Phytoplankton ecology and aquatic ecosystems: mechanisms and management

8.1 Introduction

The purpose of this chapter is to assess the role of phytoplankton in the pelagic ecosystems and other aquatic habitats. The earliest suppositions to the effect that phytoplankton is the ‘grass’ of aquatic food chains and that the production of the ultimate beneficiaries (fish, birds and mammals) is linked to primary productivity are reviewed in the context of carbon dynamics and energy flow. The outcome has a bearing upon the long-standing problem of phytoplankton overabundance and related quality issues in enriched systems, its alleged role in detracting from ecosystem health and the approaches to its control. The chapter begins with an overview of the energetics and flow of primary product through pelagic ecosystems, especially seeking a reappraisal of the relationship between biomass and production.

8.2 Material transfers and energy flow in pelagic systems

One of the essential components of ecological systems is the network of consumers that exploit the investment of primary producers in reduced organic carbon compounds. Some of these are reinvested in consumer biomass but much of the food intake is oxidised for the controlled release of the stored energy in support of activities (foraging, flight, reproduction) that contribute to the survival and genomic preservation of the consumer species in question. In thermodynamic terms, the food web serves to dissipate as heat that part of the solar energy flux that was photosynthetically incorporated into chemical bonds (see p. 355). 8.2.1 Fate of primary product in the open pelagic Based upon this simple premise, the performance of pelagic systems can be quantified in units of energy dissipated (or of organic carbon reduced and re-oxidised) per unit area per unit time, by a biomass also quantified in terms of its organic carbon content (or its energetic equivalent) and partitioned according to function (primary producer, herbivore, carnivore, decomposer). For the open sea and the open water of large, deep lakes, the scales of the input components and the rates at which they are (or can be) processed have been established in the preceding chapters. In Section 3.5.1, the attainable net productive yield of pelagic photosynthesis, across a wide range of fertilities, was suggested to be typically in the range 500–600 mg C m−2 d−1 (the thickness of the photic layer compensates for differences in concentration of photosynthetic organisms). Extrapolated annual aggregates (in the order of 100–200 gCm−2 a−1) agree well with the generalised findings of oceanographers for the open ocean, as well as those deduced from satellite-based remote sensing (Section 3.5.2). On the other hand, they clearly underestimate the cumulative production in many small to medium lakes, as well as in what were referred to as ‘oceanic hotspots’. Even so, from an investment of PAR of some 40 kJ (g Corg) −1, the synthesis of even this amount of photosynthate (4–8 MJ PAR m−2 a−1) is acknowledged to be just a tiny fraction of the annual harvestable PAR flux (less than 1% of the solar energy flux) (Section 3.5.3). So far as its role in supplying the conventional energy requirements of the dependent food chain is concerned, biological turnover represents only a small proportion of the dissipative flux. At the same time, it is evident from the modest year-to-year changes in the photosynthetic biomass in the open sea that there is little net accumulation of primary-producer mass or carbon. Taking chlorophyll levels of 20–40 mg chla m−2 to be typical for the trophogenic zone of the tropical ocean, phytoplankton standing crops remain steadfastly constrained, probably in the range 1–5 g cell C m−2 (0.04–0.20 MJ m−2). Phytoplankton concentrations in oligotrophic, highlatitude lakes may be lower still (in some cases, ≤0.5gCm−2) (Section 3.5.1). These obdurately low levels of producer biomass (B), like the production (P) it yields, are deemed indicative of the ‘unproductive’ nature of the nutrient-poor systems. Yet, as pointed out (Section 3.5.1), a P/B yield of not less than 100 g C from not more than 5 g cell carbon represents an extremely high biomass-specific productivity! Low areal biomass and low cumulated production are traditionally attributed to resource poverty. Without a simultaneously available fund of other elements, including nitrogen, phosphorus, iron and other traces especially, new biomass and new cells cannot be built and recruited. In the ocean and, to a large extent, in deep, oligotrophic lakes, very little of the photosynthetically fixed carbon is deployed in new algal biomass: as much as 97% may be vented from the active cells (Reynolds et al., 1985). Some of this is respired to carbon dioxide but a proportion is released as DOC (see Sections 3.2.3, 3.5.4). This is processed by bacteria, whose own respiration may account for 20–50% of the carbon thus assimilated (Legendre and Rivkin, 2000b; Bidanda and Cotner, 2002). In smaller oligotrophic lakes, a significant proportion of the original primary product may be exported to the sediments (but generally ≤100 g C m−2 a−1) (Jonasson, ´ 1978), to be processed there by benthic food webs. By subtraction, the potential yield of primary product available to pelagic microzooplankton or to herbivorous mesozooplankton can scarcely exceed 80% of the annual primary production (say, 30–150 g C m−2 a−1) (Callieri et al., 2002). Even these consumer pools turn over much of the carbon that they harvest in a matter of days; the proportion that is available to larger metazoans (10–25%; now rather less than 40 g C m−2 a−1,