



## Isle Royale Lakes: What's up, DOC?

**D**issolved Organic Carbon (DOC) is probably the most important aspect of lake chemistry that you have never heard of. Chemically and ecologically, DOC can critically influence a lake's temperature profile, how elements and compounds interact, and how life in a lake structures and sustains itself.

Carbon is the sixth-most abundant element in the universe and a key ingredient for most life on Earth. In lakes it takes two forms: inorganic and organic.

**Inorganic carbon** molecules are usually carbon dioxide ( $\text{CO}_2$ ) and bicarbonate ( $\text{HCO}_3^-$ , essentially baking soda). **Organic carbon** is created when plants or algae use water and  $\text{CO}_2$  (inorganic carbon) to convert solar energy into organic molecules that are stored in plant tissue (i.e., photosynthesis). From there the energy and carbon moves up the food chain to herbivores and grazers who eat plants and algae, then to carnivores who eat other animals, or omnivores who eat both. Most of the DOC that enters lakes comes from decomposing plant material in the watershed, but organisms living in the lake also contribute and may be more important depending on the context.

The “dissolved” aspect of DOC means that the molecules are very small, comprising things like amino acids, carbohydrates, lignin, and tannic and fulvic acids. DOC has many important effects on a lake, such as influencing how deep sunlight penetrates into the water column. This affects water temperature, protects organisms from UV radiation damage, and influences primary productivity.

Boreal lakes like those on Isle Royale can have higher DOC concentrations because of organic-rich soils, conifer forests, and often a large proportion of wetland soils due to the low slope of the landscape. As water percolates through soil it dissolves carbon-based organic matter. This is more pronounced in wetlands where slow flow and long residence times allow additional organic carbon to leach into

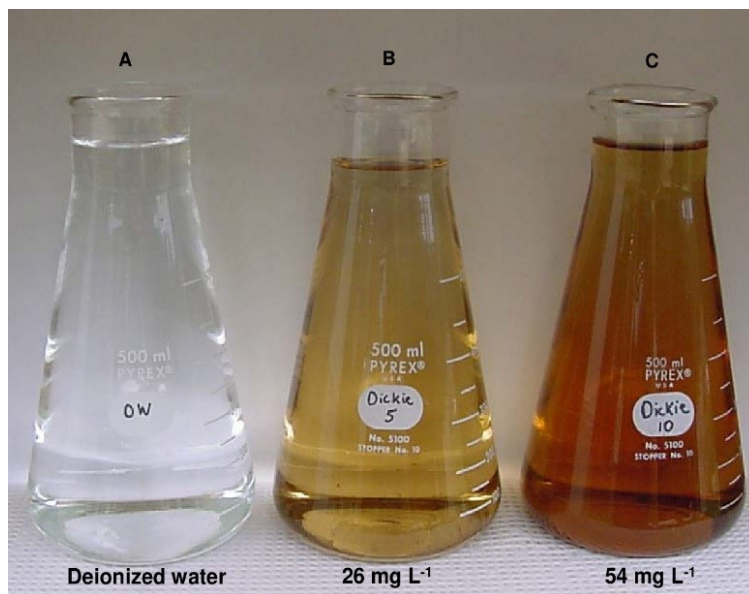


**Figure 1.** Color differences of samples based on concentration of dissolved organic carbon. PHOTO BY JEFF HUDSON, UNIVERSITY OF SASKATCHEWAN.

water. As a result, lakes with many wetlands in their watersheds tend to have a lot of carbon.

### DOC, A Natural Sunscreen

DOC attenuates (limits the effect of) both ultraviolet and visible radiation from sunlight, which reduces the damage UV radiation can do to organisms. But when DOC is at higher levels, it may also limit the amount of sunlight available for photosynthesis. This phenomenon is apparent in “tea-colored” water stained with DOC in the form of tannins from sources like conifer trees and bogs (Figure 1). **Tannins** are large molecules with phenols, which are hard for microbes to break down and therefore tend to accumulate.

By using a Secchi disc—a tool invented in 1865 by Pietro Angelo Secchi, an Italian Jesuit priest—we can estimate light penetration into water to better understand attenuation. This black-and-white patterned disc is lowered into the lake until it cannot be seen anymore (first reading), then pulled up to the point where it can be seen again (second reading).

The midpoint between these two readings is the depth being reached by about 10% of the sunlight (Figure 2).

Algae and **turbidity** (a cloudiness in the water caused by larger suspended particles) also influence Secchi readings, but DOC typically accounts for most of the attenuation in our lakes. In Isle Royale lakes, concentrations of both DOC and chlorophyll-*a* (a measure of algal abundance) influence Secchi disc depth (Figure 3). The Secchi disc can be seen at much greater depths when DOC and chlorophyll-*a* are less concentrated, but light cannot penetrate as far into the water column when these components are more concentrated (Figure 3).

### The Role of Productivity

**Productivity** is the rate at which individual organisms or populations gain energy, either by making it themselves (like plants) or eating



**Figure 2.** Taking a Secchi disc reading at Feldtmann Lake.  
NPS PHOTO

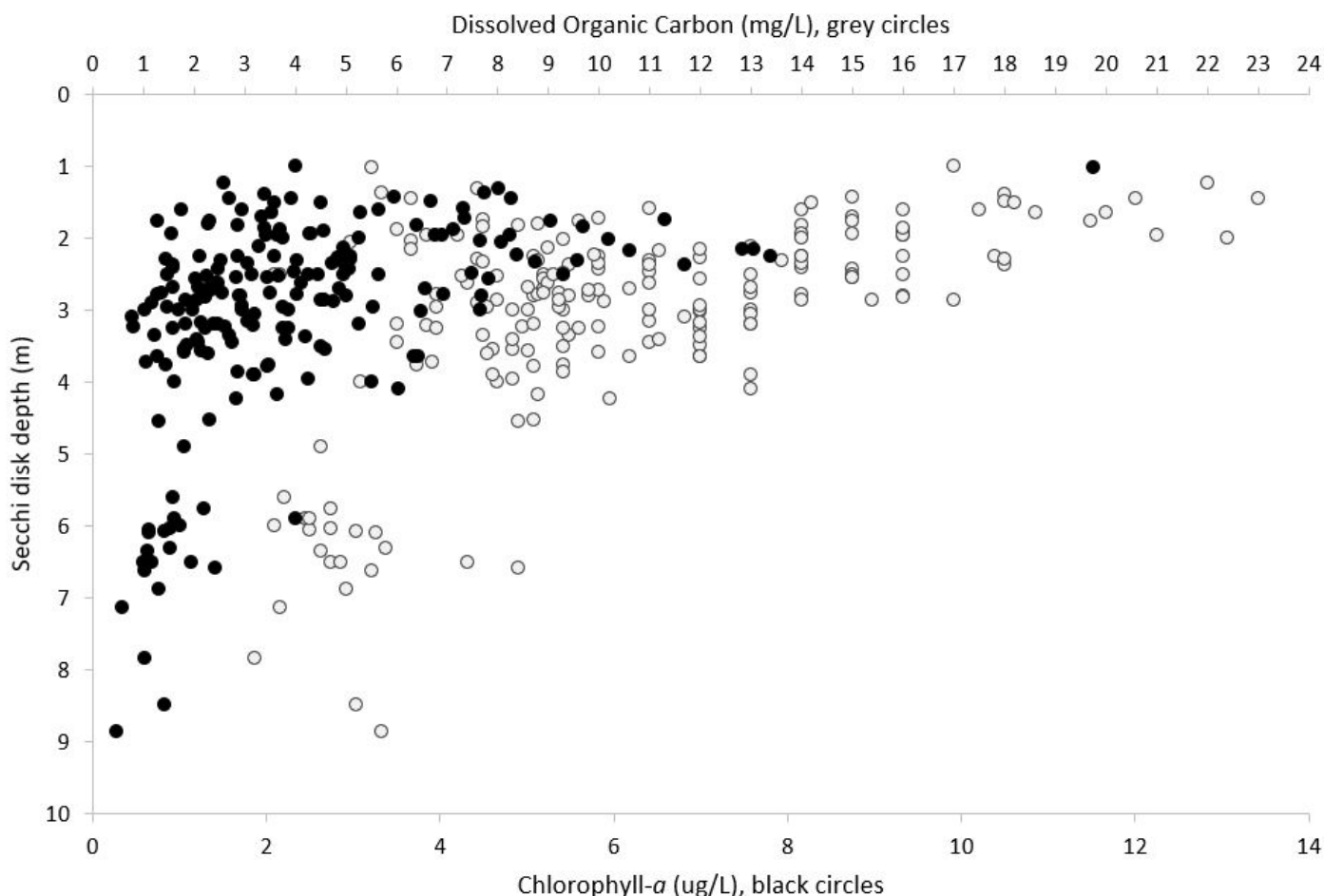


**Figure 3.** Influence of DOC and chlorophyll-*a* concentrations on Secchi disk depth as an indicator of light penetration into the water column. All ISRO water quality lakes, summer months 2008–2018.

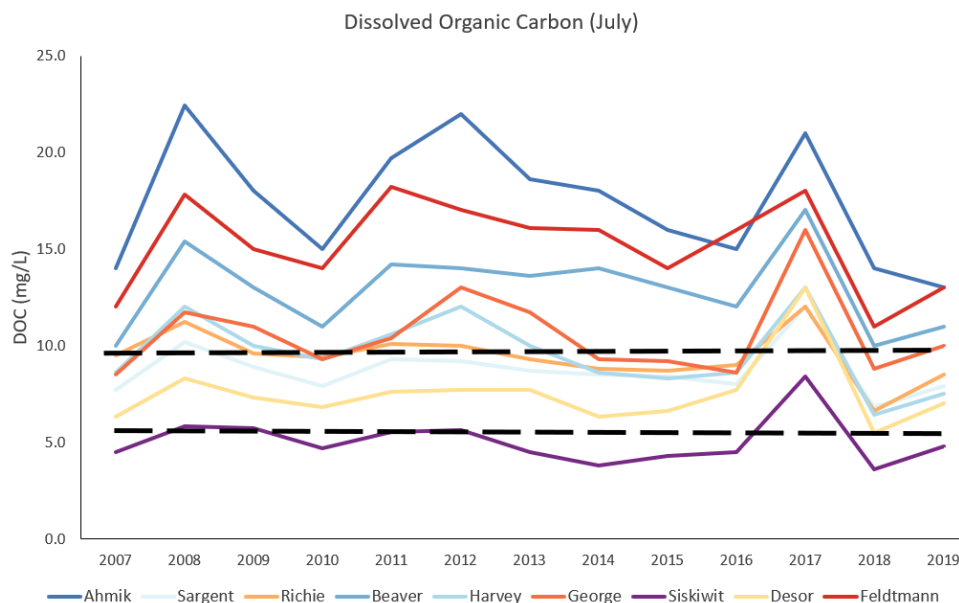


**Figure 4.** Mid-summer DOC concentrations from nine ISRO lakes, 2007–2019. Dashed lines indicate the zone between 6 and 10 mg/L.

something else. In lakes, we get a sense of algal biomass (as a proxy for productivity) by measuring the amount of chlorophyll-*a* generated through photosynthesis. High DOC attenuation means less solar energy is available for photosynthesis. Nutrients (phosphorous or nitrogen) are typically portrayed as the principle factor limiting algal growth, but DOC regulation of light availability can be so strong that algal growth may not respond to added nutrients. In contrast, lower attenuation can add to photosynthetic activity because light penetration is much greater, so these lakes may be more efficient in converting solar energy to biologically available energy.

While DOC is too small for larger animals like fish to eat directly, they can derive nutrition from it via the microbial loop. In the microbial loop, microbes consume DOC and in turn are consumed by ciliates, rotifers, zooplankton, and ultimately fish. In this way, a camper frying a lake trout or an eagle delivering a pike to its nest becomes part of a complex food web where energy is moved in an aquatic system from the molecular level to apex predators.

The line between lake productivity categories is not clear-cut, probably because each lake has different conditions influencing it. Generally, we consider a lake to be **net-heterotrophic** when DOC is above 6–10 milligrams per liter (mg/L), meaning that most of the useable energy is from a lake's watershed

(Figure 4). Below 6 mg/L are **net-autotrophic** lakes, where most of the useable energy is derived from photosynthesis occurring within the lake. ISRO lakes typically fall within a range of 5–15 mg/L, similar to the large majority of global lakes. Only one lake (Siskiwit) shows net-autotrophic conditions in mid-summer, and three (Ahmik, Feldtmann, and Beaver) are clearly net-heterotrophic. The other lakes are probably net-heterotrophic most of the time or switch between these two conditions depending on the year and season. Each of these lakes is in its own watershed,

separate from the others, so the synchronized annual patterns of peaks and troughs suggest that changes in DOC are linked to broad conditions occurring park-wide, such as patterns in precipitation (e.g., annual amount, storm intensity and frequency, timing and magnitude of snowmelt).

### ***DOC-tor, DOC-tor, gimme the news... How Humans Influence DOC in Lakes***

We influence our surroundings in many ways. Domestic or industrial waste, forest clear-cutting, and other landscape disturbances can alter DOC concentrations. A less direct influence is reflected in the weather patterns that have changed in recent decades. Since the main input of DOC to lakes is from streams draining the watershed, changing rainfall patterns are likely to influence DOC input to lakes and have effects on light penetration, habitat availability, and water chemistry. For example, when drought reduces stream flow, there is often less DOC entering a lake—up to 70% less—leading to higher transparency, a warm surface water layer that gets deeper, reduced habitat for cold-water fish, and expanding habitat for plants and animals that live in shallow waters. Yet during drought, DOC can accumulate in a watershed and be flushed into streams and lakes when rain returns.

Increased rainfall, particularly extreme events

bringing a big pulse of water, can flush large amounts of sediment and nutrients off the land. In the future, these pulses may result in a reduced availability of nutrients from the landscape. Other effects include changes in photosynthetic activity and a shift in zooplankton communities. However, quick runoff also limits the time water has to interact with soil, so lakes can respond to these events by appearing chemically more like rainfall. Even so, lakes are often resilient and may return to typical conditions quickly. It is likely that variation in rainfall patterns is an important driver in the peaks and troughs of DOC we see in Isle Royale lakes each year.

In recent decades, rainfall has become less acidic due to the reduction of sulfate released into our atmosphere, which is undoubtedly a good thing. We can clearly see this from declining sulfate concentrations in Isle Royale lakes since 2008 (Figure 5). In many lakes, the reduction of sulfate deposition is potentially creating increased color from DOC—a process called “brownification”—due to changes in soil pH that may lead to increased DOC solubility and consequent additions to waterways. These declines of sulfate in precipitation have been observed across the U.S., including at a local monitoring site in Grand Portage, 45 miles west of Isle Royale.

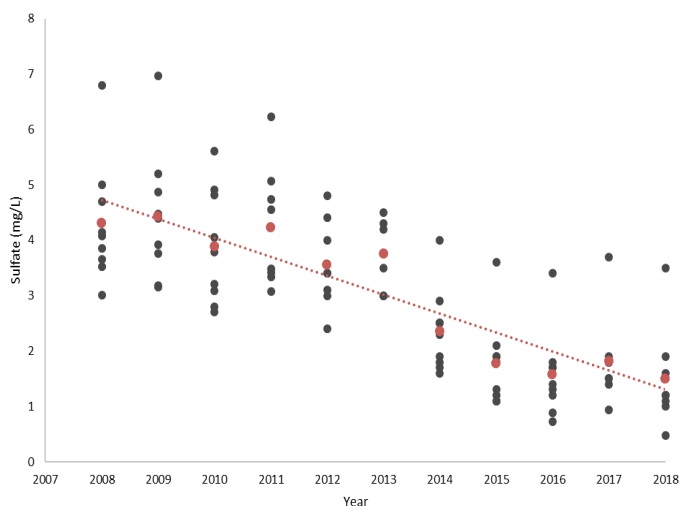


**Figure 5.** Sulfate concentrations in Isle Royale lakes, 2008–2018. Mean annual values in red with trend line.

## In Summary...

### What is DOC?

It is the carbon containing fraction of dissolved organic matter. A single sample of water may contain tens of thousands of different molecules containing DOC.

### Where does DOC come from?

Primarily plants and soils in the watershed and algae in lakes.

### What does DOC do?

It structures the light and thermal environment of the lake. It also provides a food source for microbes, which in turn feed higher organisms; algae are more important, but DOC can contribute.

### Is DOC a good thing or a bad thing?

Natural sources of DOC are an integral part of aquatic ecosystems. Whether or not it is a good or bad thing depends on the type of DOC in the water and what exactly you are looking at.

While DOC can be an important driver of a variety of lake processes, it is important to remember that climate and watershed topography are key factors that set the stage for the range of conditions that are possible in a lake. Then local factors like vegetation, soil, and hydrology enter the picture. Of the many outcomes, DOC concentrations and their own cascading effects are only a single result. While DOC can be an excellent indicator of many influential factors from the broader landscape, changes in climate and local weather systems may shift its influence in unpredictable ways.

