Biological and chemical indicators of eutrophication in the Yellowstone River and major tributaries during August 2000

Abstract

The trophic condition of the Yellowstone River and its major tributaries during low-flow conditions was better represented by algal biomass and community autecology than by nutrient concentrations in water samples. Nutrient concentrations generally were low throughout the length of the Yellowstone River, however indicators of algal biomass and the percentage of eutrophic and nitrogen-indicator diatoms were relatively high in the middle segments of the river and near the mouths of major tributaries. Algal biomass and community composition were influenced by the availability of nitrogen and water turbidity. Biomass increased with the abundance of eutrophic taxa, and was relatively small at sites dominated by nitrogen-fixing blue-green algae. Eutrophication of streams and rivers in the Yellowstone River basin is influenced by nitrogen inputs from human sources along the river corridors and within the watershed. Algal community indicators can provide an early warning of accelerated eutrophication processes, long before nuisance algal growths contribute to water-quality problems.

Introduction

Benthic algae (periphyton) are a primary source of energy to aquatic food webs in many streams and rivers in the Rocky Mountain region of the Western United States (Deacon and Spahr 1998; Spahr and Deacon 1998; Mize and Deacon 2001; Wynn et al. 2001). Differences or changes in the biomass, productivity, and structure of periphyton communities can provide a more sensitive measure of the trophic status of streams and rivers than instantaneous sampling of dissolved and total concentrations of nutrients in the water column. For example, dissolved nitrate concentrations in Midwestern eutrophic streams and rivers were relatively low at sites with large amounts of algal biomass and high rates of primary productivity and respiration (Porter 2000; Porter et al. 2001). Ambient nutrient concentrations often are small when rates of algal uptake equal or exceed rates of nutrient inflow and transport in lotic water bodies. Thus, the expression of eutrophication in algal-eutrophic streams during low-flow conditions is the algal biomass rather than elevated nutrient concentrations (Porter 2000). In turbid or heavily shaded streams, algal productivity can be limited by insufficient light. In such nutrient-eutrophic streams, the expression of eutrophication is relatively large nutrient concentrations and low algal biomass (U.S. Environmental Protection Agency 2000).

Conditions found frequently in Western streams and rivers, including a combination of clear water, open riparian canopy, and stable substrates for algal colonization and growth, can promote excessive growth of filamentous green algae such as *Cladophora glomerata*, when these conditions occur in conjunction with an enriched supply of nutrients (Welch et al. 1988; Watson and Gestring 1996; Dodds et al. 1997). In response to nuisance growths of *Cladophora* in the Clark Fork basin in western Montana, voluntary nutrient criteria were adopted as part of a total maximum daily load (TMDL) effort to control excessive biological responses to eutrophication in the basin (Watson et al. 2000). Adverse effects of excessive algal growths in streams and rivers include (1) reduction of dissolved-oxygen concentrations due to algal respiration and microbial decomposition of senescent algae, (2) organic enrichment and changes in the quality of algal food resources for invertebrate and fish communities, and (3) aesthetic, recreational, and operational concerns among anglers, irrigators, and the general public.

The autecology (physiological optima and tolerance range relative to nutrients, organic enrichment, salinity, pH, and other water-quality conditions) of algal species is well known for many common taxa, notably diatoms (Lowe 1974; Lange-Bertalot 1979; Van Dam et al. 1994). Autecological metrics have been used successfully in many studies to infer water quality conditions integrated over short periods of time (Bahls 1993; Cuffney et al. 1997, 2000; Scudder and Stewart, 2001; Hill et al. 2002). In this report, algal biomass and autecological approaches are compared for assessing spatial trends of eutrophication in the Yellowstone River and major tributaries. Objectives of this report include an evaluation of the trophic condition of the Yellowstone River, a comparison of chemical and biological indicators of eutrophication, and an increased understanding of nutrient sources and biological responses associated with tributary inflows.

Description of the Study Area

The Yellowstone River is the largest tributary of the Missouri River, draining an area of more than 180,000 square kilometers (km^2) in Montana, Wyoming, and North Dakota (fig. 1). The mean annual discharge of the Yellowstone River near its mouth is 363 cubic meters per second (m^3/s), which is equivalent to 12,803 cubic feet per second (ft^3/s)(Shields et al. 2000). Peak flows in the Yellowstone River main stem and tributaries originating in the Rocky Mountains tend to occur during May through July, as a result of snowmelt runoff. Major tributaries to the Yellowstone River include the Clarks Fork Yellowstone River, the Bighorn river system, the Tongue River, and the Powder River (fig. 1).

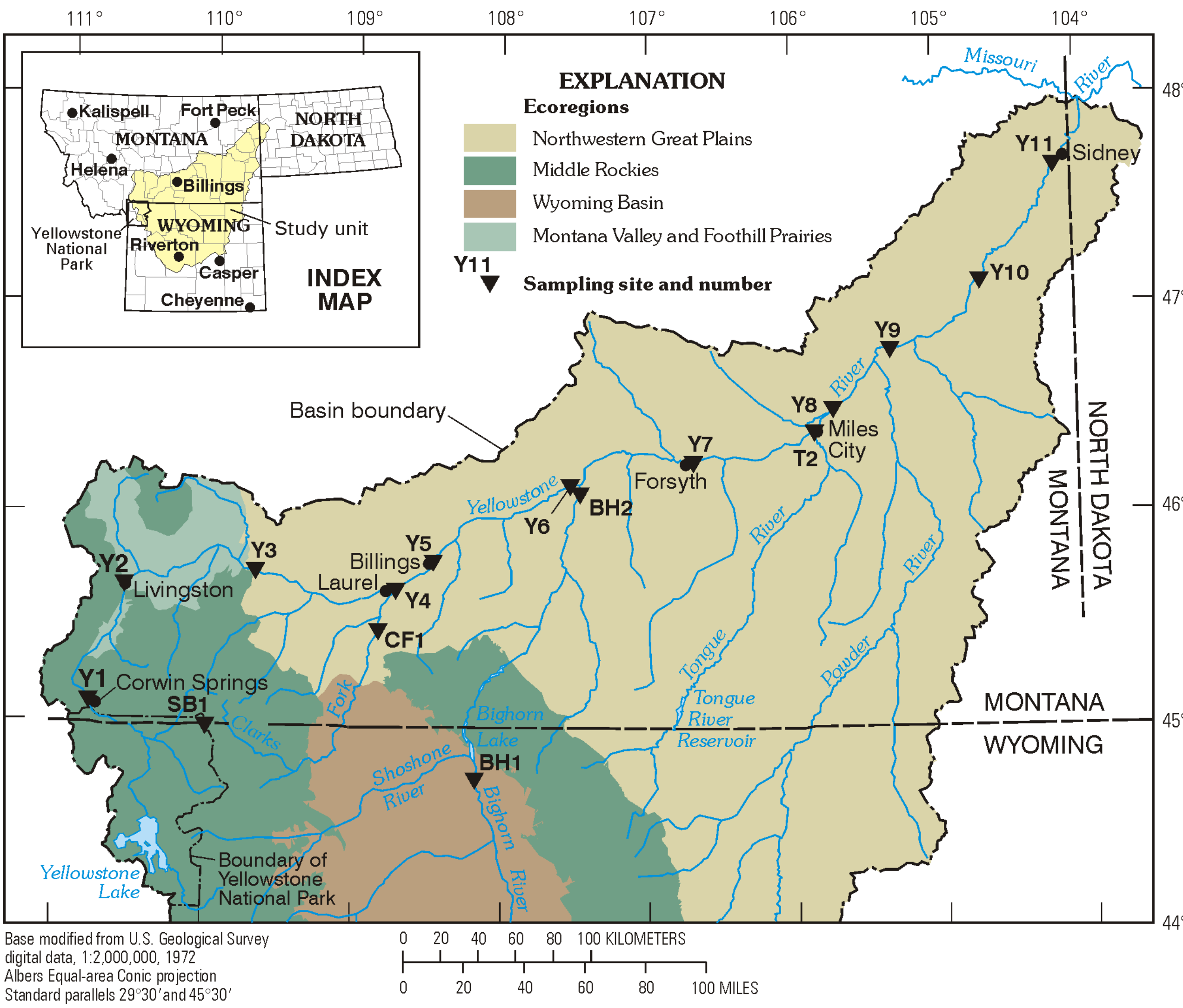

Figure 1. Location of sampling sites for the low-flow study in the Yellowstone River basin during August 2000.

The predominant land use and land cover in the Yellowstone River basin is grazing on open grass and shrub lands (Zelt et al. 1999). Grasses and shrubs dominate the potential natural vegetation in the Northwestern Great Plains ecoregion (55 percent of study area), the Wyoming Basin (21 percent) and the Montana Valley and Foothill Prairies (3 percent). About 21 percent of the basin lies in the Middle Rocky Mountains ecoregion, which features high mountains and plateaus covered by Douglas fir, western spruce-fir forests, and alpine meadows; predominant land use includes grazing, recreation, and silviculture (Omernik 1986). Crops such as sugar beets, beans, and corn are grown in the river valleys and other irrigated areas. Winter wheat and other grains are grown on widely distributed upland areas (Zelt et al. 1999).

Methods

Sample were collected at points along the main stem of the Yellowstone River and in major tributaries (fig. 1). Water chemistry samples were collected using methods described by Shelton et al. (1994). A description of water samples collected, and results for nutrient concentrations, algal standing crop, and rates of algal productivity are presented by Peterson et al. (2001). Microalgae samples were obtained by scraping periphyton from representative rocks collected from riffle areas in each sampling reach. Algae were removed from the entire exposed surface of each rock; rock samples were composited and processed as described by Porter et al. (1993). Aliquots for chlorophyll and ash-free dry mass analyses were withdrawn from the sample and processed in the USGS Wyoming District laboratory using methods described by Arar and Collins (1992) and American Public Health Association (1980), respectively. The remaining sample was preserved and shipped to the Academy of Natural Sciences of Philadelphia (ANSP) for algal species identifications, counts, and biovolume estimates.

Macroalgae samples of filamentous algae (*Cladophora glomerata*) were collected with a USGS Slack sampler (Cuffney et al. 1993) fitted with a square template delimiting 0.25 m^2. Filamentous algae were collected from 5 or more representative locations at each site. Macroalgae samples were not collected at sites where the abundance of filamentous algae in the reach was sparse. Samples were processed at the USGS Wyoming District laboratory using Standard Methods for determining dry mass (American Public Health Association 1980).

Autecological Metrics

The relative abundance of periphyton species associated with autecological-indicator groups was calculated in accordance with information presented by Van Dam et al. (1994; 2002), Prescott (1962), Bold and Wynne (1978), Lowe (1974). The percentage of eutrophic diatoms was calculated by summing the relative abundance of species classified in the range of mesotrophic to hypereutrophic autecology (category 3 through 6; Van Dam et al. 1994; 2002). The percentage of nitrogen-autotrophic diatoms (those requiring dissolved inorganic nitrogen) was calculated by summing the relative abundance of species classified as nitrogen autotrophs (category 2; Van Dam et al., 1974), and the percentage of nitrogen-heterotrophic diatoms (those responding to total organic sources of nitrogen) was calculated in a similar manner (category 3+4; Van Dam et al., 1974). The percentage of nitrogen fixers was calculated as the sum of species in algal families known to fix atmospheric nitrogen; for example, Rivulariaceae (blue-green algae; Bold and Wynne 1978) and Epithemiaceae (diatoms with endosymbiont blue-green algae; Fairchild et al. 1985; Geitler 1977).

Indicators of Algal Biomass

For microalgae samples, the biovolume of algal species was determined by obtaining measurements from representative cells of each species and applying the nearest geometric shape to estimate the average volume of one cell. Average species biovolume (in μm^3 per cell) was multiplied by the abundance of that species in the sample (cells per cm^2), then total microalgal biovolume (in $\mu m^3/cm^2$) was calculated by summing the biovolumes for all species in the sample. Because of uneven recovery of macroalgal cells in counts of microalgal samples, biovolume associated with *Cladophora* was subtracted from all samples where reported, and independent estimates of *Cladophora* biomass (macroalgae) were used for subsequent analyses. Biovolume units ($\mu m^3/cm^2$)

were converted to cm^3/m^2 by multiplying by a 10^{-8} factor. Assuming near unit density of algal cells (i.e. 1 cm^3 ~ 1 g), units of microalgal biovolume are closely related to microalgal biomass. The biomass of macroalgae (g/m^2) was determined directly by measurement of dry mass (American Public Health Association 1980). Periphyton biomass on rocks, including algae and other organisms, was determined as ash-free dry mass (g/m^2) by Standard Methods (American Public Health Association 1980).

Statistical Methods

Spearman rank correlations (Helsel and Hirsch 1992) were used to compare algal indicators with water quality conditions and environmental factors. Data were transformed (log or square root) when necessary to satisfy statistical assumptions of normality. The use of the term significant in this report implies statistical significance at a probability level of 5 percent or less ($p<0.05$).

Results: Chemical Indicators of Eutrophication

Concentrations of total nitrogen (dissolved inorganic nitrogen + particulate organic nitrogen) in water samples from the Yellowstone River were relatively low (between 0.3 mg/L and 0.4 mg/L; Peterson et al. 2001) and changed relatively little throughout the length of the river during August 2000. These concentrations are near target levels (0.3 mg/L) proposed to control nuisance filamentous algal growths in a western Montana river (Watson et al. 2000). Dissolved nitrate plus nitrite (hereafter, nitrate) concentrations in the main stem generally were less than the laboratory reporting limit of 0.05 mg/L. Where nitrate could be detected (Y5; 0.053 mg/L), the instantaneous load was estimated at about 280 kilograms per day (kg/d). Concentrations of total nitrogen (1.2 mg/L) and nitrate (0.772 mg/L) were relatively larger in the Clarks Fork Yellowstone River (CF1), however the instantaneous nitrate load (297 kg/d) was similar to Y5. In contrast, the instantaneous nitrate load in the Bighorn River (BH2) was about 775 kg/d (0.133 mg/L).

Concentrations of total phosphorus in the Yellowstone River also were relatively low, increasing from 0.016 mg/L at Y1 to about 0.038 mg/L in lower segments of the river (Y9, Y10, and Y11). The total phosphorus concentration at CF1 was 0.035 mg/L; however, concentrations in the Bighorn and Tongue River tributaries were less than 0.02 mg/L. Watson et al. (2000) proposed a total phosphorus target level of 0.02 mg/L to control nuisance filamentous algal growths in a western Montana river. Low concentrations of dissolved phosphorus (less than 0.01 mg/L) were detected at all Yellowstone River sites, however no apparent downstream trend was observed. Dissolved phosphorus concentrations also were low in tributary streams.

Water turbidity increased significantly in the Yellowstone River with the relative size of the drainage basin ($\rho = 0.864$; $p=0.008$; fig. 2) upstream from each site. Turbidity was 5 Nephelometric turbidity units (NTU) or less at sites upstream from Y7. Water turbidity increased two-fold between Y7 and Y8, downstream from the Bighorn and Tongue River tributary confluences, then increased from 12 NTU at Y9 to 24 NTU at Y11 (fig. 2), downstream from the Powder River confluence. However, the Powder River (fig. 1) was dry prior to and during the time of sampling in late August 2000. A more dramatic increase in turbidity with drainage area from sites Y9 to Y11 and greater turbidity in tributary streams than in the Yellowstone River main stem are evident from the data depicted in figure 2.

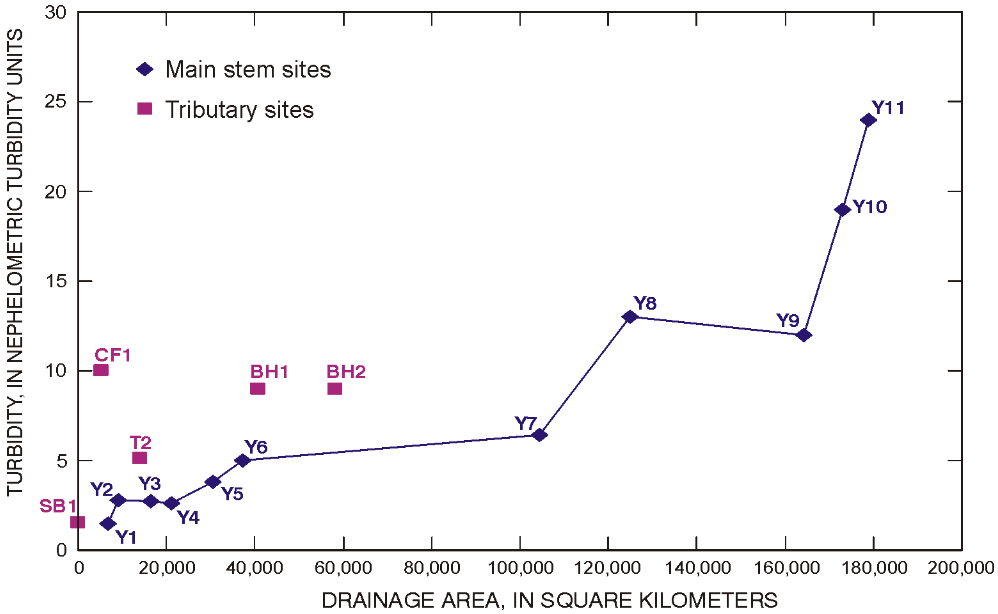

Figure 2. Turbidity relations with drainage area in the Yellowstone River basin and tributaries during August 2000.

Results: Biological Indicators of Eutrophication

Algal biomass indicators

Microalgae biovolume (fig. 3) in the Yellowstone River system was highly correlated with periphyton chlorophyll *a* (CHLa; $\rho = 0.935$; $p<0.001$) and ash-free dry mass (AFDM; $\rho = 0.922$; $p<0.001$). Algal biomass was largest in the middle segments of the Yellowstone River, notably near Billings, MT (Y5) and Forsyth, MT (Y7), but also was large in the Clarks Fork and Bighorn River tributaries. Periphyton CHLa concentrations at Y5 (797 mg/m^2), BH2 (164 mg/m^2), and CF1 (114 mg/m^2) were in the range of, or exceeded, levels commonly associated with nuisance algal conditions (U.S. Environmental Protection Agency, 2000; Peterson et al. 2001). Macroalgae biomass (fig. 4) followed a similar pattern in the Yellowstone River, with maximum biomass occurring at Y5 (490 g/m^2). All indicators of algal standing crop increased from low levels at Y1 to high levels at Y5, followed by relative decreases in biomass downstream from Y7 or Y8. Macroalgae biomass commonly exceeded estimated microalgae biomass by about an order of magnitude at over half of the Yellowstone River sites, and by 2 orders of magnitude at Y8. Relations between AFDM and microalgae biomass estimates were variable; AFDM exceeded microalgae biomass in the Yellowstone River by factors ranging from about 2x (Y3) to over 30x (Y8 and Y10).

Algal indicators of nutrient condition

The percentage of eutrophic diatoms (Van Dam et al. 1994; 2002) increased from very low levels at Y1 to nearly 50 percent of the periphyton community in middle segments of the Yellowstone River (Y5 and Y6), then decreased to low levels at Y9 and Y10, increasing downstream at Y11 (fig. 5). Eutrophic diatoms also were common in the Clarks Fork (84 percent) and Bighorn River (46 percent) tributaries near the Yellowstone River (fig. 5; CF1 and BH2). In contrast, the percentage of eutrophic diatoms was low (about 20 percent) in Soda Butte Creek (SB1) and the Tongue River (T2).

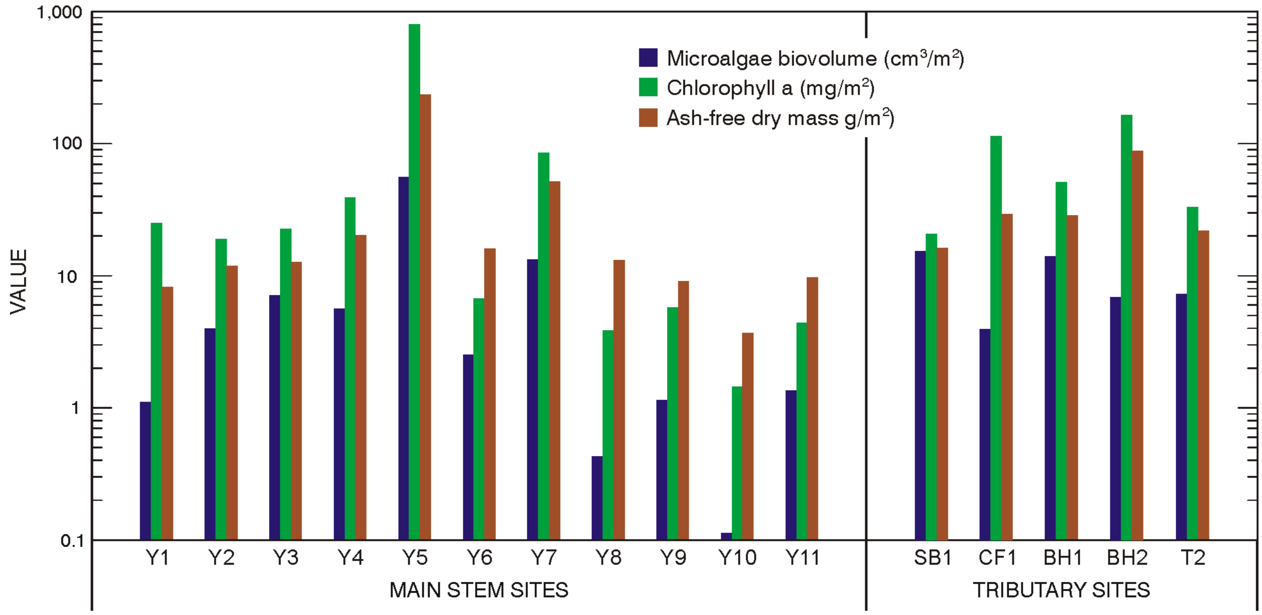

Figure 3. Microalgae biovolume, chlorophyll a concentration, and ash-free dry mass in the main stem of the Yellowstone River. (cm^3/m^2, cubic centimeters per square meter; mg, milligrams; g, grams)

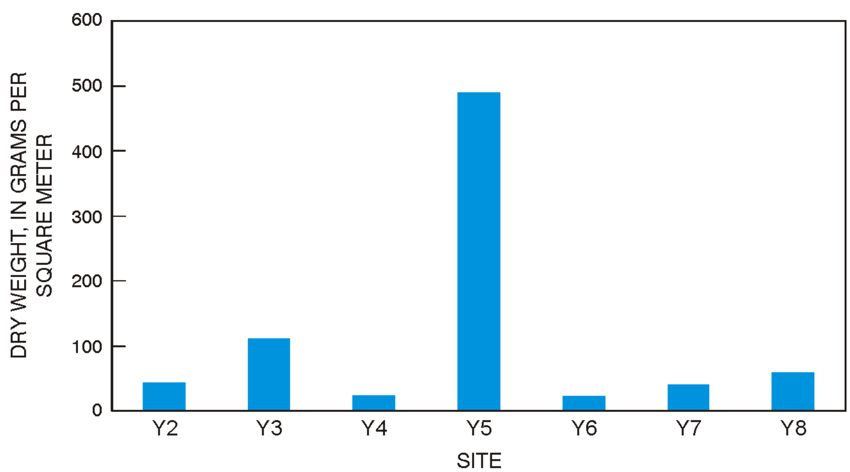

Figure 4. Macroalgae dry weight at selected sites in the Yellowstone River, August 2000.

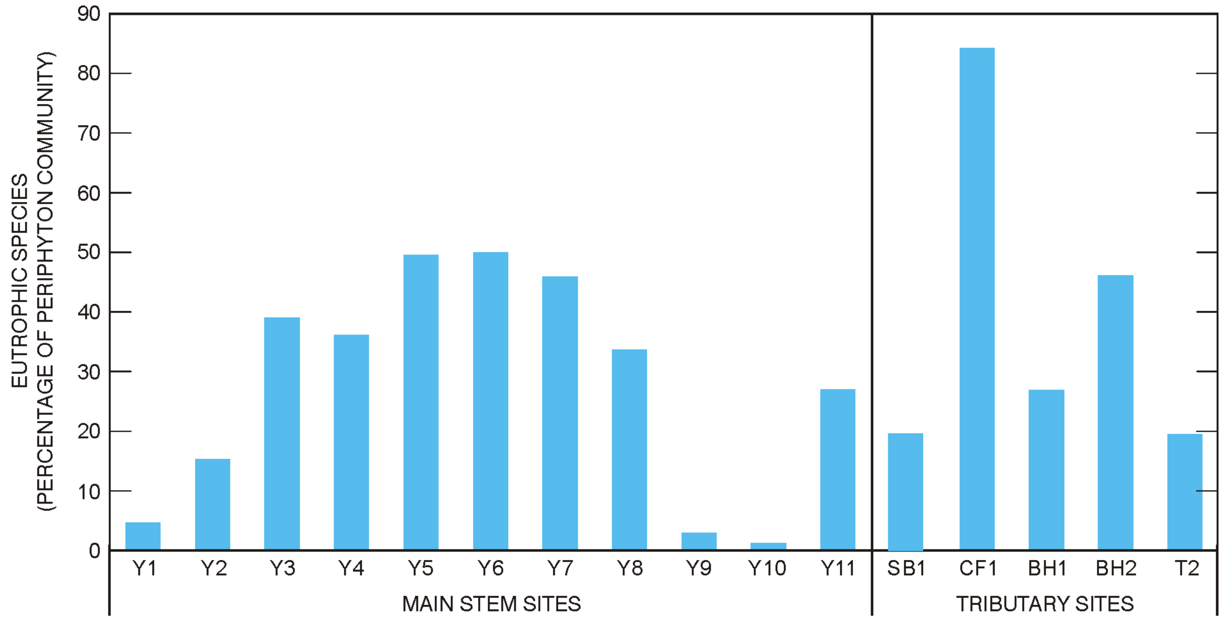

Figure 5. Proportion of eutrophic diatom species in the Yellowstone River and selected tributaries during August 2000.

The relative abundance of algal-species indicators of nitrogen-uptake metabolism (fig. 6) corresponds with other indicators of eutrophication in the Yellowstone River; for example, algal biomass (fig. 3) and rates of stream metabolism (Peterson et al. 2001). The percentage of nitrogen autotrophs (species requiring dissolved inorganic nitrogen for optimal growth; Van Dam et al. 1994) increases from Y1 to Y6, and is relatively low at Y9 and Y10. Although nitrate concentrations in the Yellowstone River generally were less than laboratory reporting limits (Peterson et al. 2001), instantaneous dissolved nitrate loads estimated for BH2 (775 kilograms per day (kg/d)) and CF1 (297 kg/d) are reflected by relatively large percentages of nitrogen autotrophs (fig. 6). The percentage of nitrogen heterotrophs (species whose growth is enhanced by organic sources of nitrogen (Van Dam et al. 1994; Tuchman 1996) is relatively large at Y11 (fig. 6) as well as in the Bighorn River (BH1) and Clarks Fork (CF1). The relative abundance of algal species that require inorganic sources of nitrogen (autotrophs, fig. 6) corresponds closely with the abundance of eutrophic diatoms in the Yellowstone River and tributaries (fig. 5). Periphyton biomass generally was large at sites where nitrogen autotrophs were abundant.

In contrast, the relative abundance of algal species capable of fixing atmospheric nitrogen (nitrogen fixers; Bold and Wynn 1978; Fairchild et al. 1985) would be expected to increase at sites where ambient nitrogen concentrations are very low, thus they could be considered oligotrophic species relative to nitrogen (Cuffney et al. 1997). The relative abundance of nitrogen fixers generally exceeded 30 percent throughout the Yellowstone River (fig. 6), as well as in Soda Butte Creek (SB1) and the Tongue River (T2) (fig. 6). The relative abundance of nitrogen fixers decreased with increases in the percentage of eutrophic diatoms and nitrogen autotrophs. Periphyton biomass typically was low at sites where nitrogen fixers (primarily blue-green algae) were abundant.

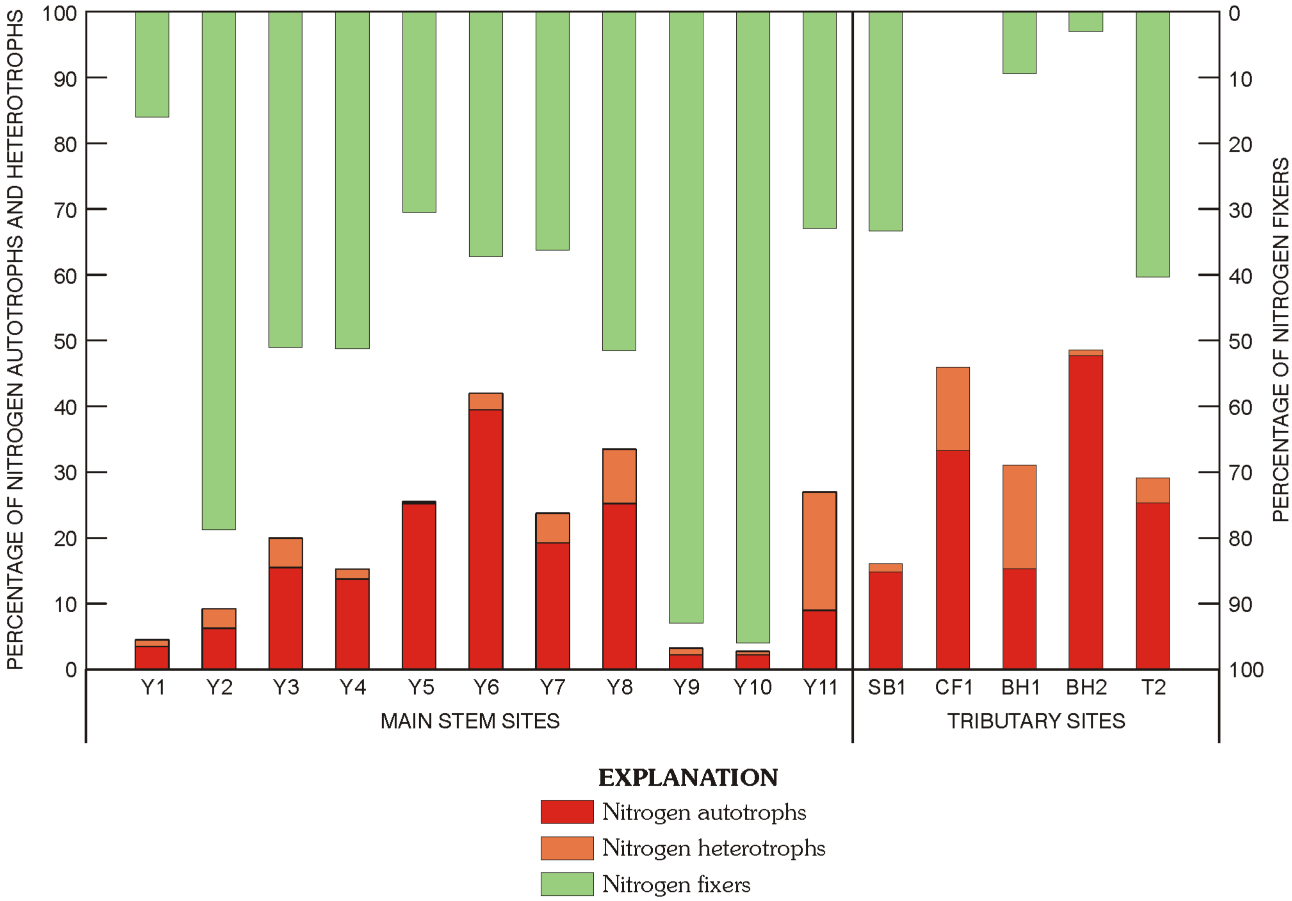

Figure 6. Nitrogen-uptake metabolism of periphyton species from the Yellowstone River and tributaries during August 2000.

Taxa richness, the number of algal species identified in a sample following a count of about 700 cells, decreased in the Yellowstone River from Y1 to Y6 (fig. 7) in association with increases in algal indicators of eutrophication, such as the percentage of eutrophic diatoms, algal biomass, and CHLa concentrations. Increases in taxa richness down river from Y6 were associated with an increased occurrence and abundance of “phytoplankton-adapted” species in the periphyton community; for example, centric diatoms (fig. 7). Water turbidity increased significantly with the percentage of centric diatoms in the benthic diatom community ($\rho = 0.835$; $p=0.028$), possibly indicating that the source of these species is from phytoplankton production in the river. High taxa richness at Y8 and Y9 (over 60 species) also may have been associated with immigration of algal species from tributary inflows, notably the Tongue River in which periphyton taxa richness at site T2 was relatively large (54 species; fig. 7).

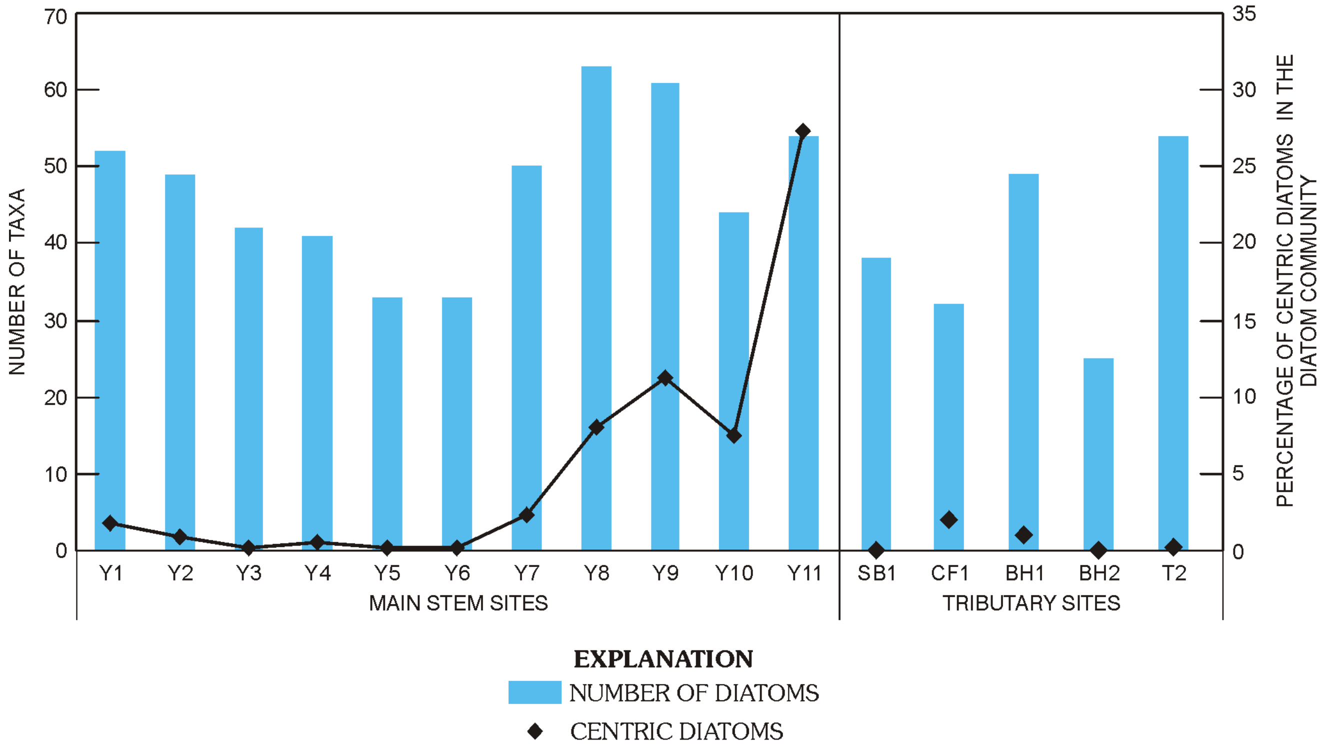

Figure 7. Periphyton taxa richness and the proportion of centric diatoms in the Yellowstone River and tributaries during August 2000.

Discussion

Water-quality regulatory agencies traditionally have focused on nutrient concentrations to assess potentially adverse effects of eutrophication on beneficial uses of streams and rivers (Environmental Protection Agency, 2000). From a water-chemistry perspective, trophic condition in the Yellowstone River system could be evaluated as consistently good throughout the length of the river. Dissolved nutrient concentrations (available for supporting the growth of algae and aquatic plants) generally were near or below laboratory reporting limits. Total nutrient concentrations also were low, particularly when compared to average concentrations reported for other streams and rivers in the United States (Mueller and Helsel 1996; U.S. Geological Survey 1999). However, algal biomass and autecological indicators of nutrient enrichment revealed eutrophic conditions and nuisance growths of filamentous algae in portions of the Yellowstone River and its major tributaries.

Potential sources of nutrients that could sustain large amounts of algal biomass in the Yellowstone River and its tributaries include residential development along some river segments and irrigated agricultural practices along other river segments (Zelt et al. 1999). The relative magnitude of nutrient fluxes from residential and agricultural sources is not well understood. In the Yellowstone River segment between the towns of Laurel (Y4) and Billings (Y5), permit data for August 2000 indicates that the largest point source contributed less than 30 percent of the nitrate load to the Yellowstone River when compared with non-point source loads of nitrate from the Clarks Fork (Pat Newby, Montana Department of Environmental Quality, written communication, 2002). Non-point sources of nutrients include natural sources, fertilizer used on agricultural crops, and rural-residential sources (septic tanks, lawn fertilizer, and domestic animal wastes). Estimated non-point source loads of nitrate contributed to the Yellowstone River were 297 kg/d and 775 kg/d from the Clarks Fork and Bighorn Rivers, respectively, during August 2000.

Algal biomass and community structure appear to be influenced by the availability of nutrients (dissolved inorganic and organic nitrogen) and the relative turbidity of the water. The abundance of nitrogen fixers at many sites, particularly those sites with relatively less human activity along upstream river segments, probably indicates that algal growth in the Yellowstone River basin generally is limited by the availability of nitrogen. Dissolved phosphorus was detected in water samples from all sites, thus we conclude that the growth of algae probably was not limited by phosphorus alone. Primarily blue-green algae (including cyanobacterial endosymbionts in certain diatoms), nitrogen fixers often become predominant in oligotrophic streams because they can fix atmospheric nitrogen (dissolved N_2 gas) to meet nitrogen uptake metabolism requirements (Bold and Wynn 1978). The nitrogen fixers can out-compete species that require external sources of dissolved nitrogen; for example, eutrophic taxa (Fairchild et al. 1985; Cuffney et al. 1997). Algal biomass was relatively small at sites where the abundance of nitrogen fixers was 50% or larger (figs. 3 and 6; Y2, Y9, and Y10).

The percentage of eutrophic species in the Yellowstone River increased significantly with increases in algal biomass and other indicators of eutrophication (CHLa and AFDM); however, relations with nitrate concentrations remain poorly understood because values mostly were less than 0.05 mg/L. Increases in algal indicators of eutrophication from Y1 to Y5 are influenced by non-point sources of nutrients, such as from the Clarks Fork Yellowstone River and rural and suburban residential development along the Yellowstone river corridor. Excellent water clarity (low turbidity; fig. 2) in the upper and middle segments of the Yellowstone River contributes to rates of algal productivity (Peterson et al. 2001) higher than found down river from Y6.

Although the percentage of eutrophic species exceeded 30 percent at all main stem sites between Y3 and Y8, algal standing crop and biomass was relatively larger at sites directly below tributary inflows (Y5 below Clarks Fork and Y7 below Bighorn River; fig. 3) than at subsequent sites down river (Y6 and Y8). However, the largest percentages of nitrogen-indicator species (autotrophs plus heterotrophs) occurred at Y6 and Y8, where water quality conditions also may be influenced by suburban sources of nutrients from Billings (Y6) and small towns upstream from Y8 (Forsyth and Miles City). The trophic condition of sites Y3 and Y4 probably is influenced by rural and suburban residential sources north of Yellowstone National Park; for example, the towns of Livingston and Corwin Springs. This finding is supported by measurable quantities of macroalgae from Y2 down river (fig. 4), and eutrophic phytoplankton CHLa levels (38.6 μg/L; Peterson et al. 2001) at Y2 during August 2000.

Increases in water turbidity down river from Y7 and nutrient enrichment in the lower Yellowstone River segments probably account for changes in periphyton community structure and indicators of trophic status. Increases in turbidity from Y7 to Y8 are attributable, at least in part, to inflows from the Bighorn and Tongue Rivers. Increases in periphyton taxa richness below Y6 (fig. 7) probably are related more to the addition (immigration) of new species from major tributaries to the Yellowstone River algal flora than improvements in water quality. In addition, the abundance of phytoplankton-adapted species; for example, the percentage of centric diatoms (fig. 7), also increases down river from Y7. The shift in periphyton community structure probably indicates the start of a transition from periphyton dominance to a phytoplankton-dominated system such as found in slow-flowing rivers and reservoirs. Increases in water turbidity between Y9 and Y11 may, in part, be associated with increases in the abundance of plankton.

Algal indicators of eutrophication are influenced by the availability of light in lower segments of the Yellowstone River because of high water turbidity (fig. 2), resulting in reduced light for periphyton photosynthesis and growth. Periphyton metrics also indicate oligotrophic conditions and low concentrations of dissolved and organic nitrogen at sites Y9 and Y10. Facultative nitrogen heterotrophs can process organic nitrogen to supply cellular energy requirements (in addition to photosynthesis), as well as acquiring sufficient nutrients required for nitrogen metabolism (Van Dam et al. 1994; Tuchman 1996). Thus, the abundance of nitrogen heterotrophs often increases in turbid rivers (or shaded streams) that are organically enriched with nitrogen. Based on nitrogen-uptake metabolism, increases in eutrophic condition between Y10 and Y11 are probably associated with increases in both dissolved forms of nitrogen (nitrogen autotrophs) and particulate organic nitrogen concentrations (nitrogen heterotrophs).

Accelerated eutrophication processes may be occurring in the upper segments of the Yellowstone River. Similar stream-eutrophication responses have been associated with increases in rural and suburban residential development in the West (Wynn et al. 2001; Spahr and Deacon 1998; Deacon and Spahr 1998). Although nuisance filamentous algal growths in the Yellowstone River basin presently are restricted to the middle portion of the river and the mouths of major tributaries, relative increases in the percentage of eutrophic algae at other sites may provide an early warning of potential eutrophication occurring in river segments that were historically of high quality. The availability of dissolved nitrogen appears to be a controlling factor in the upper and middle segments of the Yellowstone River. From a fisheries perspective, a little eutrophication may be beneficial because increases in primary and secondary productivity enhance the availability of food resources for fish, resulting in larger and heavier trout than found in streams without human sources of nutrient enrichment (Wynn et al. 2001).

Summary and Conclusions

The trophic condition of the Yellowstone River during August 2000 was better represented by algal biomass and community autecology than by nutrient concentrations in water samples. Both dissolved and total nutrient concentrations were low throughout the length of the Yellowstone River, however indicators of algal biomass and the percentage of eutrophic and nitrogen-indicator diatoms were relatively high in middle segments of the river and near the mouths of major tributaries. Low concentrations of dissolved nutrients in water samples from the upper and middle segments of the river may reflect high rates of nutrient uptake by benthic algae. This finding is similar to a conclusion reached in the Midwest (Porter et al. 2001) where nutrient concentrations decreased with increased algal biomass and rates of primary productivity and respiration (stream metabolism) in Midwestern agricultural streams and rivers.

Determinations of microalgal abundance and biomass should be supplemented with measurements of macroalgae, as shown by results in this report. Nuisance growth of filamentous macroalgae provided visible evidence of eutrophication, and the biomass of macroalgae frequently exceeded microalgal biomass by an order of magnitude or more.

Algal biomass and community composition is influenced by the availability of nitrogen and water turbidity. Algal community structure in the Yellowstone River main stem is influenced by enrichment from tributary inflows and landscape factors along the river corridor. Algal biomass increased with the percentage of eutrophic diatoms, however the nuisance eutrophication response is attributable to filamentous green algae (*Cladophora glomerata*). Biomass was relatively low at sites where nitrogen-fixing blue-green algae were predominant. Although relatively more is known about the autecology of diatoms species, as shown by our results, it is important to understand the composition and abundance of other algal taxa to understand water-quality conditions in streams and rivers.

The water-quality effects associated with rural recreational or residential development in pristine areas of the West are poorly understood. Minor amounts of eutrophication may be viewed as desirable for maintaining or enhancing sport fisheries in the region. However, excessive rates of eutrophication can result in adverse effects on dissolved oxygen concentrations and habitat requirements of fish and their food resources; for example, macroinvertebrate populations. Algal community indicators can provide an early warning of accelerated eutrophication processes, long before nuisance algal growths contribute to water-quality problems.

Acknowledgments

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