Lake Pend Oreille Littoral Periphyton Community:

An updated Trophic Status Assessment
2003

Final Report

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Tri-State Water Quality Council

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INTRODUCTION

Lake Pend Oreille is a meso-oligotrophic water body, situated in the glacially formed Purcell Trench in the panhandle of northern Idaho. The trophic condition of Pend Oreille Lake is apparently changing faster than previously thought from open-water studies. Assessments of littoral zone eutrophication (Kann and Falter 1989; Falter et.al. 1992) have corroborated reports of nuisance algal growth (periphyton) on docks, boats, and shorelines, indicating increased eutrophication in Pend Oreille Lake and River (outlet arm of the lake). Large macrophyte beds in inshore areas may also be an early indicator of site enrichment (Wagner and Falter 2002). Furthermore, the U. S. Army Corps of Engineers has maintained higher winter water levels in Pend Oreille Lake (drawdown of 2.1 m compared to 35+ years of 3.5 m winter drawdown) since 1998 to enhance kokanee (*Oncorhynchus nerka*) spawning. With lessened freezing and dessication-caused mortality to the periphyton community, the higher winter lake elevation may cause a shift in periphyton distribution and composition as well as earlier heavy growths of periphyton in permanently watered shorelines.

On the other hand, efforts have been in progress to reduce lake productivity in Lake Pend Oreille (LPO). Over the past two decades, an intensive nutrient reduction program has been pursued by the Tri-State Water Quality Council, the Montana Department of Environmental Quality (MDEQ), and the Idaho Department of Environmental Quality (IDEQ), as well as USEPA Regions 8 and 10. The Voluntary Nutrient Reduction Program (VNRP) for the Clark Fork River in Montana has had a role in attenuation, and even reversal of some aspects of upstream nutrient loading to the lake (Land & Water 2004, Tri-State Council 2004). The Council has also moved its nutrient reduction effort downstream to Idaho's Lake Pend Oreille by working with IDEQ and individual wastewater treatment entities to reduce nearshore nutrient and bacterial loading around Lake Pend Oreille. Over the past 20 years, Bayview, Trestle Creek, and Kootenai Bay are examples of local wastewater treatment programs which have maintained and even improved water quality and reduced lake trophic status of Lake Pend Oreille's nearshore (littoral) waters.

Setting

Lake Pend Oreille proper is a 383 km^2 (94,641 acres) lake with mean and maximum depths of 164 m (538 ft) and 357 m (1,171 ft), respectively (USGS 1996). It is Idaho's largest and deepest lake. It is the fifth deepest lake in the United States, after Crater L (OR), Lake Tahoe (CA/NV), Lake Superior (MI/MN), and Chelan L. (WA). Shoreline length of the lake proper (excluding the outlet, Pend Oreille River arm) is approximately 310 km (193 mi.) with a maximum width of 10 km (6 mi.). The lake has a low lake area:volume ratio and an especially low littoral area:lake volume ratio. The resulting very deep water column which traps nutrients in deep layers and low contact with littoral sediments gives the lake a high nutrient absorption capacity and inherent resistance to change in trophic state, at least in pelagic regions.

Lake Pend Oreille is an important recreational and residential water body for the area, supporting moderately dense shoreline development on the northern half of the main lake and the outlet arm as well as seasonally heavy boating and fishing use throughout the lake. Very steep shorelines and government ownership in central and southern portions of the lake have resulted in only isolated, seasonal home development there except for the small settlement of Bayview at the extreme southern end of the lake.

The lake is divided into 4 morphologically distinct basins: 1) the deep relatively poorly flushed southern end (mean hydraulic retention time greater than 10 years (Falter et al. 1992); 2) the deep central basin with its steep shorelines (mean depth >300 m); 3) the shallow northern basin (mean hydraulic retention time less than 1 year (Hoelscher et al. 1993); and 4) the lake's outlet arm on the northwest corner of the lake (essentially a large, low-velocity river and sometimes referred to as the Pend Oreille River even though the reach is upstream of Albeni Falls Dam). Most of the lake's inflow is into the northeast corner of Lake Pend Oreille from the Clark Fork River draining western Montana west of the continental divide. The lake's outlet is the Pend Oreille River exiting from the northwest corner of Lake Pend Oreille *via* the Pend Oreille River outlet arm. Shoreline length of the outlet arm is about 152 km (USGS 1996) with mean and maximum depths of the outlet arm are 7.4 m and 48 m, respectively. The outlet arm is impounded by Albeni Falls Dam on the Washington-Idaho border which controls lake level. . Mean hydraulic retention time for the entire lake is 3.2 years although most of the annual inflow moves westward across the northern basin with only limited recharge to the southern basin (Woods 1993).

Approximately 90% of the surface water inflow and close to 90% of the total nitrogen and phosphorus loads to Lake Pend Oreille enter the northeast corner of the lake *via* the Clark Fork River (Frenzel 1993), draining much of western Montana. Direct tributaries and non-point loading to the lake itself account for most of the balance. Apparent trophic status of the pelagic regions has changed little from the first limnological studies in 1911 though the most recent limnological assessments (Kemmerer et al. 1923; Stross 1953; Platts 1958; Rieman and Falter 1976; Kann and Falter 1989; Woods 1991 and 1993; Falter and Olson, 1992; Rieman and Myers 1992; Chipps 1997; and Clarke 1999).

History of Lake Level Management on Lake Pend Oreille

Maximum summer water level has been controlled at 628.6 m msl from 1952 to the present by the Albeni Falls Dam. This is 3.5m above the historic natural summer lake level. From 1966 to 1994, an annual winter drawdown then lowered lake water levels 3.0 m to 3.7 m down to a winter lake elevation of 625 m mean sea level (msl) and the historic full pool level, from mid-November through April for winter power production and spring flood control. From 1998 to the present, experimental winter drawdowns have sometimes been reduced to 2.1 m (resulting in higher winter lake levels of 626.3 m to 626.7 m msl rather than the 625 m level since 1966). These have occurred in an effort to enhance the kokanee spawning gravel environment and subsequent survival. The IDF&G also conducted these studies to determine whether higher winter water levels would improve over-winter survival of warmwater fishes through the development of additional littoral habitat, especially in the outlet arm where over-winter fish habitat for these fishes had been limited by the earlier 3.5 m winter drawdowns occurring every year (Dupont 1994, Wagner and Falter 2002). The effects of these higher winter water levels on inshore periphyton productivity have not been assessed but are likely to be minimal given the rapid colonization of periphyton on newly submerged rocks. Any summer periphyton effects should be limited to waters deeper than 2.1 m depth.

Littoral Productivity Assessment on Lake Pend Oreille

Pend Oreille Lake has been described as morphometrically oligotrophic with its deep, aerobic water column acting as a nutrient trap to more or less permanently tie up much of the incoming nutrient load (Rieman and Falter 1981; Woods 1993). Although Lake Pend Oreille has typically been classified as a moderately productive oligotrophic lake (Rieman and Falter 1976; Milligan et al. 1983), increasing periphyton (attached benthic algae) growths on boats and shoreline areas have confirmed that the trophic condition of the lake's inshore areas might have been changing faster than open-water (pelagic) areas. In response, the Idaho Department of Health and Welfare, Division of Environmental Quality, initiated near-shore studies in 1986 to supplement earlier limnological and productivity studies which had focused only on pelagic conditions of the lake (Kann and Falter 1989). Concerns were voiced that changes in the lake's trophic status might go unnoticed because high nutrient loading effects might be expected to first appear in shallower, light-rich bays and littoral areas. The nutrient-absorption capacity of the very deep pelagic water column would absorb increasing nutrients over time with no significant apparent effects, thereby masking nutrient increases. The importance of littoral productivity is further emphasized by the fact that the littoral is the focus of much of a lake's biological diversity. Lake use by society is also, of course, most intense in inshore areas. These regions may therefore serve as an early indicator of changing trophic status. Since the littoral zone serves as a buffer between pelagic waters and watershed runoff, information on littoral production and factors affecting that inshore production will be valuable for current and future management scenarios.

That early littoral work on Lake Pend Oreille was followed by a more intensive, better replicated periphyton study which assessed factors controlling littoral production at selected sites around Pend Oreille Lake in 1989 and 1990 (Falter and Olson 1990; Falter et al. 1992). That later work also related attached algae productivity to shoreline development around the lake. Both studies found high attached algae activity in shoreline areas of Lake Pend Oreille, especially in more developed embayments. Periphyton production in these higher productivity areas fell in the eutrophic range of periphyton development and were comparable to littoral values found in productive areas of large, otherwise oligotrophic lakes of the western U.S. (Falter et al, 1992). The Tri-State Water Quality Council has been studying periphyton growth at selected stations around the lake in recent years, but these data have not been used for a systematic comparison with earlier conditions.

One purpose of those earlier studies was to provide a baseline against which future conditions could be compared. In the 13 years since those periphyton production estimates of 1989-90, some inflowing nutrient concentrations have been slightly reduced (Land & Water 2004) and point and non-point controls have been implemented around the lake. Concurrently, however, population pressures, shoreline development, and boating use around the lake have increased. To evaluate the aggregate response, we repeated the 1989-90 periphyton assessment study (Falter et al. 1992) in 2003 at 13 of the16 sites studied in 1989-90 to evaluate littoral productivity for a new baseline and for comparison to 1989-90 findings.

Study Objectives

1. To assess attached benthic algae (periphyton) chlorophyll levels, biomass, production rates, and periphyton community composition in the littoral zone of Lake Pend Oreille;
2. To determine water chemistry parameters, especially nutrient levels adjacent to attached algae sites, in order to provide baseline littoral nutrient data; and
3. To compare 2003 littoral results with 1989-90 littoral results.

This study revisited littoral sites sampled in 1989 and 1990 and reported in *The Nearshore Trophic Status of Pend Oreille Lake, Idaho,* Idaho Division of Environmental Quality, Boise, Idaho (Falter, et.al. 1992). We examined change in apparent composition, biomass, chlorophyll, and growth rates of Lake Pend Oreille periphyton after the 13 year hiatus. This study also compared littoral trophic status of Pend Oreille Lake between these two study periods.

METHODOLOGY

Study Sites

This study assessed littoral nutrient status and periphyton communities at 13 of the 16 Lake Pend Oreille sites studied in 1989-90 (Falter et al 1992). Our goal was to duplicate that earlier study.

One sample site was at the lake outlet on the Pend Oreille River arm, at the Springy Point Recreational Area across the Pend Oreille River from Sandpoint. Remaining sites were chosen to represent the three morphometric regions of Lake Pend Oreille proper. Kootenai Bay, Sunnyside, Bottle Bay, Trestle Creek, and Ellisport Bay represent sites in the northern section of the lake proper. Mid-lake areas are at Warren Island, Camp Bay, Garfield Bay, Talache Landing, and Granite Point. Lakeview and Bayview were southern lake sites, for a total of 13 sample sites on Lake Pend Oreille.

Site Name	Site Code	Lake Area	Character	Development Status
Springy Point	SPR	North	Bay	Developed
Kootenai Bay	KOO	North	Bay	Developed
Sunnyside	SUN	North	Open Lake	Mod. Developed
Bottle Bay	BOT	North	Bay	Developed
Trestle Creek	TRE	North	Open Lake	Developed
Ellisport Bay	ELL	North	Bay	Developed
Warren Island	WAR	Mid	Open Lake	Mod. Developed
Camp Bay	CAM	Mid	Bay	Mod. Developed
Garfield Bay	GAR	Mid	Bay	Developed
Talache Landing	TAL	Mid	Open Lake	Undeveloped
Granite Point	GRA	Mid	Bay	Mod. Developed
Lakeview	LAK	South	Open Lake	Undeveloped
Bayview	BAY	South	Bay	Developed

Metrics Assessed at Each Site

Triplicate, independent measures in the field of: Water temperature, Dissolved oxygen, Electrical conductivity, Carbon dioxide, and Secchi Disk.

These metrics were measured at 0.5 m depth over 1.0 m deep periphyton sampling sites at randomly-placed locations over the 100 m sampling reach at each site during early August, early-September, and early October samplings. Water samples were collected with a 2-liter stainless steel Kemmerer water bottle and transferred into lab-supplied water bottles. Water bottles were stored on ice in the dark until samples were delivered to North Creek Analytical Labs, Spokane, WA late on the sampling day or early the following morning. After each single set of meter readings for water temperature, dissolved oxygen, conductivity, and pH, meters were turned off, then turned back on between replicate measures to ensure 3 independent replicates. YSI Model 55 and SCI meters were used for temperature, dissolved oxygen, and electrical conductivity measurements. Carbon dioxide was not measured and assumed to be zero because pH always exceeded 8.3.

Triplicate, independent laboratory measures of: NH_3, Total Kheldahl nitrogen, NO_3 + NO_2, Total phosphorus, Ortho phosphorus, and Total alkalinity.

All water column measures (except Secchi transparency) were taken at 0.5 m over 1.0 m-deep periphyton sample sites. In the 1989-90 study, none of these physical-chemical measures were triplicated, but triplicate replicates were taken in the current study to permit estimates of sample accuracy, precision, and reliability. Between-site and –year trends can be viewed without replication, but statistical testing of differences against future conditions is not possible. All samples were iced in the field, fixed with H_2SO_4 where appropriate, and delivered to North Creek Analytical, Spokane, WA for analysis according to Standard Methods. Additional QA/QC analyses were run on approximately 20% of additional laboratory-analyzed samples.

Periphyton.

Periphyton community composition (dominant 5 genera), ash-free oven dry biomass (g m^{-2}), monochromatic chlorophyll *a* (mg m^{-2}), pheophytin (mg m^{-2}), and Autotrophic Indices were determined from natural and artificial substrates.

These community assessments were taken from 8 replicated natural substrates collected on the 1.0 m depth contour extending over a 100 m sampling reach at each of the 13 littoral sites, and from 8 artificial substrates (unglazed, red bricks randomly placed at 1.0 m depth in the 100 m sampling reach at each of the 13 littoral sites. Artificial substrates were “aged” by soaking in Lake Pend Oreille water for 2 days, then thoroughly scrubbing the bricks prior to setting them out for the first in-lake incubation.

Field Methodology

Beginning August 4, 2003, we visited and sampled the study sites in 28-day intervals. Each sampling trip extended over approximately 4 days. Second and third samplings began on September 1 and September 29. Site visitations occurred in the same order each time. Artificial substrate incubation periods of 28 days were thus consistent between sites. Sampling was conducted between 0900 and 1800 hours. Biomass and chlorophyll samples had eight true replicates per site per time, the same replication intensity as in the 1989-90 study.

At each visit, 8 replicated natural substrates were collected and scraped to remove the periphyton from an enclosed 101.6 cm^2 (4 in^2) area. Razor blade scraping followed by brushing and rinsing the 4 in^2 area within a steel template removed attached periphyton. Scraped samples were stored in individual sealed vials on ice in the dark, until freezing that evening after the day’s sampling. Vials were individually wrapped and frozen, then shipped on dry ice to the analytical lab for analysis.

Periphyton laboratory analyses were conducted in the Limnology Laboratory of Dr. Vicki Watson, University of Montana. Protocols for Ash-free Oven-dry biomass, monochromatic chlorophyll *a*, and pheophytin were the same as Dr. Watson is using on ongoing Clark Fork River periphyton studies with one exception: pigment extraction on Lake Pend Oreille samples were by acetone leaching instead of alcohol that Dr. Watson is currently using on the Clark Fork studies. Although she has determined no significant pigment differences between acetone and alcohol extraction, acetone leaching was used on the earlier Pend Oreille periphyton work in 1989-90 so we retained that method in the Pend Oreille 2003 study.

Autotrophic indices (AI) were calculated at all sites. Autotrophic Index is equal to the periphyton biomass (AFODW of organic matter in mg/m^2 divided by the concentration of chlorophyll *a* (mg/m^2) in the periphyton. The AI is a means of describing the trophic nature of the periphyton community. Normal AI values from oligotrophic waters typically range from 200 to 500; larger values usually indicate heterotrophic associations or organically enriched water quality.

Qualitative scrapings were taken from three replicate natural substrates and from 3 artificial substrates each site at each sampling time then field-preserved in Lugol's solution. Each sample was quantified by the principal investigator to determine the dominant 4 algae genera (% of total cells and % biovolume) at each site/time.

We calculated means, standard deviation, relative standard deviation (%), standard error, and SE/mean ratios on periphyton chlorophyll, followed by 95% confidence limits around the means to determine significant differences between sites. Statistical comparisons with 1989-90 data was not possible because earlier individual replicate values at sites were not available. Only mean site values were available from that work. We did compare these study results to earlier periphyton studies on Lake Pend Oreille, including the shoreline monitoring conducted by the Tri-State Council in recent years.

Photographs of many site overviews depicting water, shoreline, and substrate conditions are presented in the "Photograph" section later in this report.

RESULTS and DISCUSSION

Littoral Water Physical/Chemistry

Table 1 summarizes littoral zone physical/chemistry at all 13 sites over the 3 late summer sampling times. Data discussed in the text are based on means. Figure 2 shows temperature across sites and between 2003 and 1989-90. North-lake sites tended to be very slightly warmer, with the exception of Springy Point and Bottle Bay, both sites at the foot of long slopes with probable spring seepage lowering temperatures. Upwelling is not a likely reason for cooler water at those sites Bottle Bay was the coolest site (20 C) and Trestle Creek the warmest north-lake site (22 C). South-lake peaks were ~21 C with coolest sites all in bays, Camp, Garfield, and Bayview (~20 C). In 1989-90, north-lake trends were comparable to 2003 (suggesting the same controllers of temperature) but mid-lake sites were >2 C warmer than in 2003 (Figure 2). Bayview was the coolest site then at ~ 19 C with deep upwelling a likely cause. Bay sites were clearly the coolest sites throughout the lake in 2003 (Figure 3).

Water transparency showed a clear pattern of increasing transparency from north-lake sites (7.5 m) to mid- and south-lake sites (9.4 and 9.5 m, respectively). Transparency trends overlapped between 2003 and 1989-90 (Figure 4). Only Kootenai Bay showed much variance from this pattern with 5.1 m mean transparency in 2003 compared to 1.8 m transparency in 1989-90 (Figure 4 and Table 2). In 2003 as in 1989-90, Granite Point and Lakeview had highest mean transparencies (~10 and 9.5 m, respectively). Figure 5 also shows that sites under the influence of mid-lake water, whether surface or upwelling, had highest transparencies. This influence was more important than location in bays or on the open lake (Figure 5). Mid-lake water apparently overrides development influence also (Figure 6).

Trophic Status Indices (TSI) calculated for transparency are depicted in Figure 7. These curves for both time periods show similar site values between the time periods (except for Kootenai Bay where sediment clay deposits produce a turbid water column) with a very slight downward trend (i.e., indicating increasing oligotrophy) from north-lake to the south (Figure 7).

Lake-wide littoral dissolved oxygen averaged 8.6 mg l^{-1} in 2003 compared to 8.3 mg l^{-1} in the slightly warmer 1989-90. Values were generally 8 – 10 mg l^{-1} with no extreme values (Table 1). No categorical trends were obvious, as was also the case in 1989-90. Electrical conductivity averaged 143.6 µs cm^{-2} in 2003, 3.3% above the 1989-90 lake-wide mean. Total alkalinity averaged 77.3 mg l^{-1} throughout the lake, the same as in 1989-90. There were no categorical trends with conductivity or alkalinity across sites.

Ammonia, Nitrate, and Kjeldahl nitrogen all fell out lower than minimum detection limits at most sites in 2003. Lake-wide mean ammonia, nitrate, and Kjeldahl nitrogen were ~0.005, 0.005, and 0.500 mg l^{-1}, respectively, compared to 0.039, 0.017, and 0.065 mg l^{-1} in 1989-90 (Table 1 and 2). Nitrogen trends in 2003 could, therefore, not be discerned. In 1989-90, however, there was a marked decline from north-lake southward through the lake (TN = 0.117 mg l^{-1} decreasing to 0.066 and 0.078 mg l^{-1} southward).

Total phosphorus averaged 6.3 µg l^{-1} in 2003 throughout the lake compared to 6.5 µg l^{-1} in 1989-90 (Tables 1 and 2). The differences were not significant at $p \leq .05$. There were significant differences between sites, however. Springy, Kootenai, and Sunnyside all had significantly lower TP in 2003. Kootenai was ~ 1 µg l^{-1} higher in 2003, while Trestle Creek declined significantly from 1989-90 to 2003 (from 10.3 to 3.9 µg l^{-1}) (Tables 1 and 2). Northeast- and mid-lake sites from Ellisport to Granite Point were consistently higher in 2003 than in 1989-90. Lakeview and Bayview TP remained the same between the two time periods. Figure 8 shows the dramatic downward TP trend in 1989-90 from north to south; This trend was absent in 2003 because of both north-lake reductions and mid-lake TP increases.

Highest TP values in 2003 were at Bottle Bay, Ellisport Bay, and Warren Island. Lowest values were Bayview and Trestle Creek (4.5 and 3.9 µg l^{-1}) (Figure 9). Sunnyside and Talache were also less than 6 µg l^{-1}. There was no apparent relationship of TP with development in 2003, in contrast to 1989-90 (Figure 10).

Trophic Status Indices (Total Phosphorus) ranged from 22 to 33 in 2003 (Figure 11) the upper range of oligotrophy (Holdren et al. 2001). In 2003, there was no discernable trend from north-lake to mid- and south-lake sites. Trestle Creek TSI-TP at 17.4 clearly was the mid-oligotrophy range.

TIN:TIP ratios in the 2003 LPO littoral dataset were very low while TN:TP ratios were very high. Both these phenomena are artifacts of the data handling. When values were below detection limits, as was generally the case with nitrogen species, I assigned a value 1/2 of the mdl, a common practice in data summarization. On average, this practice gives a value that is closer to the true value than either 0 or the stated mdl. But the 2003 detection limit of 1.00 was too high and inflated the estimated TKN. an estimated 5 x reality thereby negating the interpretation of N:P ratios. As a result, the 2003 data do not add further to the TN:TP picture in LPO's littoral. In 1989-90, littoral TN:TP ratios averaged 18.1. At that time, north-lake TN:TP ratios averaged 14, mid-lake 22, and south-lake 22 (Table 2).

2003 Periphyton

Composition: Tables 3 and 4 present periphyton composition frequency and percent biovolume on natural and artificial substrates, respectively, from 2003 littoral periphyton sampling. As shown in the following table, numeric composition of natural substrates was dominated by filamentous bluegreen algae while biovolume was dominated by filamentous green algae.

Natural Substrate Dominant Composition…

Dominant Genera	Numeric Rank	Dominant Genera	Biovolume Rank
Rivularia	**1**	***Mougeotia***	**1**
Oscillatoria	**2**	***Ulothrix***	**2**
Lyngbya	**3**	***Spirogyra***	**3**
Mougeotia	**4**	***Rhizoclonium***	**4**

Numeric composition on artificial substrate was dominated by *Rivularia*, a filamentous bluegreen and 3 filamentous green algae. Biovolume was consistently dominated by filamentous green algae.

Artificial Substrate Dominant Composition…

Dominant Genera	Numeric Rank	Dominant Genera	Biovolume Rank
Rivularia	**1**	***Mougeotia***	**1**
Mougeotia	**2**	***Spirogyra***	**2**
Zygnema	**3**	***Zygnema***	**3**
Spirogyra	**4**	***Ulothrix***	**4**

In 1989-90, natural substrates were totally dominated by the stalked, unicellular diatoms *Cymbella* (up to 70% biovolume) and *Gomphonema*. In fact, these taxa were responsible for the gray-brown "shag carpet" growths of In the mid-to late 1980s as these growths covered shoreline rocks of LPO. These 2 taxa were common in 2003 but never dominant. In 2003, however, filamentous green algae dominated periphyton composition. These filamentous green forms were significant in 1989-90 communities but not overwhelming. Filamentous greens clearly constituted a more balanced community in 2003. In 2003, no taxon exceeded 30% of the natural substrate community biovolume (*Mougeotia*) or 39% of the artificial community biovolume (*Mougeotia*) (Tables 3 and 4). In 2003, *Cymbella* averaged 18% of the natural community biovolume and less than 1% of the artificial community biovolume.

Chlorophyll and Biomass:

Chlorophyll *a* on natural substrates averaged 4.3 mg m^{-2} in 2003 (Table 5). High levels were 8.6 mg m^{-2}at Ellisport and Garfield Bays (Table 5 and Figure 12). Low levels were Warren Island, Granite Point, and Lakeview, all < 2 mg m^{-2}. Except for Garfield Bay, south-lake sites were lower than north-lake sites. Developed sites averaged higher than undeveloped sites which were slightly higher than undeveloped sites (Figure 14). Chlorophyll *a* levels in 2003 were lower at undeveloped sites than developed sites. Levels in 1989-90 were much higher than 2003 at Springy Point, Trestle Creek, Bayview, and Granite Point. Lakeview and Bayview, 2 of the 3 lowest TP sites, had lowest chlorophyll levels.

Bay chlorophyll *a* levels tended higher than open-sites by 2 to 1 in 2003 (5.5 compared to 2.6 mg m^{-2} (Table 2). This differential was significant although not as great as in 1989-90 (Figure 15). Garfield and Ellisport Bays were again high sites. North-lake mean chlorophyll was 5.3 mg m^{-2} south compared to 3.8 mid-lake, and 2.9 mg m^{-2} south-lake (significant at $p \leq .05$) Developed sites averaged 5.9 mg m^{-2} in 2003, compared to 2.8 and 2.1 mg m^{-2} at moderately developed and undeveloped sites, respectively 9 (Table 5).

The 2003 4.3 mg m^{-2} lake-wide natural substrate average compares to 18.3 in August, 1986 and 9.4 mg m^{-2} in 1989-90 (Table 7) (Kann and Falter 1988; Falter and Olson 1992).

Chlorophyll *a* on artificial substrates in 2003 averaged 1.33 mg m^{-2} or 31% of natural substrates (Table 6; Figure 13). High sites were Ellisport Bay and Camp Bay. Low sites were Bottle Bay and Granite Point.

The 2003 1.3 mg m^{-2} lake-wide artificial substrate chlorophyll average compares to 3.7 in August, 1986 and 2.7 mg m^{-2} in 1989-90 (Kann and Falter 1988; Falter and Olson 1992).

Growth rates of periphyton are gaged by accrual rates of chlorophyll on clean substrate. Chlorophyll accrual rates in 2003 averaged 0.048 mg chlorophyll day^{-1} compared to 0.091 mg chlorophyll day^{-1} in 1989-90, and 0.122 mg chlorophyll day^{-1} in 1986 (Table 6). 2003 periphyton chlorophyll growth rates were 53% of 1989-90 rates and 39% of 1986 rates.

The low chlorophyll values measured in 2003 were supported by AFODW, the best measure of dry periphyton biomass. Summer lake-wide mean AFODW on natural substrates was 5.1 g m^{-2} in 2003 compared to 14.3 g m^{-2} in 1986, 53.4 g m^{-2} in 1989, and 21.0 g m^{-2} in 1990.

AFODW *accrual* rates on artificial substrates in 2003 averaged 0.054 g m^{-2} day^{-1} compared to 0.582 g m^{-2} day^{-1} in 1989, 0.417 g m^{-2} day^{-1} in 1990, and 0.032 g m^{-2} day^{-1} in 1986 (Table 7, Falter and Olson 1992, Kann and Falter 1988). Mean chlorophyll accrual rate in 2003 was 39% of 1989-90 mean accrual rate yet AFODW accrual in 2003 was only 11% of 1989-90 accrual. This is explained by the dominance in 1989-90 of stalked diatoms with high non-photosynthetic organic material (polysaccharides) in the periphyton community. Mean 1989-90 AI was 5,584 compared to 2003 mean AI of 1,184 indicating very high proportions of non-photosynthesizing cell structure. Algae composition has a major role in the high between-year variability in periphyton growth. These number are supported by field observations that growths observed in LPO during 2003 field work were clearly very low compared to earlier observations.

Comparison With Other Regional Water Bodies

Periphyton chlorophyll a levels in the Clark Fork River above Missoula (main tributary to LPO) averaged 200 mg m^{-2} in 1987 and declined to 75 mg m^{-2} in 1998-99 as a result of nutrient reduction (Tri-State Water Quality Council 2004). Means had been as high as 450 mg m^{-2} in 1987.

Epilithic algae chlorophyll *a* values in the Rocky Reach Reservoir (mid-Columbia River, Washington state) were relatively high at a 76.7 mg m^{-2} overall mainstem mean. Attached algae chlorophyll *a* ranging from 100 to 150 mg m^{-2} was considered a threshold level for an aesthetic nuisance in Pacific northwestern (U.S.A.) and Swedish streams (Welch et al. 1988). Dodds et al. (1998) placed the boundary between mesotrophy and eutrophy for benthic algal biomass at 70 mg m^{-2} chlorophyll *a*. Epilithic algae chlorophyll *a* concentrations in the eutrophic Lower Snake River (1997-1998 summer mean) were 70 mg m^{-2} (Falter and Kraemer 2000). The natural substrate 2003 chlorophyll *a* level in LPO was low at 4.3 mg m^{-2} and 9.4 mg m^{-2} in 1989-90.

Mean epilithic algae chlorophyll *a* values in the Priest Rapids and Wanapum pools (Mid-Columbia R., Washington state) were closer to LPO levels (18.7 mg m^{-2}) during 1999 (Falter and Kraemer 2000). The range of monthly means (epilithic algae chlorophyll *a* 3.4 – 44.6 mg m^{-2}) observed there brackets the overall mean from the current study (Falter and Kraemer 2000).

Comparatively low chlorophyll *a* levels and organic biomass of LPO 2003 periphyton communities could partially be explained by the lower temperatures at mid- and south lake sites in 2003 (~2 C colder than in 1989-90). Bothwell (1988) observed that nearly 90 % of the annual variation in attached algae grown in shallow experimental British Columbia streams was due to temperature when phosphorus was not limiting. Pelagic nutrient ratios indicate that phosphorus likely is limiting in LPO more often than nitrogen but there are still times of nitrogen limitation. LPO total phosphorus values are in the low oligotrophic range (3.0-17.7 $\mu g l^{-1}$; Wetzel 2001). Total nitrogen and total phosphorus have been estimated to explain 40 % of the variance observed in attached algae biomass in temperate streams across the U.S.A. (Dodds et al. 2002).

Silver Springs, a eutrophic water in Florida had an AFODW accrual rate of 12.3 g m^{-2} d^{-1}, a rate considered very high by Wetzel (2001). Epilithic algae from the Wanapum and Priest Rapids pools (Mid-Columbia River) had mean AFODW levels of 2.7 mg m^{-2} (Falter and Kraemer 2000). Epipelic algae from an oligotrophic lake (Suomunjärvi) in Finland had low production values of 0.0011 g m^{-2} d^{-1} (Wetzel 2001). AFODW accrual rates in the Rocky Reach reservoir on the mid Columbia in Washington state ranged from 0.009 to 0.494 g m^{-2} d^{-1} (Falter and Scofield 2000). AFODW accrual rates in the Entiat River arm of Rocky Reach ranged from 0.013 to 0.236 g m^{-2} d^{-1} and averaged 0.117 g m^{-2} d^{-1} (Falter and Scofield 2000).

CONCLUSIONS

- Water in the Lake Pend Oreille littoral was warmer and more turbid at north-lake sites than at south-lake sites.
- Sites of lowest water temperatures were Bottle Bay, Lakeview, & Bayview.
- Water transparency was least at Kootenai (~5m) & greatest at south-lake sites (~ 10 m).
- TSI-transparency was ~ 30, dropping at south-lake sites, indicating oligo-mesotrophy.
- TSI-transparency in 2003 was comparable to 1989-90.
- Total phosphorus generally declined from north-lake sites to south-lake sites… (7 µg to 4 µg/l).
- There was a very slight decline of total phosphorus from developed to undeveloped sites.
- The 2003 lake-wide total phosphorus mean was 6.3 µg/l.
  The 1989-90 lake-wide total phosphorus mean was 6.6 µg/l.
- TSI- total phosphorus indicated comparable trophic status as TSI-transparency. except at south-lake sites where oligotrophy was indicated.
- As in 1989-90, pH ~8.0 - 8.8 and slightly lower at developed sites.
- Total Alkalinity ~77 mg/l in 2003 and in 1989-90.
- Ammonia was much lower in 2003 than in 1989-90.

- Periphyton chlorophyll on natural substrate was significantly greater at developed sites than at undeveloped sites (6.2 vs. 2.1 mg m^{-2}).
- Lowest chlorophyll levels were at Lakeview and Bayview, on the south end of the lake and 2 of the 3 lowest TP sites.
- In 1989, developed vs. undeveloped sites chlorophyll was 11.7 vs. 6.4 mg m^{-2}.
- Ellisport and Garfield Bays had highest periphyton chlorophyll (8.6 mg m^{-2}).
- Ellisport and Garfield Bays, along with Springy, Kootenai Bay, and Bottle Bay, were significantly greater than all other sites in 2003.
- Lowest chlorophyll sites were Warren Island, Granite Point, Talache, and Lakeview (~2 mg m^{-2}).
- There was less spread between sites in 2003 (although with significant differences) than in 1989-90.

- Natural substrate periphyton ~3x growth on Artificial substrate.
- Periphyton growth rates in LPO were very low in 2003, relative to 1989-90 and 1986 LPO data as well as other lake and river systems.
- The 3 littoral studies in LPO from 1986 – 2003 show that nearshore littoral productivity can change rapidly between years, even where the large, deep lake's pelagic regions show no change over much longer time periods.
- This methodology provides a time-integrated assessment of productivity, comparable over time, between sites, and between water bodies.
- This methodology can identify areas where shorelines or specific watershed areas may need more corrective or stringent management practices and it is rapidly responsive to watershed changes.
- This study approach can aid prioritization of management effort.

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