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Chlorophyll from algae and cyanobacteria increase with increasing total nitrogen and total phosphorus in streams and rivers

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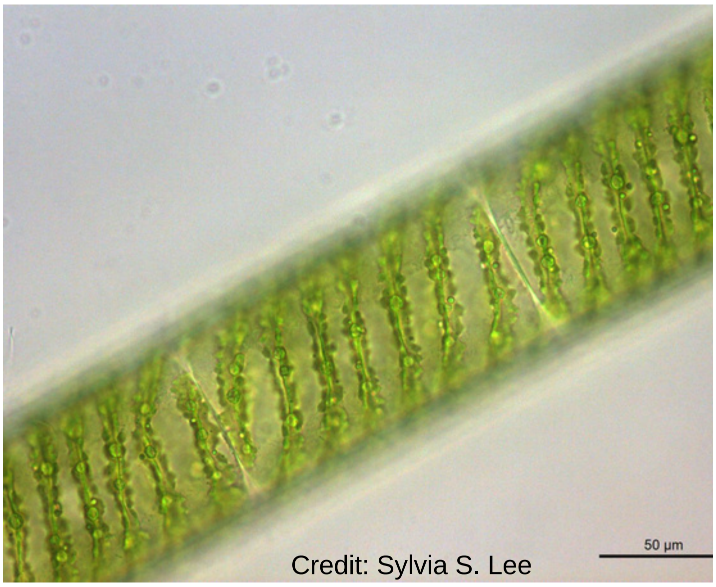

Credit: Sylvia S. Lee

Chlorophyll *a* (chl-a) concentration is a useful measure to track the effect of nutrient levels on algae and cyanobacteria that are free-living in water (sestonic) and that attach to surfaces (benthic) in streams and rivers. Across flowing waters worldwide, both sestonic and benthic chl-a increase as total nitrogen and total phosphorus increase. The rate and pattern of chl-a increase often depend on environmental context such as stream size, shape, and/or water chemistry, but complete and conclusive insights about the influence of environmental context could not be made because of gaps in the evidence base.

Why is this Evidence Synthesis Needed?

Nutrient pollution (nitrogen and phosphorus pollution) is a major stressor on stream and river ecosystems globally. Despite general acceptance of nutrient pollution as a source of stream degradation (e.g., excess growth of algae), understanding the ways that aquatic life responds is complicated, in part because environmental conditions in streams and rivers are quite variable. For example, algae may increase in response to increasing nutrients when light is abundant in streams but not when dense shading limits algal growth. This review examines the relationship between chlorophyll *a* (used to measure the abundance of algae and cyanobacteria) and nutrient concentrations in streams and rivers. It also examines how this relationship may change under a range of environmental conditions, including varying climate, watershed size, stream width, water temperature, and turbidity among many others. A compilation and synthesis of research about chlorophyll *a* and nutrient relationships across stream and river environments is needed to support decision-making, including the identification of streams and rivers with unhealthy biological communities and setting targets for maintaining or reviving healthy ecosystems.

This CEE systematic review examines how the level of chlorophyll *a* changes with total nitrogen and total phosphorus concentrations in streams and rivers and whether other environmental conditions affect how strongly chlorophyll *a* correlates with nutrient concentrations. The review summarizes and presents a synthesis of evidence from 105 articles.

Main Findings

What studies are included?

This review includes articles that examine flowing freshwater systems, or artificial streams that mimic these systems, and that report total nitrogen (TN) or total phosphorus (TP) concentrations in the water column along with concentrations of sestonic or benthic chlorophyll a (chl-a). A total of 105 articles reporting 439 individual measurements (i.e., effect sizes) of how algae respond to nutrients are analyzed. Articles were published between 1980 and 2017. There were 144 effect sizes reported from samples outside the United States (USA) and 295 from samples inside the USA. Three quarters of effect sizes were from temperate climates. Nearly all effect sizes were derived from observational field studies. For each of four nutrient-algae combinations, the following number of effect sizes are analyzed: 86 for TN-benthic chl-a, 82 for TN-sestonic chl-a, 106 for TP-benthic chl-a, and 137 for TP-sestonic chl-a.

What is the response of chlorophyll a to total nitrogen and total phosphorus concentrations in streams and rivers?

Increases in both total nitrogen (TN) and total phosphorus (TP) in the water column are associated with increases in benthic and sestonic chlorophyll a (chl-a). TP affects sestonic chl-a more than TN, whereas TN affects benthic chl-a more than TP. Where sestonic and benthic chl-a increase with TN, they also tend to increase with TP.

How are the relationships between chlorophyll a and total nitrogen and total phosphorus affected by other factors?

In this review, climate does not influence the relationship between chl-a and nutrient concentrations. Environmental conditions that do affect the relationship include: watershed area, water depth, conductivity, and turbidity (for TP-benthic chl-a); conductivity and longitude (for TN-benthic chl-a); stream gradient and nutrient concentration (for TP-sestonic chl-a); and watershed area, stream width, and nutrient concentration (for TN-sestonic chl-a).

As the concentrations of TN and TP increase to high levels, sestonic chl-a eventually stops increasing. This suggests that in areas of high nutrient pollution, algae that are free living in water become nutrient-saturated or growth-limited by another environmental factor that is correlated with nutrients, like light or turbidity. The patterns of how benthic chl-a responds at high nutrient concentrations are harder to interpret.

Year of publication was related to effect size, suggesting that chl-a increased less in response to increasing nutrients over time. This could be due to a bias that favored publication of large effect sizes in earlier years. From 2000 to 2017, relationships between chl-a and nutrients have stabilized.

The method used to measure chl-a potentially affects how much algae appear to increase in response to increasing nutrients. When fluorometry is used, algae appear to increase more in response to increasing nutrient concentration than when spectrophotometry is used. This trend is consistent across all combinations of chl-a and nutrient relationships.

What are the Implications of the Review Findings?

This systematic review confirms that nutrients consistently affect chl-a from algae and cyanobacteria in streams and rivers worldwide. It builds on previous literature syntheses evaluating chl-a and nutrient relationships and confirms that both sestonic and benthic chl-a increase when nutrients increase across a range of stream and river conditions. The review also points to limits on these relationships (e.g., potential nutrient saturation of algae at high nutrient concentrations) and that chl-a measurement method should not be overlooked when combining or interpreting studies. Lack of consistent reporting limits the ability to draw conclusions about how many environmental conditions influence chl-a and nutrient relationships. Nutrient managers responsible for protecting organisms residing in streams and rivers now have a comprehensive evidence base for how chl-a changes with changes in total nitrogen and total phosphorus concentrations in the water column.

This review provides evidence to managers to help keep biological communities in streams and rivers healthy. Credit: U.S. Environmental Protection Agency

Agriculture is a source of elevated nutrients in streams and rivers worldwide. Credit: U.S. Environmental Protection Agency

Synthesis Time Frame

The review includes studies published between 1980 and 2017. This CEE systematic review was published in October 2021.

Full Citation

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