Lake Tahoe Periphyton Monitoring Program Engaged Review

Dr. Soren Brothers, Utah State University, Lead reviewer
Dr. Ted Ozersky, University of Minnesota, Duluth, Reviewer
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Summary:

The accumulation of periphyton (attached algae) on natural rock surfaces and other substrates is a striking indicator of Lake Tahoe's water quality. Periphyton monitoring in Lake Tahoe has occurred since 1982, with near-continuous monitoring occurring since 2000. Statistical analyses found no significant lake-wide trends in periphyton biomass from 1982-2015, which contrasts with some anecdotal evidence of residents. The reviewers generally agreed that the locations and methods used for sampling status and trends were sufficient. However, there was some concern about the bias that could arise from sampling a single depth (0.5 m) in long-term trend analyses. The reviewers agreed that suggested changes to the monitoring program would improve its capabilities to track status and trends. Specific ways to improve the proposed sampling methods and spatial sampling scheme were suggested by the reviewers. Finally, the reviewers concluded that the monitoring program was consistent with best practices for similar lakes. They noted, however, that overriding aesthetic concerns may necessitate alternative monitoring metrics based on visual assessments that complement the proposed monitoring plan.

Introduction:

Resource management agencies sought an 'engaged review' (see TSAC Guidance for External Peer Review Document for details) of the existing Lake Tahoe periphyton monitoring program to assess its efficacy to track lake-wide periphyton status and trends. Review findings will be used to guide investment in the most cost-effective and defensible periphyton monitoring methods to evaluate ongoing periphyton biomass status and trends at representative locations around Lake Tahoe. Three specific review questions were developed in the charge: 1. Are the established sample locations, collection methods, and analytical procedures sufficient for assessing lake-wide status and trends for periphyton at Lake Tahoe?, 2. Would the suggested monitoring program changes (Schladow et al., 2018) improve the program's efficacy at tracking periphyton status and trends?, 3. Are the established monitoring methods and/or suggested program changes consistent with periphyton monitoring best practices for similar mountain lakes?

The review group was assigned a series of documents to review (see Peer Review Charge in appendix) and given a review charge in early December 2019. The review group met in early January to discuss key questions and concerns. The reviewers met with the author group on January 10th for 90 minutes to answer questions. From this, a short four page synopsis was developed for the resource management agencies and TSAC before final public release. This document is organized by the review questions, with short summaries followed by more detailed comments. The appendix has the review charge and the individual reviewer comments.

Question 1: Sufficiency of established program for tracking status and trends

There was some disagreement between reviewers regarding whether the current (established) program sufficiently tracks the status and trends of periphyton in Lake Tahoe. All reviewers considered the spatial extent of sites around the lake (both “intensive” and “synoptic”) to be sufficient for capturing spatial variability in lake periphyton responses across seasons (which, as one reviewer noted, is apparent from the data). All reviewers also generally approved of the methods of scrape syringes on rocks and the use of a periphyton biomass index (PBI). However, one reviewer expressed concern that the use of chlorophyll *a* for determining periphyton biomass (although admittedly a common approach, as noted by another reviewer) may represent a potential source of error as changes in periphyton-chlorophyll *a* are not always closely related to changes in biomass. This issue would not influence trends determined from analysis of periphyton ash-free dry weight, and ash-free dry weight data are also collected during routine monitoring. Two reviewers further expressed concern that by focusing on only one depth (0.5 m), potentially important zones of periphyton production may be missed by the protocol, with one noting that wave action at this depth, coupled with changing water levels, may partially obscure long-term trends. Potential mechanisms whereby different periphyton biomass accumulation at other depths might influence public perception of periphyton biomass changes over time are also proposed (linking to sloughing, seasonality of sampling, and/or water level fluctuations).

Specific reviewer comments/recommendations are provided below.

- Careful attention should be paid to documenting methods and training staff to ensure consistency in the application of all methods, especially methods which rely upon diver judgement.
- …it might be useful to assess whether or not sandy substrata could occasionally be supporting problematic periphyton biomass (planned drone sensing should address this issue)…
- It may also be useful to directly assess the precision with which biomass estimates can be made using 3 syringe samples per site (i.e., given typical values for means and standard deviations, what is the 95% confidence interval for a given site? Would increasing the sample size give enough increased sensitivity be worth the added effort?).

Question 2: Suggested improvements effects on tracking status and trends

All three reviewers generally agreed that the suggested improvements were appropriate for tracking periphyton status and trends. Furthermore, all three reviewers noted that sampling should continue at 0.5 m depth for continuity with prior monitoring efforts, and that the combination of the three replicate samples to save costs should not significantly impact the monitoring quality. One reviewer in particular supported the discontinuation of algal growth potential (AGP) experiments, which two reviewers suggested would be worth replacing with periphyton nutrient stoichiometry measurements. However, all reviewers expressed concerns regarding various specific aspects of the proposed improvements. One reviewer suggested that the reduction in “regular” monitoring sites (from 9 to 6) may significantly impact the spatial resolution of the monitoring program, while two reviewers expressed concern that the deep periphyton sampling sites proposed to be added may be challenging to establish in a repeatable way that will provide high-quality long-term data.

Specific reviewer comments/recommendations are provided below.

- An alternative approach [to sampling at the diatom-cyanobacteria transition zone], which would be less prone to operator interpretation of where the transition zone is, would be to sample at predetermined depths below the surface. For example, 0.5 m, 1.5 m and 3.0 m or some other set of fixed depths based on knowledge of periphyton ecology in Lake Tahoe.
- [Another approach would be] to have staked/set sampling locations, but also upon each visit allowing the diver to reassess the appropriateness of those locations and moving them up or down, but recording that information (providing additional monitoring information on the rate of change, if any, in the location and depth of these two periphyton communities).
- Perhaps one way for keeping the program cost-neutral is to perform diver PBI surveys at a subset of the synoptic sites rather than at all 40… Or perhaps by keeping the synoptic survey strictly focused on the 0.5 m depth until diver-based surveys from the primary sites suggest that significant additional information can be obtained by using divers.
- Replacing AGP experiments with periphyton stoichiometry monitoring and short-term experimental assessments of stoichiometric, light, and temperature constraints on periphyton production (e.g., Graham et al. 1982, J Great Lakes Res. 8:100-111) would provide the data required for management-relevant models of periphyton growth in Lake Tahoe, analogous to the *Cladophora* Growth Model used in the Laurentian Great Lakes.
- Including drone or remote-sensing detection of periphyton biomass (if preliminary tests indicate that this is a viable method) could improve program efficacy in several ways: first, this would serve to capture habitats currently not included in sampling (e.g., sandy sediments). Secondly, if management agencies are able to identify specific times of year when “excess periphyton” complaints are common, drone or remote-sensing detection could be a rapid way to quantify the situation. Finally, rapid, repeated surveys of this type could be used to quantify the amount of time that unacceptably high biomass conditions are present. If reasonable photographic records of the littoral zone exist, then it might be possible to “hind-cast” these visual-based methods to indicate if current conditions differ from historical ones.
- The planned changes to the sampling protocol should provide some additional information, particularly in years with unusual water levels.

Question 3: Consistency with best monitoring practices

All reviewers agreed that the periphyton monitoring program is in line with best monitoring practices for similar mountain lakes, given both literature and reviewer experiences. Two reviewers noted that due to the importance of public perception and aesthetics to the Lake Tahoe monitoring program, it may be worth carrying out public surveys to determine the optimal (seasonal) timing for periphyton sampling, as well as perhaps establishing an aesthetic standard scale to incorporate into the monitoring protocol.

- The agencies and TERC may consider creating a mechanism for recording public complaints about periphyton issues (if no such mechanism exists). Logged complaints should include information about the location, date and type (beach washup, slippery rocks, metaphyton) of problem. Systematic logging of these complaints could help determine what drives the perceived worsening of the periphyton problem among the public and compare that to long-term observations of status and trends.

Appendix A: Review Charge

Lake Tahoe Periphyton Monitoring Program Methods and Findings

Background

The accumulation of periphyton (attached algae) on natural rock surfaces, piers, boats and other substrates is perhaps the most striking indicator of Lake Tahoe's water quality for the largely shore-bound population (Heyvaert et al., 2013). The State Water Resources Control Board, Lahontan Region (Lahontan Water Board) has funded periphyton monitoring in Lake Tahoe since 1982. Monitoring occurred for select periods in the 1980s (1982-85) and 1990s (1989-93). Near-continuous monitoring has occurred since 2000 with a one-year gap in 2004 (Hackley et al., 2016).

In 2015, the UC Davis Tahoe Environmental Research Center (TERC) prepared an analysis of existing periphyton data for the Tahoe Regional Planning Agency (TRPA) to inform the evaluation of the threshold standard related to nearshore attached algae. Statistical analyses found no significant lake-wide trends in periphyton biomass during the 1982-2015 monitoring period. (Hackley et al., 2016).

The Lake Tahoe Nearshore Evaluation and Monitoring Framework (Heyvaert et al. 2013) recommended that periphyton monitoring using the methodology and intensity consistent with historic efforts should be continued. In anticipation of updating monitoring contract language, UC Davis provided the Lahontan Water Board with a series of program improvement suggestions to enhance periphyton monitoring effectiveness.

Review Need

Resource management agencies seek an 'engaged review' (see TSAC Guidance for External Peer Review Document) of the existing periphyton monitoring program to assess its efficacy to track lake-wide periphyton status and trends. Review findings will be used to guide investment in the most cost-effective and defensible periphyton monitoring methods to evaluate ongoing periphyton biomass status and trends at representative locations around Lake Tahoe.

Documents for Review

Lahontan Water Board Agreement 16-076-160 (Task 5 only)

Lahontan Water Board Agreement 19-024-160 (Task X only)

> Schladow, S.G., Sadro, S., Hackley, S.H. 2018. Suggested Changes to Lahontan and TRPA Monitoring Contracts. Tahoe Environmental Research Center University of California, Davis, Incline Village, NV. (pages 4 and 5)
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> Hackley S.H., Watanabe S., Senft K.J., Hymanson Z., Schladow S.G., Reuter, J.E. 2016. Evaluation of Trends in Nearshore Attached Algae: 2015 Threshold Evaluation Report. Tahoe Environmental Research Center University of California, Davis, Incline Village, NV.

Review Questions and Charge

1. Are the established sample locations, collection methods, and analytical procedures sufficient for assessing lake-wide status and trends for periphyton at Lake Tahoe?

2. Would the suggested monitoring program changes (Schladow et al., 2018) improve the program's efficacy at tracking periphyton status and trends?

3. Are the established monitoring methods and/or suggested program changes consistent with periphyton monitoring best practices for similar mountain lakes?

Three to five reviewers and a review chair (from the TSAC Peer Review Committee, PRC) will be selected by the Tahoe Science Advisory Council. The reviewers will have no affiliation with ongoing work in the Basin. The reviewers will work with review chair and authors to provide early feedback and direction. The product of this work will be a report compiling the reviewer's assessment of existing practices as defined by the review questions above. A report will be released to the public two weeks after receipt of the final work product. This report will inform the future direction of resource management agency monitoring programs.

Timeline

November – December 2019 – Select reviewers and chairperson. Agree upon review format and meetings. Gather available in-basin periphyton monitoring program descriptions and data (agency staff to provide material for review).

December 2019 – Virtual meeting with review committee and periphyton monitoring program implementers/authors

January 2020 – Compile report with reviewers and chairperson

January 2020 – Publicly release review and present initial findings to the full Council for review.

References

Heyvaert, A.C., Reuter, J.E., Chandra, S., Susfalk, R.B., Schaldow, S.G. Hackley, S.H. 2013. Lake Tahoe Nearshore Evaluation and Monitoring Framework. Final Report prepared for the USDA Forest Service Pacific Southwest Research Station. https://www.dri.edu/images/stories/centers/cwes/Lake_Tahoe_Nearshore_Evaluation_and_Monitoring_Framework.pdf

Hackley S.H., Watanabe S., Senft K.J., Hymanson Z., Schladow S.G., Reuter, J.E. 2016. Evaluation of Trends in Nearshore Attached Algae: 2015 Threshold Evaluation Report. Tahoe Environmental Research Center University of California, Davis, Incline Village, NV. https://laketahoeinfo.org/FileResource/DisplayResource/ceefbefc-f672-4d45-bdec-253aac4c203f

Appendix B: Individual Reviews

Dr. Ted Ozersky Comments:

Overview:
The Lake Tahoe periphyton monitoring program is aimed at: (a) quantifying the amount of periphyton at different locations in the upper littoral zone of the lake and (b) determining whether there are significant long-term trends in periphyton biomass. Periphyton is considered to be an indicator of nutrient pollution and other environmental change and is also a source of public complaints and perception of environmental degradation. The monitoring program was started in 1982, but only ran for 4 years before being discontinued in 1986. The monitoring program was resurrected in 2000 and has been running continuously without major modifications since then.

The program consists of 5-6 annual visits to 9 “primary” sites and a once-a-year visit to a set of ~40 “synoptic sites”. During visits to primary sites, triplicate samples of periphyton are collected using syringe scarpers and are analyzed for Chl.a and AFDW as an indicator of periphyton biomass. Additionally, a rapid assessment of periphyton biomass using the periphyton biomass index (PBI) is performed at the primary sites. Primary sites are visited 3 times/year in the spring (peak periphyton biomass period) and 2-3 times/year outside of peak growth period. The synoptic sites are visited in the spring only, when periphyton biomass (Chl a + AFDW) and PBI measurements are made. Thus far, all sites (primary and synoptic) were sampled at 0.5 m depth below water surface.

Analysis of periphyton data has revealed spatial variability in periphyton biomass, with higher periphyton abundance at sites along developed shorelines. Time series analysis showed limited trends in periphyton biomass over the course of the monitoring program (2000-2015/ 1982-2015); most primary sites showed no trend in periphyton biomass through time; one primary site showed a slight decrease in periphyton biomass and two sites showed an increase. It was also found that lake level fluctuations can affect periphyton biomass estimates from the monitoring program; specifically, lower water levels lead to higher periphyton biomass measured as Chl a. The reason for this appears to be that during low water periods, the monitoring program samples the deeper water cyanobacteria-dominated community, which is below the 0.5 m sampling depth during normal/high water years. Because the cyanobacteria-dominated community has higher biomass than the shallow water (diatom and filamentous green-dominated) community, low water years have higher biomass estimates.

The proposed revisions to the periphyton monitoring program, in large part, seem to be motivated by a desire to account for the inflated biomass estimates caused by low water levels. The monitoring team proposes to move from a snorkelling-based to a SCUBA diving-based sampling program where, instead of sampling one depth at each site (0.5 m), 3 depths are sampled: 0.5 m (to maintain continuity with historical data), 0.5 m above the diatom-cyanobacteria interface and 0.5 m below the diatom-cyanobacteria interface. The increased

cost of moving to a diver-based program will be offset by: (a) combining triplicate samples from each sampling depth for analysis; (b) reducing the number of primary sites from 9 to 6.
Review questions

1. Are the established sample locations, collection methods and analytical procedures sufficient for assessing lake-wide status and trends for periphyton at Lake Tahoe?

One of the main challenges associated with sampling of periphyton is the high spatial and temporal variability of periphyton biomass (across spatial scales ranging from cms to kilometers and temporal scales of days to years). The current program seeks to overcome this problem by using a two-tiered design, which combines detailed seasonal study at 9 sites with a once-per-year visit to ~40 sites around the lake. Small-scale spatial variability is addressed by collecting triplicate samples of periphyton at each location. This approach seems appropriate for quantifying seasonal variation (capturing both the high and low-biomass periods). This approach also seems to capture spatial variation well, with some sites having consistently higher biomass than others. The approach also shows an association between shoreline development and periphyton biomass (as would be expected). An apparently contentious question is whether the program is sufficient for assessing long-term trends in periphyton biomass. This question is motivated by the perceived increase in nuisance periphyton growth by the public while time series analysis of the periphyton monitoring program data shows limited change. I believe that the current program design is sufficient to capture long-term changes in biomass of upper littoral zone periphyton on the basis of the program's success in assessing seasonal and spatial patterns in biomass. Given that the program does a good job of capturing biomass change at each site across the year, and repeatedly shows that some sites are "high biomass sites" and some sites are "low biomass sites", it should also be able to capture a significant long-term change in biomass at individual sites and across the lake as a whole. Thus, I believe that the lack of significant temporal trends is real rather than a type 2 error caused by poor study design.

The collection methods for periphyton biomass (syringe scrapers) and for rapid assessment of biomass (PDI) are appropriate for quantifying seasonal and spatial variation and should also be suitable for assessment of long-term trends.

Periphyton biomass quantification is based on chl a and AFDW measurements, which are the standard "literature" methods for quantification of periphyton biomass. These methods, along with the PDI, are appropriate for quantifying periphyton biomass.

2. Would the suggested monitoring changes (Schladow et al. 2018) improve the programs efficacy at tracking periphyton status and trends?

The main suggested changes are (a) combining triplicate periphyton samples from each site; (b) collecting samples from 3 depths at each site using divers; (c) reducing the number of primary sites from 6 to 9.

Below I address each proposed change:

a) I believe that the move to combined triplicate samples will not result in significant loss of information for the program and will not have a negative impact on its ability to capture spatial, seasonal and long-term trends in upper littoral zone periphyton biomass.

b) While the addition of depth-stratified sampling should strengthen the monitoring program, I am not confident that the proposed depths are the optimal depths to target. The revised program proposes sampling at 0.5 m above and 0.5 m below the diatom-cyanobacteria transition zone. Conversation with the monitoring team suggests that this transition zone is not always clear cut, creating ambiguity about where to sample. The transition zone may also move up or down with changes in water level and water clarity, potentially making it difficult to determine the cause of observed long-term changes in periphyton biomass. An alternative approach, which would be less prone to operator interpretation of where the transition zone is, would be to sample at predetermined depths below the surface. For example, 0.5 m, 1.5 m and 3.0 m or some other set of fixed depths based on knowledge of periphyton ecology in Lake Tahoe. Certainly maintaining the 0.5 m depth is a good idea and should be done whatever the monitoring team decides to do about other depths.

c) Given the large spatial variation in periphyton biomass, I am unsure whether reducing the number of primary sites (from 9 to 6) is entirely worth the added information about depth distribution at the smaller subset of sites. I believe that the discontinuation of the 3 sites would lead to reduced ability to assess long-term trends in periphyton biomass.

At the same time, I understand the financial constraints that the program faces and the need to keep changes cost-neutral. Perhaps one way for keeping the program cost-neutral is to perform diver PDI surveys at a subset of the synoptic sites rather than at all 40. Since each primary site is sampled 5 times a year, monitoring the 3 primary sites that may be dropped is equivalent to 15 dives/ year. Could this be offset by performing diver PDI surveys at 25 synoptic sites (while still monitoring 0.5 m depth periphyton at all 40)? Or perhaps by keeping the synoptic survey strictly focused on the 0.5 m depth until diver-based surveys from the primary sites suggests that significant additional information can be obtained by using divers?

Overall, my recommendation would be to find a way to maintain the long-term record at all 9 primary sites.

3. Are the established monitoring methods and/ or suggested program changes consistent with periphyton best practices for similar mountain lakes?

As far as I can tell, the Lake Tahoe periphyton monitoring program is unique in its duration and extent, and thus may be the template for “best practices” for other systems. While I am not aware of other such monitoring programs, the Lake Tahoe program is in line with published methods for quantifying periphyton biomass, and its variation in space and time in streams and lakes (e.g., Biggs & Kilroy 2000; Parker & Maberly 2000; DeNicola & Kelley 2014). Specifically, the design of the program accounts for the high spatial and temporal variability of periphyton growth (multiple sampling sites, multiple replicates at each site, multiple samples throughout the year), uses different metric of biomass (chl a, AFDW, PDI) and has spanned a substantial period of time. Overall, I believe the monitoring team has done an excellent job of creating an effective and efficient sampling design.

Other comments:

I have two other comments/ suggestions that don't fall directly under one of the 3 review questions.

1. The agencies and TERC may consider creating a mechanism for recording public complaints about periphyton issues (if no such mechanism exists). Logged complaints should include information about the location, date and type (beach washup, slippery rocks, metaphyton) of problem. Systematic logging of these complaints could help determine what drives the perceived worsening of periphyton problem among the public.
2. Measurement of periphyton nutrient stoichiometry (C:N:P) could help assess spatial and temporal patterns of nutrient pollution in the nearshore and potentially add information about the drivers of nuisance growth. The costs of adding C:N:P stoichiometry would not be unreasonable: 6-9 primary sites * 5 samples/year * duplicate samples= 60-90 samples/year; this should amount to ~$1000/year (focusing on 1 depth per site).

Dr. Steve Francoeur comments:

Review Questions and Charge
1. Are the established sample locations, collection methods, and analytical procedures sufficient for assessing lake-wide status and trends for periphyton at Lake Tahoe?
2. Would the suggested monitoring program changes (Schladow et al., 2018) improve the program's efficacy at tracking periphyton status and trends?
3. Are the established monitoring methods and/or suggested program changes consistent with periphyton monitoring best practices for similar mountain lakes?

1. Are the established sample locations, collection methods, and analytical procedures sufficient for assessing lake-wide status and trends for periphyton at Lake Tahoe?

Given the program's focus on aesthetic periphyton biomass and beach fouling (which appears to be caused primarily by shallow, diatom-rich periphyton), the focus on shallow sampling locations is appropriate, despite the ability of Lake Tahoe periphyton to persist at much greater depths. Use of only a 0.5m sampling depth can lead to some problems of interpretation, especially in low- or high-water years, as noted in the planned revisions.

The sampling locations are well-distributed, with a good mix of regular and synoptic locations. With care, the number of sampling locations could likely be slightly reduced and still provide adequate coverage.

The collection methods and analytical procedures are generally sufficient. Careful attention should be paid to documenting methods and training staff to ensure consistency in the application of all methods, especially methods which rely upon diver judgement. The focus on rock substrata is consistent with general patterns in periphyton biomass (typically highest on hard substrata), but it might be useful to assess whether or not sandy substrata could occasionally be supporting problematic periphyton biomass (planned drone sensing should address this issue, see below). It may also be useful to directly assess the precision with which biomass estimates can be made using 3 syringe samples per site (i.e., given typical values for means and standard deviations, what is the 95% confidence interval for a given site? Would increasing the sample size give enough increased sensitivity be worth the added effort?). If samples are going to be composited in the future (as suggested in the planned revisions), then there would be no increased analytical cost for taking more than 3 samples at each depth at each site.

2. Would the suggested monitoring program changes (Schladow et al., 2018) improve the program’s efficacy at tracking periphyton status and trends?

The removal of the periphyton AGP experiments would reduce costs with essentially no loss in monitoring program efficacy. Replacing AGP experiments with periphyton stoichiometry monitoring and short-term experimental assessments of stoichiometric, light, and temperature constraints on periphyton production (e.g., Graham et al. 1982, J Great Lakes Res. 8:100-111) would provide the data required for management-relevant models of periphyton growth in Lake Tahoe, analogous to the *Cladophora* Growth Model used in the Laurentian Great Lakes.

Including drone or remote-sensing detection of periphyton biomass (if preliminary tests indicate that this is a viable method) could improve program efficacy in several ways: first, this would serve to capture habitats currently not included in sampling (e.g., sandy sediments). Secondly, if management agencies are able to identify specific times of year when “excess periphyton” complaints are common, drone or remote-sensing detection could be a rapid way to quantify the situation. Finally, rapid, repeated surveys of this type could be used to quantify the amount of time that unacceptably high biomass conditions are present. If reasonable photographic records of the littoral zone exist, then it might be possible to “hind-cast” these visual-based methods to indicate if current conditions differ from historical ones.

The planned changes to the sampling protocol should provide some additional information, particularly in years with unusual water levels. Compositing samples from the same location and depth, as suggested in the planned revisions, is acceptable. Maintaining a “0.5 m” sampling depth for consistency with past surveys (as described in the planned revisions) is important.

Routine monitoring of periphyton stoichiometry would provide management-relevant data, and could lead to early detection of problem locations (i.e., detection of a nutrient-content response in the early stages of local nutrient pollution, prior to development of high periphyton biomass).

3. Are the established monitoring methods and/or suggested program changes consistent with periphyton monitoring best practices for similar mountain lakes?

In general, yes. The existing program is strong, and the proposed changes will increase information and reduce artifacts (yearly depth fluctuations) and inefficiencies (removal of AGP experiments).

Given the program's focus on aesthetic periphyton biomass and beach fouling, if the specific times of year when "excess periphyton" complaints are common does not correspond to the usual periphyton survey times, then in may be wise to include these times as a new survey date.

Given the program's focus on aesthetic periphyton biomass and beach fouling, it may be useful to develop an aesthetic standard scale by surveying lake users/stakeholders, and then include scores on this scale as part of the monitoring.

It is difficult to estimate the odds that a "type II error" might have been made for estimates of periphyton biomass over time in Lake Tahoe. The survey focuses on quantifying maximum biomass on a common surface (rock) that supports the greatest periphyton biomass at shallow depths. Perhaps consultation with a statistician experienced in time-series modelling could result in an estimate of how likely it is that a rise in shallow rock-based peak biomass at any of the nine routine sampling sites could remain undetected by the survey program. Based on the conference call discussion, it does not seem likely that deep periphyton biomass is contributing greatly to the aesthetic problems, but it is possible that the duration of high biomass conditions (or extent of biomass development on less-preferred substrata, like sand) might possibly have changed over time. Some of the proposed changes to the survey methodology could help evaluate and address these potential issues.

Dr. Soren Brothers Comments:

1. Are the established sample locations, collection methods, and analytical procedures sufficient for assessing lake-wide status and trends for periphyton at Lake Tahoe?
2. Would the suggested monitoring program changes (Schladow et al., 2018) improve the program's efficacy at tracking periphyton status and trends?
3. Are the established monitoring methods and/or suggested program changes consistent with periphyton monitoring best practices for similar mountain lakes?

1. The sample locations (both the 9 focused and broader synoptic sites) appear to be appropriate for capturing the spatial variability of the lake. Regarding the collection

methods and analytical procedures, I can perceive several potential reasons why a public perception of increased periphyton (if accurate) was not captured by the applied methods (as I understand them from the provided materials and discussions). First: The monitoring protocol uses measurements of chlorophyll a for assessing periphyton biomass – while phytoplankton biomass is often well correlated with chl a content, this relationship is not always so apparent in periphyton assemblages (e.g., see Baulch et al. 2009, "Benthic algal biomass – measurement and errors", in the Canadian Journal of Fisheries and Aquatic Sciences). For instance, some periphyton species are known to produce non-photosynthesizing stock, which may hypothetically be observed by the public, but may not track as a significant change in measured chl a content. I have no personal experience with assessing how variable this is, though, between periphyton species and locations, and so can't comment on how likely this would be as an important factor to consider here – though it may be worth keeping in mind, and (if not already done) using the corresponding AFDW measurements to assess how well chl a likely tracks biomass from collected samples. The PBI approach being used is also a useful method that should not be affected by this error. Second: By only measuring periphyton growing on rocks at 0.5 m below the water, the sampling protocol may be introducing other variables that may complicate or obscure long-term trends. For instance, if the lake is at a period of rising water levels, rocks at this depth may have only been recently inundated, and may thus not have been submerged for long enough to fully develop biofilm mats. Alternatively, if water levels are dropping, larger periphyton mats approaching the littoral surface may have been significantly sloughed by increased exposure to wave action (or foot traffic if located near any popular tourist sites). Even with stable water levels, wave action could have a significant effect on periphyton growing at 0.5m, and this effect might mask long-term changes. Additionally, it is not fully clear to me whether the increase in periphyton observed/described by the public was specific to periphyton growing on rocks at 0.5m, or if it also (or instead) included, for instance, periphyton mats that had washed up on the beach (which may be sourced deeper in the water column, beyond current sampling depths) or periphyton that had become exposed on beaches following declines in water levels (both of which would not be accounted for in the current sampling methods). Third: The timing of the current protocol focuses particularly on the spring, which is the time that periphyton productivity is greatest, and blooms are considered to be most prevalent. However, it is not clear whether this also the only period of concern for the public, influencing their observation that the occurrence of periphyton is changing. If part of the public concern is from washed up/sloughed periphyton biomass, I imagine this could happen later in the year, after peak productivity (and it could also, as mentioned above, be sourced from deeper parts of the lake that are not being monitored). Alternatively, the public perception of increasing periphyton biomass may hypothetically result from lower water levels in Lake Tahoe exposing deep, static periphyton zones (i.e. down to the cyanobacteria mat layer described), which would likely have a stronger perceived effect in late summer vs. springtime, although it's not immediately apparent from the provided data on Tahoe's long-term lake elevation that this is a reasonable source of error (given that there's not a clear long-term decline in the lake's water levels). However, it may potentially fit with the data presented in Fig. 8 of the provided Hackley 2016 document for Deadman Pt., in which low water years appear to be generally associated with elevated periphyton biomass, and vice versa.

In sum, there are several sources of potential error in the lake sampling methods that may result in missing long-term trends in Lake Tahoe's periphyton.

2. The proposed changes would effectively improve upon several of the above-mentioned potential shortcomings in the current protocol. I believe that joining samples into triplicates should not significantly affect the data, and I also agree that it is important for consistency to continue sampling at 0.5m. I believe that adding two depths to the monitoring protocol will be beneficial, even at the loss of three of the lake's sites, as it will provide extra periphyton biomass data which will not be consistently affected by wave action, and it may allow for a greater accounting for the effects of water level changes on observed biomass. One issue that came up during discussions, which I believe is important to consider and resolve, is whether the 2nd and 3rd sampling depth are set as static locations on each sampling campaign (i.e. marked with a stake and flagging tape, so that there is no subjectivity that goes into the diver's site selection), or whether each diver should make a judgement call on each visit to determine appropriate sites 0.5 m above and below the divide between the stalked diatom and cyanobacteria layers. My recommendation might be a somewhat harmonized approach – attempting to have staked/set sampling locations, but also upon each visit allowing the diver to reassess the appropriateness of those locations and moving them up or down, but recording that information (providing additional monitoring information on the rate of change, if any, in the location and depth of these two periphyton communities).

3. To my understanding, these periphyton monitoring protocols, and the recommended changes, are setting an appropriately high, and necessary, standard for mountain lakes.