

Efficient function of the base of plankton food webs: Concepts for management of healthy freshwater ecosystems

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Abstract

The base of the food web consists to two major pathways for transport of metabolic energy and critical nutrients, such as P, to higher trophic levels: the grazing food chain (GFC) and the microbial food web (MFW). Our research shows these pathways differ in efficiency and response to trophic conditions. Under eutrophic conditions ineffective grazing on phytoplankton can lead to inefficient transfer of energy through the MFW. Under hyperoligotrophic conditions nutrient use for growth may be diminished. Ecosystem managers need to consider the relative flux between the GFC and the MFW in management of ecosystem health.

Introduction

Ecosystems are the ultimate units of nature through which the efficiency of energy and nutrients is regulated (Odum, 1960). Not all ecosystems function with the same efficiency. One characteristic of “healthy” ecosystems is efficient transport of metabolically available energy and critical nutrients through the base of the food web. One of the major characteristics of “unhealthy” plankton ecosystems is inefficient transfer of primary production from phytoplankton to zooplankton; another characteristic is inefficient use of nutrients for growth of plankton within this food web. Based on our recent research, here we address these concepts of efficiency of energy transfer and nutrient use in ecosystems of differing trophic states, ranging from hyperoligotrophic to hypereutrophic, as occur in the Great Himalayas. Our aim is to provide Great Himalayan plankton biologists and ecosystem ecologists with these concepts to consider in developing strategies for management of the health of these aquatic resources.

Plankton Food Webs in Communities of Differing Trophic Status

Investigations over the past 20 years have shown the significance of the microbial food web in freshwater and marine ecosystems (Figure 1). For many years investigations of plankton food webs focused solely on phytoplankton primary production that resulted in algal growth and the grazing of phytoplankton by zooplankton via the grazing food chain (GFC). Photosynthate released as dissolved organic matter, bacterial production and bacterivory were considered to be insignificant until the seminal investigations by Sherr and her colleagues demonstrated that the microbial food web (MFW) could transport significant fractions of carbon to zooplankton (Sherr and Sherr, 1988). Our subsequent studies in the North American Great Lakes showed that the relative amount of C transported through each pathway differed seasonally and was dependent on the trophic status of the community (Hwang and Heath, 1997, 1999; Heath et al., 2003).

The GFC and MFW differ in the efficiency of energy transfer from phytoplankton to zooplankton. Energy transfer through the MFW is less efficient because of the increased average number of trophic links (Pomeroy and Wiebe, 1988). Conditions that lead to a relative decrease of material transfer through the GFC lead to diminished efficiency, according to this view. Differences in growth rates of various taxa and rates at which those taxa can be grazed affect food web efficiency, the fraction of photosynthetic energy passed to successive trophic levels per unit time (Slobodkin, 1959). As we have discussed elsewhere (Heath et al., 2003), availability of growth-limiting nutrients (e.g. P) can lead to alterations of phytoplankton community composition that in turn alter the efficiency of grazing by zooplankton. Some phytoplankton taxa efficiently use low concentrations of available-P, being at a competitive advantage when limiting nutrients are low. Such “oligotrophic” species or “affinity strategists” (Sommer, 1989) succeed because of their superior affinity for critical nutrients. Generally these taxa are readily edible and can be efficiently grazed by zooplankton. Other algal taxa utilize nutrient enrichment for rapid growth, displacing species with slower growth rates. These “growth strategist” species have a high growth rate despite have relatively low affinity for limiting nutrients (Sommer, 1989). Many of the cyanobacteria that

persisted in the eutrophic Great Lakes, notably Lake Erie, were either poorly grazed, displaced other species as “growth strategists,” or both (Makarewicz, 1993). Eutrophication can now be viewed as an “unhealthy” condition of an ecosystem caused by nutrient enrichment that leads to altered phytoplankton community composition and ultimately to food web inefficiency due to diminished C-transfer through the GFC.

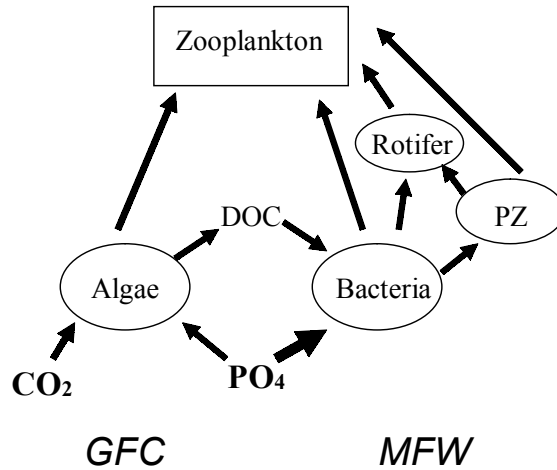


Figure 1. Schematic of contemporary view of the structure of the base of the planktonic food web in the Great Lakes. GFC, grazing food chain; MFW, microbial food web. DOC, labile dissolved organic carbon; PZ, protists (HNAN and ciliates); Zooplankton include cladocerans and copepods.

Food webs transfer critical nutrients, such as phosphorus, as well as carbon and energy to higher trophic levels. Recent investigations indicate that the apportionment of phosphate to phytoplankton and to bacterioplankton is a function of the trophic status of the community (Figure 2). In eutrophic communities, phytoplankton dominate phosphate uptake; in oligotrophic communities, phosphate is taken up primarily by bacterioplankton. The reasons for this altered apportionment between phytoplankton and bacterioplankton are unclear. A very recent study suggests that the relative availability of substrate for bacterial growth modifies the affinity of bacteria for phosphate (Gao, 2002). When carbon resources for bacterioplankton growth is high (e.g. in eutrophic communities), phosphate uptake by bacteria is relatively slow and bacterial P composition is only slightly higher than that of P-limited phytoplankton. By contrast, when carbon resources are low, phosphate uptake by bacterioplankton is rapid and the P-content per cell becomes very high (Gao, 2002). Our recent research in oligotrophic Lake Superior indicates that the nutrient use efficiency (NUE) of P by bacteria for growth is very low in the least productive regions of the lake (Heath and Munawar, personal observations). These findings taken together indicate that in highly oligotrophic habitats nutrients may be sequestered and not lead to an efficient production of bacteria. Under such conditions mobilization of P through the MFW may be critical for maintenance of transport of P to higher trophic levels.

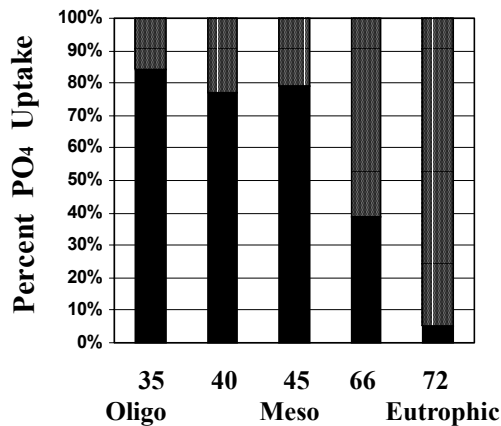


Figure 2. Stacked bar graph showing percent of phosphate taken up per minute by bacterioplankton (dark) and phytoplankton (light) in different regions of the Great Lakes, reported by trophic status of community at time of sampling. Horizontal axis shows Trophic State Index (TSI) determined from chlorophyll content per L (Carlson 1977).

Implication for management of freshwater ecosystems in the Great Himalayas

Because of the rapid eutrophication of many of the aquatic resources in the Great Himalayas, ecosystem management needs to focus on the effects of alteration of trophic status, especially as it relates to ecosystem health. Our current work and that of others suggests ecosystem managers need to focus on the function of the base of the food web, as it relates to the balance between fluxes through the GFC and the MFW. Inefficiencies in growth and transport of materials and nutrients can occur at both extremes of the trophic axis. Under eutrophic conditions, growth of phytoplankton that are ineffectively grazed can lead to inefficient energy transfers through the MFW. Under hyperoligotrophic conditions the use of nutrients for organism growth may be constrained.

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