Limnology of Flathead Lake

Flathead Lake is one of the least culturally-eutrophied lakes in comparison to other large lakes in the Northern Hemisphere (Figure 2). With an area of 480 km^2 and volume of 23.3 km^3, seasonal heating and cooling is slow, and the lake moderates temperature and precipitation patterns around the lake. Surface temperatures range from

The cooling effect of Flathead Lake often produces dramatic storm area effects.

freezing during midwinter on very cold years to a maximum of 22^{o} C in late summer on hot years. Summer stratification is intense, and a thin warm layer lies above most of the volume of the lake that never exceeds 6 – 8^{o} C.

The lake circulates to the bottom all winter in most years, with the entire water column reaching 2^{o} C during very cold winters and sometimes briefly freezing over during calms. Stratification initiates in June and fall turnover typically occurs in late October. The less dense water near shore circulates counterclockwise around the colder water in the main part of the lake owing to the gravitational force of the Earth's rotation. This Coriolis current entrains the inflow from the Flathead and Swan rivers pulling the river water down the west shore. This is very observable during spring freshet (snowmelt) when the river is turbid and warmer than the main lake.

Flathead Lake occasionally freezes during periods of cold, calm weather

The less-dense turbidity plume of river water overflows the denser, colder lake water and moves down the west shore, the dirty brown water appearing in strong contrast to the deep blue waters in the deeper parts of the lake. The Coriolis current persists all year, but is less observable in the fall.

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Most of the year Flathead Lake is crystal clear. Fine sediments from the Flathead River freshet reduce clarity during spring, depending on the intensity of the runoff. Nonetheless, the average depth of visibility (Secchi disk) over the last 25 years was 9 m (30 ft) with values exceeding 20 m (66 ft) often recorded in the fall. Biomass in the lake is uniformly low (1.0 µg/l chlorophyll) year around. Pelagic primary production (Figure 2) is limited by paucity of nitrogen (N) and phosphorus (P) (Spencer and Ellis 1990). As noted above, the river system does not export much of a nutrient load. Surprisingly, during the last two decades as much as 30% of the annual N and P load was fallout from the atmosphere, mainly from fugitive dust from local rural roads, smoke particulates from forest fires and agricultural burning inside and often far outside (usually west) of the Flathead Basin. Nutrient loading from human sources upstream of Flathead Lake has steadily increased over the last three decades and annual loading weakly correlates with increasing primary production.

Organisms < 10 µm in size (microplankton), mostly bacteria and very small green and bluegreen algae, are responsible for 90% of the total primary production (Ellis and Stanford 1982). But diatoms (>400 species and varieties), dinoflagellates and other macro-algae, are always very visual in plankton samples. A vernal bloom of large diatoms occurs in the spring along with the microplankton in response to elevated nutrients, increasing day-length and warming water. By late summer when the lake is thermally stratified, primary production and sinking of plankton to the bottom depletes nutrients in the surface waters and productivity begins to decline.

In 1984 and 1994 lakewide blooms of macro-algae, *Anabaena flos aqua* and *Botryococcus*, were documented prior to fall turnover. These algae had never before been observed at the midlake site in Flathead Lake during 100 years of lake studies. The algae collected in wind rows on the shoreline and clearly represented sudden and alarming declines in water quality. *Anabaena* and *Botryococcus* were common in late-summer samples in other years but did not reach bloom proportions. These outbreaks of macro-algae likely are linked to increasing nutrient inputs from human activities. Similar patterns of lake eutrophication of course have been documented many times worldwide, and the Federal Clean Water Act requires states to reduce nutrient loading in impaired lakes.

Efforts to reduce nutrient pollution from human sources have been initiated in the Flathead Basin in response to the apparent decline in water quality associated with steadily increasing primary productivity and the observed *Anabaena* blooms (Figure 2; Stanford et al. 1997). However, the mechanisms and interactions that cause these rare events in Flathead Lake and other large lakes are not clear. Certainly primary productivity is at or approaching a threshold in which complex interactions favor production of macro- over micro-plankton.

Mysis Relicta

The highest annual rate of primary production occurred in 1988, corresponding with onset of the trophic shift caused by the establishment of *Mysis relicta* in the lake (Figure 2). Mysid numbers peaked in 1986-7, and the food web shift from pelagic to benthic (bottom-dwelling) orientation in the higher trophic levels of the lake food web was firmly in place for the first time in 1988.

This suggests a “top down” stimulus on phytoplankton production: the mysids had virtually eliminated the cladoceran grazers by 1988, which may have altered microbial nutrient cycling to favor microconsumers that cycle biomass and nutrients rapidly, thereby increasing primary production rates. On the other hand, atmospheric fallout of nutrients was very high in the summer of 1988 from extensive forest fires and smoke plumes in the Flathead Basin and in adjacent areas. Similar levels of smoke occurred during the fire years of 1998 and 2000 and primary production levels were again above the trend line. *Anabaena* did not bloom in 1988, 1998 or 2000. Conclusions about mechanisms controlling the productivity in Flathead Lake remain elusive in spite of the long term record. However, this does change the obvious conclusion that *Mysis relicta* is the strong interactor in the lake food web, influencing trophic structure at multiple levels and far beyond expectations based on its biomass alone.

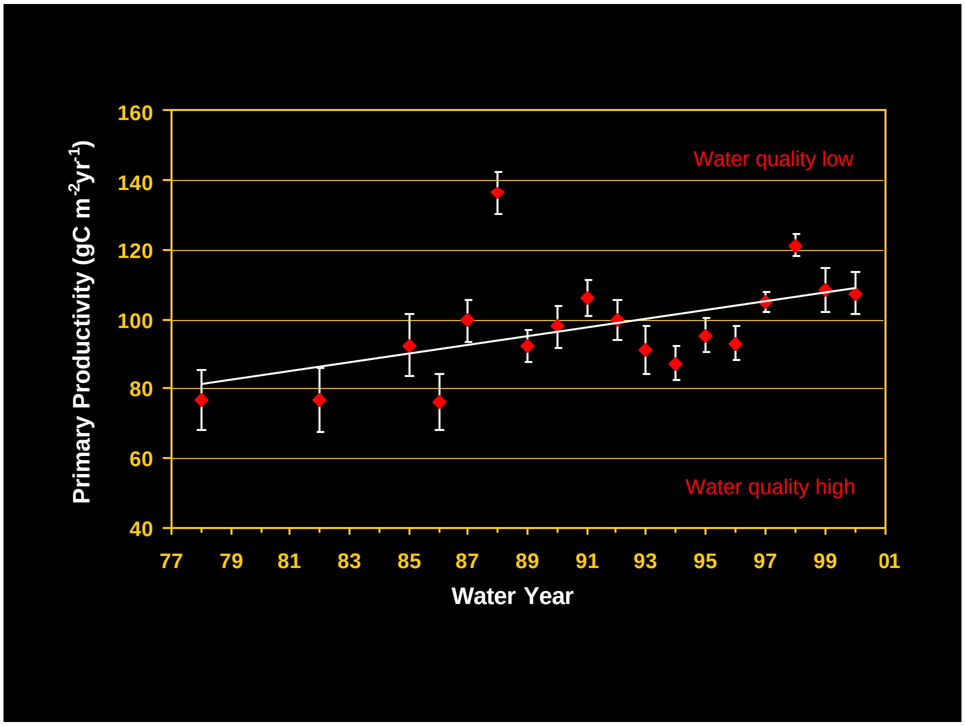

Figure 2. Water Quality in Flathead Lake Measured as Annual Rate of Primary Production, 1977-2001. Primary production was measured with ^{14}C uptake in 4 hr. midday incubations using methods of Pregnall (1991). Data are means (± 1 standard deviation) of 12-15 measures throughout the year. The trend line is significant ($P<0.01$): water quality is deteriorating as primary production increases.

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