## What's All That Green Stuff in the Backcountry: Algae in 2005

Anecdotal evidence in the spring and summer of 2004 suggests an unusual profusion of algae in the South Coast's relatively pristine creeks and streams - those in backcountry Forest Service and Wilderness areas without the agricultural and urban uses we usually associate with high nutrient levels and eutrophication. Can this truly be the situation, or is it simply another example of subjective self-delusion? Although scientific measurement data to conclusively settle the argument are unavailable (alas, no smoking gun), enough evidence exists to present a reasonable circumstantial case that algae, indeed, are much more plentiful. And as David Thoreau once said, "circumstantial evidence is sometimes conclusive, for example, when you find a trout in the milk."

Here, I'll present the "evidence." You can decide whether or not it's convincing. It's a tale of conductivity, of sun and rock, of nitrogen and phosphorus, but most of all, it's a tale of big storms and the effect they have on all of these things.

## The Conductivity Story

Figure 1 shows standard conductivity (conductivity at $25^{\circ} \mathrm{C}$ ) for upper San Antonio Creek (VR10) and the North Fork of Matilija Creek (VR14), two sites in the Ventura Stream-team program that reflect backcountry conditions.


Figure 1. Conductivity measured at two Ventura sampling locations (VR10 and VR14) and on Rattlesnake Creek (RSO2). Conductivity at Rattlesnake was measured from collected samples or recorded by in situ conductivity/pressure sensor. Flow on the Ventura River (at Main Street) is shown in the background.

The creek sampled at VR14 flows out of undeveloped Forest Service terrain, and while VR10 is located below Ojai, most of the upper San Antonio tributaries originate in mountain areas to the north of the town. RS02, located on Rattlesnake Creek at Las Canoas Road, is another undeveloped Forest Service catchment; a hiking trail being the only man-made improvement in this watershed. The Ventura streams are sampled once a month and the values in Figure 1 generally represent background or baseflow conditions. Occasionally a sampling date coincides with, or soon after, a storm. Those conditions yield the sharply depressed values on the graph (e.g., in May 2003).

Conductivity, everything else being equal, generally increases with the age of water - the longer water is in contact with soil or geologic strata, the higher its conductivity: groundwater has higher conductivity than water from soil, and older groundwater higher conductivity than younger. Rainfall dramatically lowers stream conductivity, being as young as water ever gets; rainfall conductivity in the Santa Barbara/Ventura area is around $20 \mu \mathrm{~S} / \mathrm{cm}$. And although conductivity increases as storm runoff moves by various pathways to the stream, it still remains much lower than the values normally found in this region's creeks and rivers. Rattlesnake conductivity measurements, from samples collected mainly during and immediately after storms, show the dramatic decreases that occur with rain.


Figure 2. Daily flow on the Ventura River (at Main Street, VR01) from January 2001 to July 2005. Estimated baseflow is shown in black, while flows during storm-influenced periods are shown in yellow. Daily flow on July 1, for every year since 1998, is shown in the table.

Figure 1 has two dashed lines: one indicating the baseflow or background conductivity trend at VR14 from January 2001 to October 2004 (i.e., a line connecting non-storm conductivity
values), and the other for Rattlesnake during 2003 and 2004. Both, along with VR10 and all other sites for which I have data, show similar increasing trends (see "The Ventura River - a look at rainfall and the river" at http://www.stream-team.org/report.html). Increased conductivity, i.e., an increase in the amount of dissolved solids, is caused by either an increase in the conductivity of a stream's source waters or because flow has become more concentrated through increased evaporation. Or both.

Approximately every 8-10 years winter rains are far above average (greater than 150\% above average), and these big years dictate long-term flows in South Coast creeks and rivers. Absent these extraordinary events, the region would be reduced to near-desert conditions. Big years (i.e., big rainfall winters) occasion copious mountain runoff and flooding, move a vast majority of the sediment that makes its way to the ocean, and most important to this discussion, recharge the groundwater table. In the intervals between big years, the water-table falls, diminishing the amount of water supplied to streams between storms. Figure 2 illustrates the big year impact on river flow: most obviously, flow increases with the number and intensity of storms (for example, compare 2002 with 2005), but groundwater flows during the following dry-season also increase - an increase that usually carries over for a few years (e.g., the low summer flows of 2002-2004). This is further illustrated in Figure 3.

A receding water-table means a decreased supply of younger groundwater and an increasing dependence on older, higher-conductivity groundwater to furnish dry-season flow. However, lower flows also mean slower and shallower flows, and the increased growth of aquatic and riparian vegetation, which in turn increases evaporation and transpiration and further elevates conductivity.

The last big year was 1997/98. The last big year, that is, until 2004/05. And the impacts of a new big year can be seen in Figures 1 and 2: much higher June and July flows and a dramatic drop in conductivity to levels lower than were seen back in 2001. Both responses have the same cause: recharge of the groundwater table with newer, lower-conductivity waters and increased groundwater inflows into streams from recently elevated water-tables.

## Big Storm Nutrients

Big storms do not simply cause floods and recharge groundwater, they also carry nutrients into the upper level of the groundwater table. Absent the beneficent hand of human management, undeveloped forested areas generally do not leak nutrients. The low amounts of any nitrogen and phosphorus mobilized by storms are quickly gobbled up by growing plants and bacteria. Nutrients are usually tightly held in undisturbed systems, and rapidly recycled. New supplies enter from above - dissolved in rain or as particulates in dry and wet deposition (alas, most of these also have anthropogenic sources, but that's a story for another time).

There are exceptions. Zones where biological uptake is constrained by adverse environmental conditions - cold, heat, snow and drought - can leak nutrients: deposition exceeds utilization and runoff carries the excess into streams. A good example would be snow-covered alpine catchments where a pulse of nitrate accompanies early snowmelt. Chaparral covered hillsides, where heat and the absence of water constrain the growth of bacteria and vegetation, are another. And where nutrients lie unused, they can be swept into streams by the storms of winter.


Figure 3. The impact of big years on the water table is illustrated by the relationship between annual (water-year) rainfall (represented here by downtown Santa Barbara) and July 1 flow at Main Street on the Ventura River. The upper chart illustrates that the relationship is non-linear above average rainfall (greater than 15 inches) produces exponentially increasing amounts of summer flow. The lower panel illustrates that big years tend to increase dry-season flows for 2-3 years. The dashed black line in both charts marks average annual rainfall (14.3 inches) while the red line indicates average July 1 flow ( 12.4 cfs ).

Figure 4 illustrates this pulse of storm-carried nitrate from the Santa Barbara backcountry. The horizontal line marks the typical baseflow phosphate concentration, $1.6 \mu \mathrm{M}$, i.e., the characteristic concentration seen during non-storm periods in Rattlesnake Creek over the years. Notice that baseflow nitrate concentrations cycle around the same $1.6 \mu \mathrm{M}$ value. In contrast, nitrate concentrations during storms climb near $200 \mu \mathrm{M}$, over 100-times higher. But not during all storms, just major events: smaller storms rarely generate concentrations as high as $50 \mu \mathrm{M}$.
During 2002 all storms were small storms, and nitrate concentrations above $10 \mu \mathrm{M}$ were unusual.


Figure 4. Nitrate and phosphate concentrations in Rattlesnake Creek (RS02) from December 2001 to June 2005. Flow at Rocky Nook Park (in Santa Barbara) is shown in the background and the horizontal line indicates the typical, non-storm phosphate concentration.

However, higher concentrations are not the whole story, more important is the total quantity of nutrients flushed from the backcountry by stormflows. Quantity is the product of concentration multiplied by flow. Since big storms not only produce higher nitrate concentrations, but generate most of the annual flow, they dominate the export of nitrate - and phosphate, since phosphate concentrations also increase during storms - from the backcountry. As an example, 2003 had only a single large storm; it occurred in March and generated $50 \%$ of the total nitrate exported by Rattlesnake during the year - along with $40 \%$ of the total phosphate.
A truly big year, a year like 2005, sees a huge increase in nitrate export. Compared with the entire 2003 water-year, export out of the Rattlesnake backcountry during January, February and March of 2005 was more than 20 -times higher. However the important point is not simply high export, an amount of nitrate so large that it dwarfs contributions from agricultural and urban
areas in big years, but that a significant percentage of the mobilized nitrate ends up elevating concentrations in the upper water-table. As a rule-of-thumb only a quarter of the annual coastal rainfall ends up as streamflow, the remainder satisfies soil-moisture deficits and biological requirements - and recharges groundwater. And in big years this recharge is high in nitrate.

## Sun and Rock

Along with affecting seasonal flow and nutrient concentrations, big storms modify the physical environment of streams and rivers. In the boom-or-bust rainfall lottery that determines stream conditions along the South Coast (Santa Barbara has had as little as 4.5 and as much as 47 inches of rain a year), big years wreck havoc: uprooting plants and brush, toppling riparian trees and moving sediment downstream. And havoc creates favorable conditions for algae by increasing the light levels necessary for photosynthesis, by removing competitive aquatic plants and by improving the benthic environment through restoration of clean gravels and cobbles to the stream bottom. In contrast, the minimal disturbance of low rainfall years favors aquatic plants and riparian vegetation as fine sediment needed for rooting is trapped and as an increasingly confined water-way reduces algal habitat. As a further insult, the high light levels needed by algae are reduced as vegetation overshadows the water surface.

Since, on average, only one out of eight is a big rainfall year (the interval has varied from 2 to 26 years since 1866), and two out of three years have less than half the average runoff, backcountry physical conditions usually favor plants over algae. I don't have photos showing these differences in backcountry areas, but a series of before and after (before and after the winter of 2005) photos taken at sites on the lower Ventura River will illustrate the point.

Photo 1 shows conditions below the Main Street Bridge in May 2004 and the changes that had occurred by May 2005. The January flood removed plants, brush and trees, introducing light and removing competition, and freeing flow to cover a wider swath of the river bed. The increased flows that followed the rainy season (from elevated groundwater levels) dramatically expanded the water-way area available for algal growth. In May 2004 there was no noticeable algae below the bridge, in 2005 algae dominate the scene. Changes in physical conditions above the bridge (Photo 2) were similar: river widening, the removal of competing aquatic plants and overhanging vegetation and the exposure of clean rocks and cobbles on the river bottom. The pattern of change in Photo 3 (Shell Bridge, 3 miles upstream) is identical. Finally, Photo 4, a before and after close-up of the river near the Main Street Bridge, illustrates the change in bottom conditions caused by a big winter. The faster, deep flows in the lower scene have favored crustal algae in contrast with the filamentous green alga, Cladophora, shown in the upper (and which dominates the 2005 scenes in Photos 1 and 2). However, decreasing flows since the photo was taken have allowed Cladophora, the king (or is it queen?) of this region's benthic algae, to dominate.

I don't mean to imply that the storms of 2005 caused changes in backcountry streams as drastic as those shown in the photos, but that these kinds of changes did occur. The true extent of change, highly dependent on the amount of rainfall and runoff and the sensitivity of stream reaches to erosion, remains unknown. But however unknown the extent, change did occur; and it favored algal growth.

## Nutrient Evidence for Above Normal Algal Growth

Absent direct measurements of benthic algae, can the nutrient data be used to substantiate anecdotal evidence of abnormal amounts of backcountry algae? I believe the answer is yes.


Figure 5. Nitrate and phosphate concentrations in Rattlesnake Creek (RS02) during the winter of 2005. The dashed black and solid blue lines indicate trends in nitrate and phosphate, respectively, following the last major storm pulse in March; the solid black line marks the longterm baseflow phosphate concentration from Figure 4. Flow at Rocky Nook Park (approximately 1.2 miles downstream) is shown in the background.

Here's where the argument gets strange so you'll have to follow closely. At the beginning of April, after the passage of the last major storm of the season, phosphate concentrations never recovered to the long-established stable concentration of $1.6 \mu \mathrm{M}$ indicated by the solid black line in Figures 4 and 5. It's now been four months since that time and still no full recovery; the phosphate trend during these months is marked by the blue line in Figure 5. Never before (or at least since December 2001) has phosphate virtually vanished to this extent, nor for this long (see Figure 4). And this is not just a Rattlesnake thing. All over the region, phosphate has declined to "never been seen before" levels.

Nitrate also went through the floor (the dashed line in Figure 5); aside from some slight increases during the small storms of May 2005, nitrate steadily declined from April through June. By late May, nitrate had fallen below the detection limit. What could cause this unusual depletion of nutrient concentrations? My answer is the extraordinary algal blooms experienced this spring.
Other backcountry streams experienced similar changes. In Figure 6, nitrate and phosphate concentrations from March to September are plotted for the North Fork of Matilija Creek, the other pristine stream introduced at the beginning of this essay. Note that from 2001 through 2004 phosphate concentrations show a roughly similar pattern of a slow increase during the dryseason. However, in 2005, phosphate abruptly decreased between March and April and has
remained at an extremely low concentration for four months - similar to what happened at Rattlesnake Creek.


Figure 6. Phosphate (lines) and nitrate (bars) concentrations at VR14 (N. Fork Matilija Creek) from March through September, 2001-2005 (some months are missing). In the nitrate bar graph the monthly concentrations for each year are given chronologically from left to right; all use the same grey color except for 2005, which is shown in orange.

Nitrate at VR14 also decreased between March and April 2005, dropping below the detection limit in May. Only in July, after the peak of the algal bloom had passed, did phosphate (but not nitrate) show signs of recovery. Recovery at Rattlesnake started earlier. By the end of June nitrate concentrations began a rebound to near-normal concentrations (around 1-2 $\mu \mathrm{M}$ ).

The essence of the nutrient argument is that at first they were there, and in great abundance due to this extraordinary year; and then they weren't. It's frequently said, "the absence of evidence is not evidence of absence" (Carl Sagan), but here we do have evidence of absence. However, some might prefer to quote Lewis Carroll: Alice laughed, "There's no use trying," she said, "one can't believe impossible things." "I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."


Photo 1. Looking south from the Main Street Bridge (VR01): May 2004 (above), May 2005 (below).


Photo 2. Looking north from the Main Street Bridge (VR01): May 2004 (above), May 2005 (below).


Photo 3. Looking north from the Shell Bridge (VR03): September 2004 (above), May 2005 (below).


Photo 4. In the vicinity of the Main Street Bridge (VR01): a detail of the river bottom, May 2004 (above), May 2005 (below).

