Synthesis of Biostimulatory Impacts on California Wadeable Streams, Sutula et al. (2018), SCCWRP Technical Report (TR) 1048. - Cliff Dahm Review

After reading this technical report twice and thinking about the overall content, I have two general impressions that I wish to share before addressing the charge questions. The first general point that struck me was the benefit that would come from focusing this synthesis more directly on streams and small rivers (wadeable). "Wadeable streams" is in the title, and a narrower review and synthesis has some utility. A quick check of the number of papers on eutrophication found in a Web of Science search is almost twenty-five thousand (24,792) scientific papers, and papers with both eutrophication and streams in the title and/or abstract still totals 1832. This remains a daunting number of papers to synthesize, but more tractable than looking at all aquatic ecosystems where eutrophication has been studied. Taking this tact would mean developing a wadeable stream conceptual model (page 28) and staying focused on streams and smaller rivers throughout chapters two and three of the synthesis.

One benefit of a narrower scope for the synthesis in chapters two and three is that some additional informative stream and river research on nutrient impacts could be highlighted and discussed. California has many regional biomes in the state, but a major biome type is Mediterranean. There has been some excellent research over the last decade or so out of Spain that looks at the impacts of multiple stressors on streams, nutrient loading and cycling in Mediterranean streams, structural and functional characteristics of streams in Mediterranean climates, and ways to use functional attributes of streams to evaluate ecosystem condition. Researchers like Daniel von Schiller, Susana Bernal, Eugenia Marti, Vicenc Acuna, Arturo Elosegi, Sergi Sabater, Miquel Ribot, and Francesc Sabater have really improved our knowledge of how Mediterranean streams respond to light, nutrients, land use, effluents, and multiple stressors. For example, von Schiller et al. (2007) studied the effects of nutrients and light on periphyton biomass with contrasting land use. Izagirre et al. (2008) used long-term continuous sensor data to determine the environmental controls on whole-stream metabolism. Bernal et al. (2013) reviewed how hydrologic extremes modulate nutrient dynamics in Mediterranean climate streams. Aristi et al. (2015) examined how effluents from wastewater treatment plants affected river ecosystem metabolism and whether the effluents were a subsidy or a stress. Von Schiller et al. (2017) synthesized the approaches, sensitivity, and criteria for use of river ecosystem processes (rather than just structural methods) to understand how multiple stressors affect streams and rivers. I serve on the scientific advisory board for the Catalan Water Research Institute (ICRA) and on the scientific review committee for a European Union project looking at multiple stressor effects on streams and rivers (GLOBAQUA). The quality of the research on Mediterranean wadeable streams is excellent, and I recommend synthesizing and reviewing some of this research in the California wadeable streams technical report.

The second general impression that I have is that although "biostimulatory" or eutrophication potential should be based on total nitrogen (TN) and total phosphorus (TP), there is a considerable amount of uncertainty in using these measurements as dependent variables. Yes, there is some uncertainty in the measurements themselves and in the sampling, storage, and transport of the grab sample to the laboratory, but most of the uncertainty lies in the use of a single point in time to link to the algal community, the benthic invertebrate community and the proposed primary biostimulatory indicators for California wadeable streams (organic matter accumulation, water column chemistry, and harmful algal bloom indicators). Algae and benthic invertebrates are responding to stream conditions from days to weeks to even months or a year. Ideally, the assessment of TN and TP would capture variability over time. Regrettably, there is no methodology to make continuous in situ measurements of TN and TP to get at variability on daily, weekly, and monthly time scales. There are, however, emerging sensors that continuously measure nitrate, phosphate, and ammonium (e.g. Bernhardt et al. 2018; Pellerin et al. 2016; Cohen et al. 2013; Sherson et al. 2015). An indicator of eutrophication is the increasing percentage of the inorganic and bioavailable forms of nitrogen and phosphorus compared to the totals of nitrogen and phosphorus. Therefore, I recommend that both TN and TP and nitrate, phosphate, and ammonium be measured at sampling sites. This allows the percentage of inorganic N and P to TN and TP to be calculated as another potential indicator for eutrophication and opens the door to the use of advanced sensor technology to measure nutrients at similar time scales to the development of indicator organisms like benthic algae and macroinvertebrates.

Below are some short answers for the charge questions that the Panel was asked.

- Comment on the degree to which the conceptual models and indicators/measures reviewed in Sutula et al. TR 1048 provide a strong conceptual foundation for understanding pathways of impact of eutrophication and linkage to biostimulatory substances and conditions in wadeable streams, in particular:
  1) Do the conceptual models of impacts to human and aquatic life related uses capture all major pathways of impact?

  The first conceptual model (Figure 1.1) that shows six biostimulatory conditions and substances is straight forward and useful. The six arrows with nitrogen and phosphorus loading, hydromodification, light availability, organic matter loading, physical habitat alteration, and temperature showcase the main pathways that influence eutrophication for wadeable streams. Figure 2.1 is a box and arrow diagram that examines drivers, response variables, ecosystem services, and impacts to beneficial uses. This is a generic figure for a wide range of aquatic ecosystems affected by eutrophication. Figure 2.8, however, does not represent a stream ecosystem. Terms like hypolimnion, epilimnion, stratification, viscosity, salt intrusion, and phytoplankton are really not describing a stream. A stream-focused conceptual model is really needed here.

  2) Should any additional pathways be considered?

  I think the major pathways have been identified and covered well. There is some complexity within each of the six arrows in Figure 1.1 that might be considered further (e.g. light availability encompasses total suspended solids, dissolved organic carbon, and riparian zone structure), but this does not need to be shown on the conceptual model. Figure 2.1 is particularly thorough on the ecosystem responses to biostimulatory drivers, and the drivers are in good agreement with the arrows in Figure 1.1.

- Comment on the completeness of the review of indicators, in particular:

  1) Should all measure of indicators and nutrients occur during the index period for bioassessment?

This would be desirable but, in some cases, not essential. If a long-term data base for nutrient concentrations or the measurement of key indicators is available, these data should not be eliminated simply because they do not occur during the index period. Flexibility should not be sacrificed on the altar of orthodoxy.

  2) When considering the multiple indicators included in the eutrophication synthesis, which indicators do the SAP member feel are most critical for biostimulatory impact assessments?

Nine primary indicators of eutrophication are recommended to assess biostimulatory impacts in Table 2.10. Four deal with organic matter accumulation, two are chemical measurements in the water column, two linked to harmful algal blooms, and one is causal (TN and TP). Supporting indicators are 11 including benthic algal community composition and benthic macroinvertebrate community composition. Critical measurements I recommend are benthic and water column algal biomass, macroalgal cover, benthic algae and macroinvertebrate community structure, TN, TP, and inorganic nutrients, light availability, temperature, and habitat type.

  3) How should the multiple indicators be evaluated in combination with each other to assess biostimulatory impacts? Should some indicators hold more weight in the assessment than others, either consistently or for particular types of water bodies or conditions?

These questions are best addressed after some pilot studies utilizing the multiple indicators selected for assessment are applied. Streams in different biome types may well be evaluated differently. There also are likely to be seasonal differences and water year type effects. Implementing some pilot evaluation studies would help answer these questions.

  4) Are there any technical reasons why any of the indicators included in the eutrophication synthesis should be excluded from an assessment? How frequently should indicators and nutrients be measured to best characterize conditions?

Cost is likely to be a constraint for many of the supporting assessments, and most of the harmful algae assays are not routine. Similarly, continuous water quality instruments are getting cheaper and more routine, but there still are cost concerns for instruments, quality assurance/quality control, data analyses, and data management.

5) Are there additional eutrophication indicators that should be reviewed?

I support taking a look at the percentage of dissolved inorganic nutrients in the TN and TP pools. I also think that nutrient spiralling estimates have utility although not a routine measurement. In general, there are functional components of streams that are indicative of eutrophication (von Schiller et al. 2017) that could be coupled to structural components.

6) Are conclusions of the eutrophication indicator review appropriate, given the stated evaluation criteria? Should any conclusions be reconsidered?

The conclusions are appropriate giver the evaluation criteria. At this stage of development, I do not see where reconsideration is required.

- Comment on the synthesis of thresholds, in particular:
  1) Are the conclusions of the review of thresholds appropriate?

The conclusions seem appropriate. The fact that the thresholds derived from the aquatic life-use (ALU) related biointegrity goals and changepoint thresholds in California were in good agreement with similar analyses for streams across the United States is reassuring.

2) The literature review produced less information on organic matter or nutrient thresholds that are linked to human protection endpoints than for aquatic life. Are there additional literature sources that could be used to improve this?

I am not an expert on human toxicology from potential stressors that would develop from eutrophication and the impact of biostimulatory changes to wadeable streams. One pathway is harmful algal blooms that in wadeable streams would often be from benthic cyanobacteria. Much of the review of HABs was not focused on wadeable streams. I would recommend a shorter and more focused examination of stream literature and those attached forms known to produce toxins.

- Are there technical ways to address stakeholder concerns?

This is a difficult question to answer. What specifically are the stakeholder concerns? One concern is the setting of numeric criteria for TN and TP that cannot be met by current wastewater treatment technologies. Once specific concerns are identified and clear questions asked, a better answer for this question can be provided.

References Cited

Aristi, I., D. von Schiller, M. Arroita, D. Barcelo, L. Ponsati, M.J. Garcia-Galan, S. Sabater, A. Elosegi, and V. Acuna. 2015. Mixed effects of effluents from a wastewater treatment plant on river ecosystem metabolism: subsidy or stress? Freshwater Biology 60:1398-1410.

Bernal, S., D. von Schiller, F. Sabater, and E. Marti. 2013. Hydrological extremes modulate nutrient dynamics in mediterranean climate streams across different spatial scales. Hydrobiologia 719:31-42.

Bernhardt, E.S., J.B. Heffernan, N.B. Grimm, E.H. Stanley, J.W. Harvey, M. Arroita, A.P. Appling, M.J. Cohen, W.H. McDowell, R.O. Hall, Jr., J.S. Read, B.J. Roberts, E.G. Stets, and C.B Yackulic. 2018. Limnology and Oceanography 63:S99-S118.

Cohen, M.J., M.J. Kurz, J.B. Heffernan, J.B. Martin, R.L. Douglass, C.R. Foster, and R.G. Thomas. 2013. Diel phosphorus variation and the stoichiometry of ecosystem metabolism in a large spring-fed river. Ecological Monographs 83:155-176.

Izagirre, O., U. Agirre, M. Bermejo, J. Pozo, and A. Elosegi. 2008. Environmental controls of whole-stream metabolism identified from continuous monitoring of Basque streams. Journal of the North American Benthological Society 27:252-268.

Pellerin, B.A., B.A. Stauffer, D.A. Young, D.J. Sullivan, S.B. Bricker, M.R. Walbridge, G.A. Clyde, Jr., and D.M. Shaw. 2016. Emerging tools for continuous nutrient monitoring networks: Sensors advancing science and water resource protection. Journal of the American Water Resources Association 52:993-1008.

Sherson, L.R., D.J. Van Horn, J.D. Gomez-Velez, L.J. Crossey, and C.N. Dahm. 2015. Nutrient dynamics in an alpine headwater stream: Use of continuous water quality sensors to examine responses to wildfire and precipitation events. Hydrological Processes 29:3193-3207.

Von Schiller, D., V. Acuna, I. Aristi, M. Arroita, A. Basaguren, A. Bellin. L. Boyero, A. Butturini, A. Ginebreda, E. Kalogianni, A. Larranaga, B. Majone, A. Martinez, S, Monroy, I. Munoz, M. Paunovic, O. Pereda, M. Petrovic, J. Pozo, S. Rodriguez-Mozaz, D. Rivas, S. Sabater, F. Sabater, N. Skoulikidis, L. Solagaistua, L. Vardakas, and A. Elosegi. 2017. River ecosystem processes: A synthesis of approaches, criteria of use and sensitivity to environmental stressors. Science of the Total Environment 596-597:465-480.

Von Schiller, D., E. Marti, J.L. Riera, and F. Sabater. 2007. Effects of nutrients and light on periphyton biomass and nitrogen uptake in Mediterranean streams with contrasting land uses. Freshwater Biology 52:891-906.

Errata from Materials in the Technical Report

The report as a whole would benefit from careful editing of the document. I noted editing issues as I read (and there were many), but I will not note minor edits in the errata. The focus here will be on more substantive questions or concerns. The references section also needs some careful checking for formatting, completeness, and missing citations. I will include missing references I noted in the text in the errata, but I did not do a systematic and thorough check of all the references.

Page 1 – Eutrophication is one of the top three causes for impairment of water in the US. What are the other two in the top three?

Page 4 – What is the source of the definition of "wadeable streams?" The salinities in freshwater ecosystems are generally not "ocean derived." They are rock-water interaction derived.

Page 7 – The argument is made that wadeable streams in their natural and undisturbed state are low productivity. I am not sure what is meant by low productivity, but stream and river theory hypothesizes greater productivity in these streams and small rivers than in either smaller streams or larger rivers.

Page 7 – You state that increasing nutrient inputs increase the percentage of bioavailable nitrate, ammonium, and phosphate relative to dissolved organic forms. This seems a compelling argument for combining both TN and TP measurements with inorganic nutrient measurements where the data exist.

Page 11 – Arid and semi-arid land streams have strong spatial patterns in attached and floating algal mats linked to patterns of ground water/surface water interactions. An upwelling region will be algal mat rich and a downwelling region will be algae poor. The pattern often is not anthropogenic nutrient loading.

Page 12 – The oxidized forms of iron and manganese are electron acceptors.

Page 13 – Sulfates in freshwater derive from more than just marine shales. For example, gypsum-rich soils can be major sources of sulfate.

Pages 13 – 15 – I think a focus on HAB toxins in wadeable streams is preferable to this very general overview of HAB toxins in all aquatic ecosystems. The Fetscher et al. (2015) seems to be an important reference for wadeable streams.

Page 16 – I'd be interested in references to support the statement that DOC content can be increased by algal production. Most of the work I know argues that algal DOC is labile and rapidly taken up and processed. Therefore, algal-dominated streams are low in DOC.

Page 16 – Not all predators are secondary consumers. Many if not most are tertiary or higher consumers.

Page 17 – Higher pH levels shift the equilibrium from ammonium to ammonia thereby increasing toxicity.

Page 18 – Your section 2.1.4 has a strong estuarine and marine focus. I'd recommend keeping a focus on streams and rivers.

Page 22 – Most readers will not know the term "tychoplankton." I'd define the word here and in your appendix.

Page 23 – The Ode et al. (2007) reference is not in the references.

Page 24 – The Fetscher et al. (2014) reference needs to be an "a" or "b".

Pages 25-27 – This section is largely repetitive with the materials in pages 13-15. Some condensing or complete removal is needed.

Page 28 – This estuarine conceptual model should be replaced with a conceptual model that is focused on wadeable streams.

Page 29 – Isn't this section really about water column or sediment biogeochemistry? pH is the negative logarithm of hydrogen ion activity. I would not characterize four orders of magnitude for hydrogen ion activity to be narrow.

Page 30 – I highly recommend the Bernhardt et al. (2018) review paper to help you frame and discuss the materials found on this page and the following two pages for streams and rivers. The reference is: Bernhardt et al. (2018) The metabolic regimes of flowing waters. Limnology and Oceanography 63:S99-S118. The Dodds (2002) reference is not in the references.

Page 31 – Figure 2.9 is an estuarine example of rather poor quality. How about a stream or river figure? The Dodds (2006) reference is not in the references (although a Dodds et al. (2006) is).

Page 32 – This link between the production of algae and high levels of DOC in streams and rivers is not well supported in the literature in my opinion. Black and brown water streams and rivers are characterized by lots of wetlands in the catchments and recalcitrant DOC from higher plants. Algal leachate generally degrades quickly.

Page 33 – Is vertical stratification of the water column an issue for wadeable streams? Nitrogen, phosphorus, and silica can be associated with both organic matter and inorganic matter.

Page 34 – Another pathway worth discussing briefly is the inhibition of nitrification under hypoxic and anoxic conditions.

Page 35 – Is the paragraph about urea relevant for wadeable streams? The author of many of the references (some of which are not in the references cited) is Patricia Glibert (not Gilbert). The references are overwhelmingly estuarine or marine.

Page 36 – You should define "HUC6." Figure 2.10 is unreadable. Hydrothermal vents in the ocean are examples of aquatic ecosystems not solar powered.

Page 37 – Lots of the text is focused on pelagic environments rather than streams. Some references are missing at the beginning of section 2.3.3.

Page 40 – Grazing by higher trophic levels can most definitely affect eutrophication. The references in the text are estuarine, but there are good examples in stream ecology. The research of Mary Power in the Eel River in California is an excellent example.

Page 44 – The report has multiple versions of this table with minor changes. Can one overall table be used?

Page 46 (and also on pages 72 and 80) – I really find this up arrow, down arrow, plus bold and italicized text format to be hard to follow.

Page 49 – I understand your focus on criteria from other US states, but I wonder if there is useful information from the European Union Water Framework Directive (WFD).

Pages 52-54 – These figures are difficult to read. Can the figures be upgraded to more clear versions?

Pages 58-59 - These figures are not readable.

Page 61 – The Dodds et al. (1988) reference is not in the references. One word of caution concerning the use of C:N ratios to indicate organic source material in streams. Well-developed soils also have low C:N ratios in the organic matter compartment.

Page 63 – Please upgrade the quality of the figure.

Page 64 – Dodds (2006) is not in the references.

Page 65 – Tetra Tech (2018) is not in the references.

Page 66 – You have me confused. Diel oxygen variability is the maximum daily value minus the minimum daily value. Why would you divide by two?

Page 67 – Diel dissolved oxygen is not a flux. It is a concentration (mg/L).

Pages 69-72 – This is another big section on harmful algae and their toxins. Is this needed again? Lots of the references once again are estuarine and marine instead of focusing on streams and small rivers.

Page 73 – Ger et al. (2009) is not in the references.

Page 74 – These references are not in the references cited section: Sutula and Senn (2015), Sutula and Senn (2011), Yuan et al. (2014), and Yuan and Pollard (2015).

Page 77 – Figure 3.14 is not readable.

Page 81 – The units for TN, TP, Chl-a, and AFDM should be spelled out in the Table 4.1 legend.

Pages 102-104 – The management terms and scientific terms are useful. Be sure to go through the document carefully so as to include all such terms found in the text.