

On July 25, 2008, Santa Barbara Channelkeeper completed a forth round of diel measurements of dissolved oxygen (DO) and $p \mathrm{H}$ on the Ventura River. As before, measurements were made either in the stream or from samples collected by bucket tossed from a bridge into the center of flow (bucket samples allow faster and easier measurement, especially at night). Pre-dawn measurements were made from 4:15 to 6:06 AM, afternoon measurements between 2:30 and 3:55 PM. The dissolved oxygen values recorded, along with differences between the two readings, are shown on the graph (in mg/L, i.e., ppm). Originally, back in April, we sampled 10 river locations and 2 sites in the lagoon. Since then the program has been somewhat modified: The same two lagoon locations are still being sampled, as well as 6 of the river locations (VR01, 06, 07, 13, 14 and 15), but three new sites were added in June. The new locations, VR03.5 (just above the C. Large confluence, 0.5 km below the treatment plant outfall), VR06.3 (just above the San Antonio confluence, 3.4 km above Foster Park) and VR12.9 (at the Camino Cielo ford, 0.3 km below the confluence of the main and N.F. branches of the Matilija), are all sites being surveyed this summer by the UCSB-TMDL project. The substitutions were made to replace sites that have since gone dry (Canada Larga, VR04; and the middle Ventura sites, VR11 \& 12) or that presented particular sampling problems (VR03). Lagoon sites are identified as VR00; the sampling locations are along the east (e) and west (w) sides of the railroad causeway over the Ventura estuary.

The chart shows July $25^{\text {th }}$ results along with those from earlier diel measurements (April 9 \& May 15, if available, and June 17) to illustrate changes as the algal season continues. The latest results are shown in darker shades of color to help them stand out.


Figure 1. VR07 from the concrete ford: upper photo - June 17 ${ }^{\text {th }}$, lower - July $25^{4}$. Note the increase in vegetation and the decre ase in flow since June - and how sparse the algae has become. Delta-DO in June was $8.1 \mathrm{mg} / \mathrm{L}$; delta-DO in July, 6.0 .


Figure 2. VR03.5, looking upstream from the Canada Larga confluence: upper - June 17 ${ }^{\text {th }}$, lower - July 25 ${ }^{\text {min }}$. Agair, the decrease in flow can be seen on the foreground group of rocks and, although difficult to discem, July water has a darker appearance to to increasing diatom dominance.

Algal growth produces a daily cycle in both DO and $p \mathrm{H}$ : daylight photosynthesis adds oxygen while removing carbon dioxide; nighttime respiration reverses the process. DO concentrations in the surrounding water typically peak around mid-afternoon and decline to a minimum just before sunrise. The magnitude of the change in DO reflects (1) the abundance of algae, (2) the extent of their biological productivity, i.e., how hard they are working, and (3) the amount of water in which this change in DO is reflected. A fixed amount of algae will produce increasingly greater changes in DO as the volume (or flow) of water decreases.

The location with the greatest diel variation was VR03.5, just below the Ojai Treatment Plant (from $\sim 7.1$ to $14.0 \mathrm{mg} / \mathrm{L}$, i.e., from $78 \%$ saturation to over $172 \%$ ). This represents a change from the previous month when the variation, which I'm going to hereafter call delta- $D O$, was greatest at Main Street (VR01). All three sites on the lower river (VR06.3 and below) had lower delta-DO in July than in the previous month. Indeed, all sites, except for VR15, showed a decrease in delta-DO.


Since flows have appreciably decreased since the June measurements (the Foster Park hydrograph, shown above, indicates flow on July $25^{\text {th }}$ was about one-third that of June $17^{\text {th }}$; elsewhere on the river, measured flows were down by at least $50 \%$ ), the reduction in delta-DO can only have been caused by a reduction in overall algal productivity (similar algal densities and rates of productivity would have produced greater diel variations with this pronounced a flow decrease). And indeed, the included photographs do show a reduction in algal density and water depth (i.e., a flow decrease) at almost every site (Figures 1-7).

Various factors probably play a role in this reduction of productivity. Over the past couple of months a gradual senescence, decay and, finally, disappearance of cladophora has taken place throughout the river, followed by its replacement with other genera (diatoms on the lower river, enteromorpha in the middle reaches above Foster Park, and spirogyra in the upper watershed. These "replacement" algae are coming in at lower densities (possibly due to nutrient limitation in many


Figure 3. VR01, looking upstream from Main St. Bridge: upper - June 17 ${ }^{\text {th }}$, lower - August $11^{\text {th }}$. I've used a slightly later photo to emphasize vegetational encroachment (by Ludwigia here) and the drying out of the eastside of the river channel (all of which are decreasing algal habitat).
locations) and may also not be as productive as cladophora on a gram for gram basis.
A shrinkage in available habitat is also taking place. Lower water levels, of course, leave much narrower stream-widths available for algal growth, but in many reaches aquatic plants are now dominant at the water's edge and beginning to colonize the mid-channel itself. Figure 3 shows a good example of the Ludwigia invasion at Main Street, along with the now dried-up eastern channel where this plant played an important role in dewatering. We are now past the point of mid-summer and days are getting shorter, and sunlight less intense. Combined with the growth in riparian vegetation, especially in narrower reaches (see Figure 4), this may translate into lower light availability. Finally, nutrients are becoming scarcer. Partly due to reductions in overall groundwater inflows, and partly because whatever inflows remain tend to come from lower, older (thus more nutrient depleted, especially in nitrogen) strata. And as flows decrease the overall flux of nutrients also decreases (think of concentration as a measure of "quality," and flux - the product of concentration and flow - as a measure of available quantity); since both flow and concentration are decreasing, the flux decrease is greater than either. Which is why the only healthy-looking algae in a reach are now often found in areas with very rapid currents (the flux experienced by any given patch of algae varies considerably, since flux, like flow, is unequally distributed across the width of a stream.


The above graph summarizes delta-DO values over the past 4 months ( 2 months at the most recently added locations) at sites currently being sampled (for simplicity lagoon data are not shown). VR15, on Matilija Creek above the dam, stands out a exception to the general trend of a decrease in delta-DO from mid-June to the end of July (the July value was zero at VR14). Why this is so remains a puzzlement. Declining flow, exaggerating the impact of whatever algae does remain, is one obvious factor, but flows have similarly declined at all the upper locations (VR12.9 and the other Matilija sites). I haven't included any site photos of these

Lower water-levels, a reduced water-way, sunlight and nutrient competition from aquatic plants, increased shading by riparian vegetation, changes in dominant algal species, lower light intensity and shorter days past the midsummer point, and, last but not least, greatly reduced nutrient availability (both in concentration due to prior uptake and in flux due to greatly reduced current speeds) may all be factors in the reduction of algal growth.

Figure 4. These are photcs of the UCSB-TMDL lower San Antonio survey site just upetream of the Ventura confluence (also called VR07, but located about a half mile below the
Charnelkeeper site with the same name): May $16^{\text {* }}$ on the left, August 11 ${ }^{\text {midelow. Note the }}$ subsequent growth in both aquatic plants and riparian vegetation. Here, aquatic plants growth is not particularly notable, compared with that at other locations, but the bordering willows, now nearly 10 ft high , are.
locations in this report because there doesn't appear to be any marked differences between June and July. However, on a July $15^{\text {th }}$ visit Ben and I did note a slight increase in algae (although wishful thinking also remains a possibility), mainly spirogyra and chara, along with some nostoc. Pool waters also seemed to have a pronounced greenish tinge. Thus increases in diatoms and/or phytoplankton are possibilities. VR15 does differ significantly from the other upper watershed locations in one respect: increased exposure to sunlight since the arundo removal project eliminated a major part of riparian vegetation above the dam. Extra exposure to sunlight could be the underlying cause of the delta-DO increase. The mid-afternoon water temperature of $29.4^{\circ} \mathrm{C}\left(85^{\circ} \mathrm{F}\right)$ on July $25^{\text {th }}$ is a measure of this increased exposure; and increased temperature, in itself, will increase biologic productivity. On the $25^{\text {th }}$, VR15, and downstream sites with VR15-influenced waters, had mid-afternoon temperatures higher than at any of lower river location.


The above chart, a plot of mid-afternoon and pre-dawn water temperatures taken during the four diel sampling events, illustrates the extraordinarily high July temperatures at VR12.9, 13 and 15. Note the marked difference between VR15 and VR14, caused by VR14's location on the narrower, well-shaded North Fork of the Matilija.

The July diel temperature variation at VR15 was also the most extreme: almost $10{ }^{\circ} \mathrm{C}$. It was also the most extreme in June, and, with the exception of VR07, in May. As I pointed out in the last diel report, considering that the proposed Matilija Dam removal project's stated purpose is the restoration of steelhead habitat, perhaps someone should begin paying attention to these temperature extremes.


Figure 5. VR06.3, looking upstream from just above the San Antonio confluence: upper - June $17^{\overline{4}}$, lower - July $25^{\text {ti }}$. In June, algae was still vibrant at this location; near the end of July most of the cladophora had disappeared (the brown color on the submerged rocks results from the remains, often coated w/diatoms). The green algae remaining was mostly enteromorpha. I've circled the same rock in both photos to show the flow decrease since mid-June.


Figure 6. VRO6, looking downstream from the bridge: upper - June $17^{\text {th }}$, lower - July $25^{\text {th }}$. In July, benthic algae (presumably, cladophora, the mats are enteromophora) was still green at Foster Park, but much less dense and vibrant compared with June. Since the photos were taken at different angles I've drawn a line through a 3-rock grouping to help identify the same locations.

In contrast, the location with the lowest mid-afternoon temperatures, and the second narrowest range of variation, was VR06.3, mainly because these waters are derived from groundwater inflows, most of which originate less than a mile upstream. The narrowest variation in temperature was found at VR13; here flow originates in seepage and flows over the dam - and in both cases the shallow impounded lake provides enough thermal inertia to buffer rapid changes. We saw the same effect in the May lagoon measurements, when water was impounded by a sand berm blocking the lagoon mouth.

I want to return to the delta-DO measurements and discuss how they might be used in a quantitative sense. As mentioned previously, the diel DO variation is a measure of both algal productivity and the quantity of water being modified by this productivity. Of course, this is an over-simplification, other factors can modify dissolved oxygen concentrations, and it begs the question of just where this modification might begin to take place. But as a first order approximation, in reaches where algae appear dominant, it seems a reasonable proposition.

I'm going to define a new term, Algal Intensity, as a measure of algal productivity, i.e., the combined effect of the amount of algae and their photosynthetic activity. Algal Intensity (AI) is calculated by multiplying delta-DO by flow; if delta-DO is measured in $\mathrm{mg} / \mathrm{L}$ and flow in cubic feet per sec (cfs), the resulting unit for Algal Intensity is $\mathrm{mg} / \mathrm{L}^{*}$ cfs. With appropriate conversion factors this could be reduced to mg of dissolved oxygen $/ \mathrm{sec}$, but the actual units of measure are, at this point, unimportant. (Expressed differently AI/Q = delta-DO; when algal productivity increases - an increase in biomass or activity or both - delta-DO increases; when flow increases, delta - DO decreases.) What is important is the potential of converting an easily measured water quality parameter, dissolved oxygen, into a measure of algal activity simply by multiplying it by flow.

Unfortunately, as it turned out, flow data are not readily available at all the monitored sites. Foster Park, with a USGS gauge is ideal, and flow at locations below Foster Park can be estimated by adding average treatment plant outflow (my figure is 2.35 cfs , taken from one of the Matilija Dam studies; Ron, if you have an updated daily average MGD value for plant effluent I'd sure appreciate knowing it). (Flows at all locations below the treatment plant are more-or-less the same. In 2003 I did many sets of multiple measurements at the regular Channelkeeper monitoring sites (VR01, $02 \& 03$ ), and the between-site variation was within the standard error of measurements at any one site. This is not to say that there are no flow differences, but that whatever differences existed were too small to be distinguished by my measurements.)

Elsewhere, Ventura County maintains, or has maintained during some period in the past, gauges at or near VR07, 13, 14 and 15. However, their most recent data is not yet available online. Monthly Channelkeeper monitoring surveys also measure flow, but not at every site, nor every month. Accordingly, to estimate flow for purposes of testing my latest brainstorm, I plotted dry-season flows for 8-10 years of County data along with 2008 Channelkeeper measurements, when available. I retained County data for the years that most resembled, in magnitude, the dry-season flows of this year. If the Channelkeeper measurements exhibited a similar pattern of flow decrease, I used them to derive an equation from which I could estimate flow on any diel survey date. At VR13, which had no Channelkeeper flow measurements, I simply used a regression equation to extend the 2008 County data that were available (up


Figure 7. VR06, looking upstream from the bridge: upper - June $17^{\text {th }}$, lower - July $25^{\text {th }}$. Differences here do not appear as pronounced as those below the bridge (but see Figure 7), except for a reduction in the amount of floating algae; the June mats were mostly cladophora, enteromorpha in July.

through June 1 in this case) into July and August. It's probably easier to show than explain. Here are the results for VR15; the graph is a semi-log plot on which recessional flows, i.e., gradually decreasing flows typically seen following a storm or, in this case, following a wet season, typically plot as a straight line. Ventura County data for the nearest gauge above Matilija Dam exist only for 1964-69. Dry-season flows in 1966 and 1968 most resembled those measured by Channelkeeper this year (red squares) - 1966 was drier, 1969 wetter. In that Channelkeeper values follow the same pattern (i.e., have a similar slope), I consider them reasonably valid and have used them to derive the equation shown in the graph. I then used the equation to calculate flow on each of the diel sampling days.

Finally, I estimated flow at VR12.9 by adding the flow estimates for VR13 and VR14. I've obsessively belabored this flow business because this is where the greatest error lies; my flow estimates may be off by as much as $40 \%$. Be that as it may, I used these flows to calculate Algal Intensity (AI) for each of the sites; a chart of the results is shown on the next page. There is a marked contrast between it and the delta-DO graph: the algal peak at all sites is now shown to have occurred in April, not in May when delta-DO was at a maximum. AI in April at VR01 was twice that of May, and had decreased to approximately $15 \%$ of the April peak by the end of July. Inter-site comparisons indicate that AIs at the upper basin sites were only a fraction of those at VR01 during the peak of the algal season - roughly $8 \%$. I could go on, but what I consider most interesting is that these are all testable conclusions. If there existed another measure of algal activity or productivity, the accuracy of the AI comparisons could be evaluated.

There is another measure, of course. Chlorophyll-a (chl-a), the active ingredient, so to speak, in photosynthetic production is currently the most common measure of whether or not algal growth in a stream or river reach is deemed excessive. (In the Malibu nutrient TMDL targets for the mean and maximum allowable chl-a values were 50 and 150 mg per square meter, respectively.) The problem with chl-a measurements is the difficulty in collecting representative samples and


Figure S. VRO6, algal close-up just upstream of the bridge: upper - June $7^{\text {th }}$, lower - July $25^{\text {th }}$. I've placed a square on Figure 6 to indicate the area these two photos highlight. Absent a useable photo from June $17^{\text {th }}$, I'm using one from June $7^{\text {th }}$ (taken 3 days after Kristie's algal survey of this site).

the expense of analyzing them. Here I'm proposing that easy measurements of delta-DO and flow may be able to act as a proxy for chl-a. The UCSB-TMDL project measured chl-a at many of the these same locations in late May and early June. It would be interesting to see how well the AI estimates compare. For example: was overall chl-a roughly the same at VR01 and VR03.5; was it 85-90 \% lower at VR15; was it roughly the same at VR12.9 and VR15; and did these two sites have about 5-times more chl-a than VR14?

One problem is that AI purports to be a measure of gross or total algal activity whereas Kristie's (and everyone else's) mean chl-a estimates for a reach are per unit area estimates. For Kristie's reaches, converting average $\mathrm{mg} / \mathrm{L}$ estimates into total chl-a is relatively straight-forward: multiplying the mean chl-a concentration by average reach width and by 100 meters (the length used in all her surveys). Differences in total reach chl-a estimates could then be compared with the AI conclusions. But on second thought, perhaps not.
Let's work at it from the other side. I'm proposing that AI estimates can be used to compare gross algal productivity at different times and between different sites; they can also be used to compare relative productivity if we were to divide by average stream width, i.e., converting gross productivity into productivity per foot of width. This would allow more realistic comparisons if conditions at different times, or between different sites, varied considerably. (Alas, I don't have measurements of stream width.) Of course this begs the question of where to measure that width. Fortunately, stream width is generally relatively uniform and the average of

4-5 measurements, a few tens of feet apart, made while working upstream from the point of DO measurement should suffice.

The bigger, as yet unanswerable, question is how far upstream does the region of algal influence causing the measured delta-DO value extend? If we knew the answer, AI could be divided by that length and the average width, and a measure of algal productivity, directly comparable with chl-a per square meter, calculated. We are not likely to know the answer any time soon. That distance probably varies with both site and time of year, and could be influenced by a host of possible factors: flow, stream width, current speed, algal density and health, type of reach (whatever combinations of pool, run and riffle extend upstream), turbulence . . . hell, even airpressure. And the list could go on and on.

So I would also propose trying a comparison based on similar measures: AI per foot of width (using average stream widths derived from Kristie's transects) compared with chl-a per foot of width, the latter calculated by multiplying the mean chl-a per sq. meter for each reach by the 100 meter reach length and making the appropriate conversion. The second round of UCSB algal measurements is about to begin, and Channelkeeper will make an effort to complete a final set of diel measurements on some day during the same period so that a more direct comparison can be made.


Finally, to bring this report to some kind of close, July $p \mathrm{H}$ values, along with those of previous months, are shown in the preceding graph. Both $p \mathrm{H}$ and DO have similar diel patterns: in the presence of algae, $p \mathrm{H}$ changes track those of DO. As photosynthesis removes carbon dioxide from water, i.e., removing acidity, and replaces it with oxygen, $p \mathrm{H}$ rises to an afternoon peak; it then declines to a pre-dawn minimum as night-time algal respiration restores carbon dioxide to the flow (making it more acidic). Aerobic decay, where oxygen fuels the breakdown of organic material and is converted to carbon dioxide (i.e., increasing acidity), is another process that should be kept in mind.

In general, upper-watershed sites have shown little or no change in average $p \mathrm{H}$ from June to July. I attributed a substantial decrease in $p \mathrm{H}$ at these locations between April and May to aerobic decay, and a June rise to a reduction in decay at the tail end of that process. It would appear to follow that the maintenance of June values into July indicates a similarity of condition. However, explaining the ups-and-downs of $p \mathrm{H}$ variation has become so complicated that I may not even be convincing myself. A June-to-July tale for VR15 looks pretty simple: average $p \mathrm{H}$ has stayed the same, indicating a near constant rate of aerobic decay, while the range of diel variation has increased in line with a measured increase in delta-DO.

In July, a similar $p \mathrm{H}$ pattern was found at VR14, but here delta-DO was actually negative - a midafternoon value lower than that at pre-dawn. Go figure. On the lower river (VR06 and below) average $p \mathrm{H}$ has notably increased. My best guess is that aerobic decay has considerably diminished, and that a goodly portion of the dead cladophora noticed in June has now moved on south. For these sites, at least, there has been a consistent relationship between variations in DO and $p \mathrm{H}$ : a change of $1 \mathrm{mg} / \mathrm{L}$ in DO was matched by a change of about 0.15 pH units (or conversely, a $7.5 \mathrm{mg} / \mathrm{L}$ diel variation in DO has been accompanied by a 1 unit change in $p \mathrm{H}$ ). For some reason it takes about twice the DO variation to produce the same $p \mathrm{H}$ change at VR06.3 and VR07. Upper basin ratios between DO and $p \mathrm{H}$ variation tend to be both smaller than those on the lower river, and to vary considerably more.

We don't know how acid neutralizing capacity (ANC, also known as alkalinity), which directly affects this relationship as a measure of the buffering ability of water - the ability to moderate or resist $p \mathrm{H}$ change - varies between these sites (determining this variation and also how ANC might change as the season progresses could be a very interesting study), but it makes sense that ANC would be most consistent on the lower river - reaches where the dominant influence during the dry-season was mostly Foster Park groundwater (in July, when Ojai effluent began to exert greater influence on waters below the treatment plant, the ratio at VR06 also began to predictably diverge). What's intriguing to me is that if the delta-DO/delta- $p \mathrm{H}$ ratio is a good proxy for ANC, the noticeably different ratios at VR06.3 (averaging 12.4 for June and July) and VR06 (6.8) may indicate completely different sources for the groundwaters that make up flow at both these locations.

Now for the lagoon. Note the substantial changes in July $p \mathrm{H}$ from the measurements of previous months: the diel variation has decreased by nearly half, and pre-dawn values are more than half a unit higher. Looking back at the initial graph in this report, delta-DO, especially on the eastside of the lagoon has also noticeably decreased.

These changes are mostly due to the continued opening of the lagoon to tidal inflows. The sand berm at the lagoon mouth has either remained open, or has been frequently re-breached.


Figure 9. VR00, July $25^{\text {the }}$. upper - an incoming aftemoon tide sweeping into the lagoon; lower - the green color indicates the dominance of phytoplankton in the lagoon, especially on the upstream side of the RR causeway. The lower photo also shows a rare example of filamentous algae, in this case entwined around a surken branch; more typically, tidal surges have swept the bottom clear.

Phytoplankton continue to dominate primary production in the lagoon (Figure 9), but tidal inflows, especially on the eastside (closest to the lagoon mouth), have considerably reduced the diel DO variation. Inflowing sea water, with its high ANC, also provides additional buffering against $p \mathrm{H}$ change. (During mid-afternoon on July $25^{\text {th }}$, with an inflowing tide, standard conductivity at VR00e was $13.5 \mathrm{mS} / \mathrm{cm}, 8.1 \mathrm{mS} / \mathrm{cm}$ at VR00w; seawater has a standard conductivity $\sim 53 \mathrm{mS} / \mathrm{cm}$ ). Also responsible for the July increase in minimum pH , has been the relative absence of aerobic decay in the lagoon. The tidal surge (or the daily cycle of damming and un-damming freshwater flows above the reach of saltwater) has moved almost all the dead filamentous benthic algae, killed by the initial breach of the berm in early June, out of the lagoon - and the bottom muds are now completely anaerobic.

Photos taken on July 15 and 25 (and on other Channelkeeper sampling days) can be downloaded at:
http://sbc.lternet.edu/~leydecke/Al's_stuff/Recent\ Stream-Team\ Photos/
Also available on this site are photos taken during a walk from VR06.3 to VR11 by Diana and me on August $11^{\text {th }}$, and others taken during a sample collecting trip with Ben on August $27^{\text {th }}$.

Photos of the UCSB-TMDL algal survey at:
http://sbc.lternet.edu/~leydecke/Al's_stuff/Ventura\ Nutrient\ TMDL/TMDL\ algal\ s urvey\%20photos/

Posted PDF copies of all my previous Ventura Nutrient TMDL reports can be found at:
http://sbc.lternet.edu/~leydecke/Al's_stuff/Ventura\ Nutrient\ TMDL/My\ PDF\ files \%20on\%20algae\%20\&\%20nutrients/

