water

MDPI

Comment

Harmful Cyanobacteria in Three Oregon Lakes: Comments on Hall et al. Beyond Water Quality Advisories and Total Maximum Daily Loads (TMDLs). *Water* 2019, *11*, 1125

Joseph Eilers

MaxDepth Aquatics, Inc., Bend, OR 97701, USA; j.eilers@maxdepthaq.com; Tel.: +1-541-390-2911

Received: 16 September 2019; Accepted: 8 November 2019; Published: 25 November 2019

check for updates

Abstract: The article "An Ecological Function Approach to Managing Harmful Cyanobacteria in Three Oregon Lakes: Beyond Water Quality Advisories and Total Maximum Daily Loads (TMDLs), *Water* 11:1125" by Hall et al. critiques the current approach used by the state of Oregon with regard to managing cyanobacterial blooms and offers the proper functioning condition (PVC) as a superior method of managing cyanobacterial blooms in lakes derived from nonpoint sources of pollution. They evaluated three lakes in Oregon as examples of how this approach could be applied to support water quality improvement. Two of the three lakes, Lemolo and Diamond, experienced cyanobacterial blooms, not as a function of nonpoint source loadings from the watershed, but rather because of internal nutrient cycling associated with high fish biomass. The third lake, Tenmile Lakes, in additional to having a greatly altered fish community, also experiences cyanobacterial blooms (CyanoHABs) issues because of timber harvest on steep slopes, loss of wetlands, altered watershed hydrology and nutrient input from septic systems. The authors' attempts to use satellite images and PVC methodology on the stream networks is incomplete with respect to Tenmile Lakes and is totally misdirected regarding Lemolo and Diamond Lakes. Although I don't support the current system employed by the state of Oregon to manage lakes experiencing CyanoHABs issues, the proposed approach offered by staff with the U.S. Environmental Protection Agency will yield little water quality benefit for the lakes in question.

Keywords: cyanobacteria; CyanoHABs; internal loading; fisheries; TMDLs; proper functioning condition (PFC)

---

1. Introduction

The manuscript by Hall et al. *Water* **2019**, *11*, 1125 [1] offers a critique and extension of Oregon's total maximum daily load (TMDL) process for managing harmful cyanobacterial blooms (CyanoHABs) by focusing on ecosystem function instead of using response indicators of CyanoHABs.

The authors offer an approach they term the Proper Functioning Condition (PFC), which appears to encourage restoring ecologically functioning stream and riparian wetland systems. They noted that "proper ecological hydrological, and geomorphic functioning of lake and river catchments is important and including this in the total catchment management activities to protect water quality and reduce CyanoHabs is essential." They concluded that the ecological function of lakes could be restored through application of best management practices (BMPs), TMDLs, CyanoHAB advisories and PFCs. The inherent assumption in this approach seems to be that the three example lakes that they evaluate are affected to a large degree by watershed activities. I re-examine the three lakes they chose as examples and show that two of the three lakes are responding to internal cycling of nutrients associated with elevated fish biomass and the third lake (Tenmile Lakes) is affected by several major sources of nutrients, only some of which are related to watershed activities. Additionally, the use of CyanoHABs postings by Oregon, a metric used by Hall et al. to illustrate lakes response to purported watershed activities, is invalid because there is no systematic method for CyanoHABs postings in the state. The CyanoHABs postings in the state are largely haphazard.

2. Diamond Lake

The authors incorrectly list Diamond and Lemolo Lakes as part of the Oregon Southwestern Coast Range. They are in the Oregon Cascades Range. The watershed for Diamond Lake is contained wholly within the Umpqua National Forest, portions of which are subject to timber harvest. The authors show older figures of clear-cuts in the vicinity of Diamond Lake, but outside the watershed for Diamond Lake, and compare these with more recent figures of areas harvested by thinning, also located outside the Diamond Lake watershed. What timber harvest has been conducted since the major fires of 1910 has been limited to selective thinning to remove small parcels of standing dead timber [2]. The implication by Hall et al. is that timber harvest was the major factor causing the CyanoHABs events occurring in Diamond Lake. This is incorrect. The soils in the watershed have high infiltration rates and there are no identifiable areas of erosion contributing to sediment loading in Diamond Lake. Diamond Lake has two surface inlets, Silent Creek and Short Creek, both of which are low-gradient streams derived almost entirely from groundwater discharge. They lack sufficient capacity to transport much sediment. Nearly all the additional nutrient loading to Diamond Lake was associated with internal cycling from high biomass of invasive cyprinids [3]. Once the tui chub (*Gila bicolor*) biomass was eliminated through a rotenone treatment [4], water quality improved dramatically [3]. The lake was restocked with rainbow trout (*Onchorhynchus mykiss*) and subsequent illegal introductions of tui chub and golden shiner (*Notemigonus crysoleucas*) have increased fish biomass, but it remains well below the estimated 250 tonnes of fish biomass present prior to the rotenone treatment. Although low density populations of the colonial cyanobacterium *Gloeotrichia echinulata* are common during the summer, no intensive CyanoHAB events comprised of *Anabaena* (now referred to as *Dolichospermum)* have resumed (R. Miller, 28 August 2019, Pers. Comm.). The paleolimnological analysis of Diamond Lake demonstrated that prior to fish being stocked in Diamond Lake circa 1910, cyanobacteria populations were low [5]. The increase in fish biomass following fish stocking and subsequent introductions of tui chub confirmed that internal cycling of nutrients supported abundant cyanobacterial populations. This was evident again with the elimination of fish in 2006 and the return to high water quality [3]. Tui chub and golden shiners were once again illegally introduced into Diamond Lake following the 2006 rotenone treatment, but the biomass of the minnows has apparently been kept in check by the introduction of piscivorous brown trout (*Salmo trutta*) and tiger trout (brown trout x brook trout [*Salvelinus fontinalis*]) by Oregon Department of Fish and Wildlife (ODFW). Throughout these cycles of fish introduction and eradication the primary driver of cyanobacteria blooms, especially those associated with *Anabaena*, are derived from the changing abundance of fish biomass. There is no evidence that timber harvest or other watershed activities have played any measurable role in nutrient processes in the lake or CyanoHAB events [6].

3. Lemolo Lake

Lemolo Lake is located about 15.5 km downstream of Diamond Lake and receives discharge from Diamond Lake through Lake Creek. The primary surface inlet is from Spring River, which as the name implies, is a groundwater-dominated stream. The authors indicate that the number of days of CyanoHAB posting in Lemolo Lake was caused by elevated nutrient influx from Diamond Lake before and during the rotenone treatment of 2006. It is correct that cyanobacteria and nutrients from Diamond Lake were transported to Lemolo Lake and contributed to cyanobacteria issues in Lemolo Lake through 2006. However, Lemolo Lake continued to experience intense *Anabaena* and *Gloeotrichia* blooms following the 2006 rotenone treatment in Diamond Lake. When Diamond Lake had a transparency of 12 m in July 2007, Lemolo Lake continued to experience major CyanoHAB events.

At this time, it became evident that the water quality problems in Lemolo Lake were no longer directly attributed to water quality in Diamond Lake. Examination of fish populations through netting and hydroacoustics found that large numbers of tui chub had entered Lemolo Lake through Lake Creek during the drawdown of Diamond Lake. Initial plans to prevent tui chub from moving downstream to Lemolo Lake were abandoned by the Oregon Department of Fish and Wildlife (ODFW) because of logistical challenges. Consequently, Lemolo Lake received tonnes of tui chub that moved into the lake during the drawdown of Diamond Lake. Lemolo Lake became impacted by internal cycling of nutrients to a degree not previously experienced. Mechanical harvesting to remove most of the tui chub was successful in reducing the biomass of tui chub, but this was offset to a considerable degree of trout stocking pursued by ODFW and increased recruitment of kokanee presumably because of the decreased competition with tui chub. The initial improvements in water quality that was achieved with the reduction of fish biomass were evident in monitoring data of phytoplankton populations during the study [7]. Once again it was demonstrated that fish biomass was a major contributor to CyanoHABs in Lemolo Lake. No evidence of watershed contributions from timber harvest or other watershed activities were linked to increased nutrient input to Lemolo Lake.

4. Tenmile Lakes

The authors state that the cause of CyanoHABs in Tenmile Lakes is the same as in Lemolo Lake. This is not the case. Tenmile Lakes (comprised of North and South Tenmile Lakes) has poor water quality, as evidenced by repeated cyanobacteria blooms, because of several factors (in random order), (1) timber harvest with little adherence to mandated buffer strips, (2) a legacy of channelization of streams along long narrow catchments and elimination of wetlands to allow for livestock grazing, (3) extensive shoreline housing construction and likely high incidence of poorly functioning septic systems that deliver nutrients to the lakes, and (4) a legacy of mismanagement of fisheries by the Oregon Game Commission (now ODFW). Timber harvest leads to high rates of erosion on the steep slopes in these catchments and although there are regulations for mandated buffer strips to minimize erosion, these regulations are not aggressively enforced by the Oregon Department of Forestry. The naturally meandering streams were replaced with stream channels bordering each side of the narrow catchments. These parallel channels reduced flooding in the catchments and allowed for dairy and other livestock operations to create pasture in the former wetlands. There are several hundred homes that border the extensive shorelines of the dendritic lakes. Septic systems "function" in the sandy soils because water passes through the soils rapidly (and thus meet septic requirements for sufficiently permeable soils), but retention of nutrients in these soils is likely to be low. Lastly, these lakes were formerly enormously productive anadromous fisheries as evidenced by the commercial fishery that once operated in the lakes [8]. The largest reduction in the salmonids occurred when ODFW introduced largemouth bass into the lakes to control an introduced population of smaller centrarchids (bluegills and yellow perch) [8]. Instead of preying on centrarchids, bass preyed on young salmonids. This changed the nutrient regime of the lakes from a marine-derived seasonal input of decaying salmonid carcasses to a year-round population of centrarchids that likely increased internal nutrient loading to the lake. The water quality problems in Tenmile Lakes are complex and involve altered hydrology (stream channelization), accelerated erosion from timber harvest, conversion of wetlands to pasture, uncontrolled septic inputs, a radically altered fishery, and failure of the regulatory agencies to systematically address any of these issues. The so-called "proper functioning condition" or PFC described by the authors appears to address a small portion of the causes of water quality challenges for Tenmile Lakes. Although the Oregon Department of Environmental Quality (ODEQ) accepted the reports submitted by Eilers et al. [9,10] for the Tenmile Lakes TMDL, we see no evidence that ODEQ has initiated any action to address the critical factors contributing to the water quality problems in the lake. The lakes are frequently posted for CyanoHABs, but these postings are not connected to actions that address water quality issues.

5. CyanoHABs Reporting in Oregon

The authors incorrectly relate the reported incidence of CyanoHABs postings in Oregon to the actual number of cyanobacterial blooms in each lake. The reporting of CyanoHABs in the state is voluntary and is dependent on local organizations such as lake districts or interested state or federal agencies with the resources to collect and process the samples. There is no requirement that a lake experiencing a cyanobacteria bloom in Oregon be posted. For example, Wickiup Reservoir, a reservoir operated by the U.S. Bureau of Reclamation (USBR) frequently experiences cyanobacteria blooms based on satellite imagery processed by ODEQ [11], yet the reservoir is seldom posted for CyanboHABs. There is no requirement that the USBR sample Wickiup Reservoir for cyanobacteria and postings are only entered when another organization intervenes. Consequently, the public record of cyanobacteria postings for Wickiup Reservoir and many other lakes in the state is subject to random availability of resources from other entities. Furthermore, the criteria used within the state to determine if a lake should be posted for CyanoHABs has evolved over the years. Postings during early years of the program could be made based on visual observations of shoreline scums, which are still an option. Later postings were made based on cell counts of potentially toxigenic taxa by taxonomists. Current postings are based on measured concentrations of cyanotoxins in addition to the option of observations of scums. Additionally, the program for posting CyanoHABs in Oregon is managed by the Oregon Health Authority (OHA), not the ODEQ. In 2009, the Oregon Health Authority, Public Health Division assumed responsibility for the decision-making process and for issuing and lifting public health advisories when CyanoHABs were detected. The agency received a five-year grant for cyanobacteria surveillance that terminated in 2013. Without the support available through that federally funded program, the incidence of reporting declined after 2013 which likely explained the lack of CyanoHABs reported by the authors (for example, Figure 1). There is little relationship between the CyanoHABs postings by OHA and actions by ODEQ. Nor does the completion of a TMDL by ODEQ necessarily result in any specific remedial action designated by the agency.

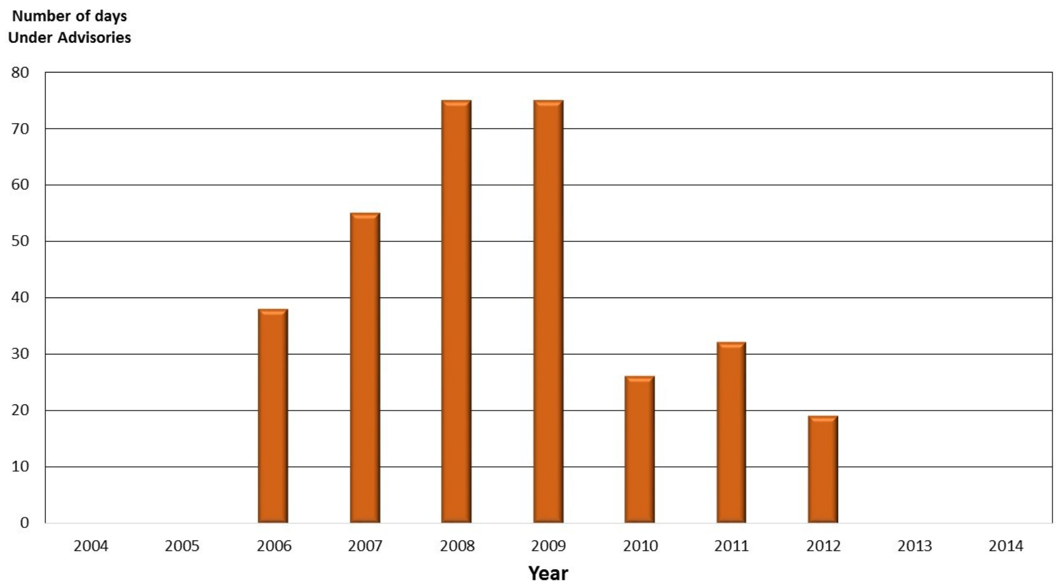

Figure 1. Oregon Department of Environmental Quality's (ODEQ) harmful cyanobacterial bloom (CyanoHAB) advisories for Lemolo Lake, and the number of days under an advisory. Current (post-2014) data has not been posted on the website: (Available online: http://www.oregon.gov/oha/ph/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/index.aspx; accessed on 28 May 2019). Note: There were no CyanoHAB advisory days for Lemolo Lake in 2004, 2005, 2013, and 2014.

6. Discussion

The authors are commended for trying to develop an improved approach for dealing with the current problems of lake management in Oregon. The TMDL approach being used by ODEQ is inadequate to address water quality problems in lakes of the state as exemplified by CyanoHAB reporting. Posting of CyanoHAB occurrences does little to address the causes of the cyanobacteria blooms. If the posting of cyanobacteria blooms were mandatory and applied systematically it would be an initial step towards identifying causes of blooms and seeking solutions. However, posting of CyanoHABs in Oregon is voluntary and applied using multiple criteria. The most critical component lacking in the ODEQ approach is the will to enforce water quality standards and implement the water quality management plans on which the TMDLs are based. Part of the problem is that implementation of best management practices has been removed from the purview of ODEQ and placed in sister agencies such as the Oregon Department of Forestry for management of the forest practices and the Oregon Department of Agriculture for agricultural lands. Both agencies have been slow to implement actions to reduce nutrient loading from watersheds. Another major impediment to correcting cyanobacteria blooms in Oregon lakes is funding. ODEQ has little discretionary budget to apply to lake investigations or water quality improvement. Most of the available funding for improving surface water quality in the state is distributed by the Oregon Watershed Enhancement Board (OWEB). The funding grants processed by the OWEB are generally submitted by watershed councils or other land-use management agencies and require strong local support to receive funding. Therefore, any proposed project that is somewhat controversial is unlikely to receive funding. OWEB has been distributing grants since 1988 but has yet to fund a lake-related project with the primary goal of removing a lake from the TMDL list. Consequently, funds for dealing with water quality problems in Oregon lakes are scarce.

Although I agree in principle with the objectives stated by Hall et al., the example lakes offered are largely unrelated to "resiliency" in their respective watersheds. Two of the three lakes were demonstrated to have water quality problems derived wholly by fish management practices and the third lake was partially impacted by a greatly altered fishery. Cyanobacteria problems derived from internal loading of nutrients derived from high fish biomass are recognized by ODEQ [11] as one of three major factors associated with cyanobacterial problems in the lakes of the state. I suggest that the authors incorporate an "ecosystem functioning" component for in-lake processes in their approach. The relationship between fish biomass and related water quality problems has been well defined (cf. [12]). In this way, processes that affect lakes can be incorporated into a seamless approach that will have the capability of addressing both watershed and in-lake processes.

7. Conclusions

The manuscript by Hall et al. incorrectly ascribes water quality conditions in three Oregon lakes to watershed factors when this is only partially correct in the case of Tenmile Lakes and is totally incorrect in the cases of Lemolo and Diamond Lakes. The dominant factor associated with CyanoHABs in Diamond and Lemolo Lakes is internal cycling of nutrients associated with elevated fish biomass. An altered fishery is also a contributing factor contributing to water quality problems in Tenmile Lakes. Consequently, a methodology described as restoring ecosystem function in the watershed would appear to have no application to these lakes. The authors attempt to relate the incidence of reported CyanoHABs to actions in the watershed when there are no consistent program requirements for reporting cyanobacterial blooms. The incidence of CyanoHABs postings in Oregon is haphazard and consequently is an unreliable metric for water quality conditions in lakes in the state.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/11/12/2482/s1.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Hall, E.S.; Hall, R.K.; Aron, J.L.; Swanson, S.; Philbin, M.J.; Schafer, R.J.; Jones-Lepp, T.; Heggem, D.T.; Lin, J.; Wilson, E.; et al. An ecological function approach to managing harmful cyanobacteria in three Oregon lakes: Beyond water quality advisories and total maximum daily loads (TMDLs). *Water* **2019**, *11*, 1125. [CrossRef] [PubMed]
2. USDA. *Diamond Lake Restoration Project final Environmental Impact Statement, Umpqua National Forest*; USDA: Roseburg, OR, USA, 2004; p. 580.
3. Eilers, J.M.; Truemper, H.A.; Jackson, L.S.; Eilers, B.J.; Loomis, D.W. Eradication of an invasive cyprinid (*Gila bicolor*) to achieve water quality goals in Diamond Lake, Oregon (USA). *Lake Reserv. Manag.* **2011**, *27*, 194–204. [CrossRef]
4. Finlayson, B.J.; Eilers, J.M.; Huchko, H. Fate and behavior of rotenone in Diamond Lake, Oregon, USA following invasive tui chub eradication. *Environ. Toxicol. Chem.* **2014**, *33*, 1650–1655. [CrossRef] [PubMed]
5. Eilers, J.M.; Loomis, D.; St. Amand, A.; Vogel, A.; Jackson, L.; Kann, J.; Eilers, B.; Truemper, H.; Cornett, J.; Sweets, R. Biological effects of repeated fish introductions in a formerly fishless lake: Diamond Lake, Oregon, USA. *Fund. Appl. Limnol. (Arch. Hydrobiol.)* **2007**, *169*, 265–277. [CrossRef]
6. Eilers, J.M.; Gubala, C.P.; Sweets, P.R.; Hanson, D. Effects of fisheries management and lakeshore development on water quality in Diamond Lake, Oregon. *Lake Reserv. Manag.* **2001**, *17*, 29–47. [CrossRef]
7. Eilers, J.M. *Water Quality Monitoring and Cyanobacterial Investigations for Lemolo Lake, Oregon: 2008–2013*; Final report prepared for the Umpqua National Forest, Roseburg, OR, USA and PacifiCorp Energy; PacifiCorp Energy: Portland, OR, USA, 2014; p. 76.
8. Abrams, R.; Reiners, P.E.; Hurtado, J.A.; Mullarkey, W.G.; Bender, R.E.; Rumreich, T.J.; Conver, T.A. *Tenmile Basin fish Management Plan*; Oregon Department of Fish & Wildlife: Salem, OR, USA, 1991; p. 87.
9. Eilers, J.M.; Vache, K.; Moser, K. *Tenmile Lake Nutrient Study, Phase, I*; Report to Tenmile Lake Basin Partnership; Tenmile Lake Basin Partnership: Lakeside, OR, USA, 2000; p. 82.
10. Eilers, J.M.; Vache, K.; Kann, J. *Tenmile Lakes Nutrient Study, Phase II*; Report to Tenmile Lake Basin Partnership; Tenmile Lake Basin Partnership: Lakeside, OR, USA, 2002; p. 136.
11. Schaedel, A. Oregon DEQ Harmful Algal Bloom (HAB) Strategy. June 2011. Available online: https://www.oregon.gov/deq/FilterDocs/habs.pdf (accessed on 14 August 2019).
12. Griffiths, D. The direct contribution of fish to lake phosphorus cycles. *Ecol. Freshw. Fish* **2006**, *15*, 86–95. [CrossRef]