Influence of Sublittoral Microphytobenthos on the Oxygen and Nutrient Flux Between Sediment and Water: A Laboratory Continuous-flow Study." *Mar. Ecol. Prog. Ser. (Ger.)*, **74**, 263 (1991).
113. Sweetts, J.-P. R. A., *et al.*, "Oxygen-consuming Processes at the Profundal and Littoral Sediment-Water Interface of a Small Mesoeutrophic Lake (Lake Vechten, The Netherlands)." *Limnol. Oceanogr.*, **36**, 1124 (1991).
114. Fiebig, D. M., and Lock, M. A., "Immobilization of Dissolved Organic Matter From Groundwater Discharging Through the Stream Bed." *Freshwater Biol. (G. B.)*, **26**, 45 (1991).
115. Shearer, C. A., and Webster, J., "Aquatic Hyphomycete Communities in the River Teign. IV. Twig Colonization." *Mycol. Res.*, **95**, 413 (1991).
116. Czczuga, B., "Studies of Aquatic Fungi. Part 16: Aquatic Fungi of the River Pisa and Its Tributary, the River Skroda." *Acta Hydrochim. Hydrobiol. (Ger.)*, **19**, 57 (1991).
117. Thomas, K., *et al.*, "Changes in Concentration of Aquatic Hyphomycete Spores in Lees Creek, ACT, Australia." *Mycol. Res.*, **95**, 178 (1991).
118. Thomas, K., *et al.*, "A Dynamic Model of Fungal Spora in a Freshwater Stream." *Mycol. Res.*, **95**, 184 (1991).
119. Bärlocher, F., "Intraspecific Hyphal Interactions Among Aquatic Hyphomycetes." *Mycologia*, **83**, 82 (1991).
120. Bärlocher, F., "Fungal Colonization of Fresh and Dried Leaves in the River Teign (Devon, England)." *Nova Hedwigia (Ger.)*, **52**, 349 (1991).
121. Gessner, M. O., and Schwoerbel, J., "Fungal Biomass Associated with Decaying Leaf Litter in a Stream." *Oecologia (Ger.)*, **87**, 602 (1991).
122. Chergui, H., and Pattee, E., "An Experimental Study of the Breakdown of Submerged Leaves by Hyphomycetes and Invertebrates in Morocco." *Freshwater Biol. (G. B.)*, **26**, 97 (1991).
123. Christian, R. R., and Wetzel, R. L., "Synergism Between Research and Simulation Models of Estuarine Microbial Food Webs." *Microb. Ecol.*, **22**, 111 (1991).
124. Lane, D. J., *et al.*, "Evolutionary Relationships Among Sulfur- and Iron-oxidizing Eubacteria." *J. Bacteriol.*, **174**, 269 (1991).
125. Rahat, M., "An Ecological Approach to Hydra-cell Colonization by Algae-Algae/Hydra Symbioses." *Oikos (Den.)*, **62**, 381 (1991).
126. Vacelet, E., and Thomassin, B. A., "Microbial Utilization of Coral Mucus in Long Term *In Situ* Incubation Over a Coral Reef." *Hydrobiologia (Neth.)*, **211**, 19 (1991).
127. Uriz, M. J., *et al.*, "An Approach to the Ecological Significance of Chemically Mediated Bioactivity in Mediterranean Benthic Communities." *Mar. Ecol. Prog. Ser. (Ger.)*, **70**, 175 (1991).

## Toxic effects of chemicals on microorganisms

Rodolfo Barreiro, James R. Pratt

### METHODOLOGY

Dutka *et al.*<sup>1</sup> assessed the spatial variability between sediment samples and evaluated the sensitivity and selectivity of different sediment extraction procedures (Milli-Q water extract, HCl-KCl

buffer pH 2). They used a battery of tests, finding ATP-TOX system and Mutatox tests the most responsive options for all types of samples. Natural populations of bacteria and phytoplankton (Trenton Channel, Detroit River) showed a significant suppression of substrate uptake (<sup>3</sup>H-glucose or <sup>3</sup>H-adenine by bacteria, <sup>14</sup>C-bicarbonate by phytoplankton) when exposed to contaminated sediments (toxic organics: zinc, lead, and copper) compared to bioassays without sediment or with uncontaminated sediment.<sup>2</sup> Using soil samples from an abandoned chemical manufacturing facility (2,3,6-trichlorobenzeneacetic acid the main pollutant), Donnelly *et al.*<sup>3</sup> concluded that the most accurate assessment of toxicity was obtained with a water extract to measure the leaching potential and a solvent extract (methylene chloride and methanol) to determine the relative total hazard of the sample.

The genotoxic potential of XAD2 resin concentrates from a heavily polluted stream was evaluated by the induction of genome conversion and point mutation in *Saccharomyces cerevisiae* D7 strain (a short-term test).<sup>4</sup> Concentrates were proposed to deal with compounds present in very low concentrations and not amenable to current analytical methodology. Premdas and Kendrick<sup>5</sup> proposed a bioassay system (buoyant propagules of the aeroaquatic fungus *Pseudoaegerita matsushimae*) for pesticides concentrated in the surface microlayer (mainly those dispersed in oil-based carrier as pentachlorophenol or 2,4-dichlorophenoxyacetic acid).

New methods (pulse-field gel electrophoresis) used in gene mapping were validated as a test for the rapid assessment of chromosomal damage in *S. cerevisiae*.<sup>6</sup> Effects of chemicals known to interact with DNA (N-methyl-N'-nitro-N-nitrosoguanidine, *cis*-Platinum (II) diaminechloride) were compared with the effects of other chemicals (trichlorethylene) for which such an effect has not been shown.

The usefulness and sensitivity of uranin staining (fluorescent dye) as an indicator of the impact of organic pollutants on algal membrane integrity were evaluated using a pool of water-soluble components of crude oil as test substances (benzene, toluene, ethylbenzene, and three xylene isomers).<sup>7</sup> The method provided higher sensitivity than previous ones (release of labeled photosynthates), was more accurate than direct microscopic counts, was sensitive within the range of concentrations with inhibitory effect on cell growth, and could be performed in air-tight flasks needed for highly volatile organic pollutants.

The usefulness of <sup>3</sup>H-thymidine incorporation to assay the toxic effect of copper, nickel, and linear alkylbenzene sulfonate on naturally occurring bacterioplankton was evaluated by Martinez *et al.*<sup>8</sup> The method proved useful in a system with permanent mixtures of fresh and sea water (Rhône River plume). Incorporation of [<sup>3</sup>H-methyl] thymidine and exoenzymatic activities of phosphatase and protease was used to test the sensitivity of natural bacterioplankton to selected toxicants (copper, tetrapropylbenzene sulfonate, K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>, atrazine, and XAD-concentrates of the organic fractions from the river water).<sup>9</sup> Thymidine incorporation was more sensitive to all compounds than the enzymatic activities.

Fluorescence of 3-(3,4-dichlorophenyl)-1,1-dimethylurea was more appropriate (artifact free) for assessment of deleterious effects on phytoplankton photosynthesis than radiocarbon uptake, especially in oligotrophic environments contaminated with dispersed oil. This technique was very sensitive, rapid, and easy to use. It was considered a reliable indicator of photosynthesis