Introduction To Fresh Water Microbiology

1. Introduction

It is now generally accepted that life originated between 3.5 and 4 billion years ago in the aquatic environment, initially as self-replicating molecules. The subsequent evolution of prokaryotes, followed by eukaryotes, led to the existence of microorganisms which are highly adapted to aquatic systems. Life in the aquatic environment (freshwater and marine) has numerous potential advantages over terrestrial existence (Alberts et al., 1962). These include physical support (buoyancy), accessibility of three-dimensional space, passive movement by water currents, dispersal of motile gametes in a liquid medium, minimal loss of water (freshwater systems), lower extremes of temperature and solar radiation, and ready availability of soluble organic and inorganic nutrients. Potential disadvantages of aquatic environments include osmotic differences between the organism and the surrounding aquatic medium (leading to endosmosis or exosmosis) and a high degree of physical disturbance in many aquatic systems. In undisturbed aquatic systems such as lakes, photosynthetic organisms have to maintain their position at the top of the water column for light availability (Abraham et al., 1997).

Water covers seven-tenths of the Earth's surface and occupies an estimated total volume of 1.38 ×109 km3 (Table 1). Most of this water occurs between continents, where it is present as oceans (96.1 per cent of global water) plus a major part of the atmospheric water. The remaining 3.9 per cent of water (Table 1.1 shaded boxes), present within continental boundaries (including polar ice-caps), occurs mainly as polar ice and groundwater. The latter is present as freely exchangeable (i.e., not chemically-bound) water in subterranean regions such as aquifers at varying depths within the Earth's crust. Non-polar surface freshwaters, including soil water, lakes, rivers and streams occupy approximately 0.0013 per cent of the global water, or 0.37 per cent of water occurring within continental boundaries. The volume of saline lakewater approximately equals that of freshwater lakes. The largest uncertainty is the estimation of groundwater volume. Annual inputs by precipitation are estimated at 5:2 ×108 km3, with a resulting flow from continental (freshwater) systems to oceans of about 38 600 km3 (Horne and Goldman 1994).

Microorganisms may be defined as those organisms that are not readily visible to the naked eye, requiring a microscope for detailed observation. These biotas have a size range (maximum linear dimension) up to 200 mm, and vary from viruses, through bacteria and archea, to micro-algae, fungi and protozoa. Higher plants, macro-algae, invertebrates and vertebrates do not fall in this category and are not considered in detail, except where they relate to microbial activities. These include photosynthetic competition between higher plants and micro-algae and the role of zooplankton as grazers of algae and bacteria (Alexopoulos et al., 1996).

Freshwater environments are considered to include all those sites where freshwater occurs as the main external medium, either in the liquid or frozen state. Although frozen aquatic environments have long been thought of as microbiological deserts, recent studies have shown this not to be the case. The Antarctic sub-continent, for example, is now known to be rich in microorganisms (Vincent, 1988), with protozoa, fungi, bacteria, and microalgae often locally abundant and interacting to form highly structured communities. New microorganisms, including

freeze-tolerant phototrophs and heterotrophs, have been discovered and include a number of endemic organisms. New biotic environments have also been discovered within this apparently hostile environment – which includes extensive snow fields, tidal lakes, ice-shelf pools, rock crystal pools, hypersaline soils, fellfield microhabitats, and glacial melt-water streams (Allan 1995). Many of these polar environments are saline, and the aquatic microbiology of these regions is considered here mainly in terms of freshwater snow fields in relation to extreme aquatic environments and the cryophilic adaptations of micro-algae. This book deals with aquatic systems where water is present in the liquid state for at least part of the year. In most situations (temperate lakes, rivers, and wetlands) water is frozen for only a limited time, but in polar regions the reverse is true. Some regions of the ice-caps are permanently frozen, but other areas have occasional or periodic melting. In many snow fields, the short-term presence of water in the liquid state during the annual melt results in a burst of metabolic activity and is important for the limited growth and dispersal of snow microorganisms and for the completion of microbial life cycles (Allison et al., 2000).

Within inland waters, aquatic sites show a gradation from water with a low ionic content (freshwater) to environments with a high ionic content (saline) – typically dominated by sodium and chloride ions. Saline waters include estuaries (Sections 2.12 and 2.13), saline lakes (Section 2.15.3) and extensive regions of the polar ice-caps (Vincent, 1988). The high ionic concentrations of these sites can also be recorded in terms of high electrical conductivity (specific conductance) and high osmotic potential. The physiological demands of saline and freshwater conditions are so different that aquatic organisms are normally adapted to one set of conditions but not the other, so they occur in either saline or freshwater conditions. The importance of salinity in determining the species composition of the aquatic microbial community was demonstrated in a recent survey of Australian saline lakes (Gell and Gasse, 1990), where distinct assemblages of diatoms were present in low salinity (oligosaline) and high salinity (hypersaline) waters. Some diatom species, however, were present over the whole range of saline conditions, indicating the ability of some microorganisms to be completely independent of salt concentration and ionic ratios. Long-term adaptability to different saline conditions is also indicated by the ability of some organisms to migrate from saltwater to freshwater sites, and establish themselves in their new conditions. This appears to be the case for various littoral red algae of freshwater lakes (Section 3.1.3), which were originally derived from marine environments (Lin and Blum, 1977). Differences between freshwater/saltwater environments and their microbial communities are particularly significant in global terms (Chapter 2), where the dominance of saline conditions is clear in terms of area coverage, total biomass, and overall contribution to carbon cycling.

Freshwater environments show wide variations in terms of their physical and chemical characteristics, and the influence these parameters have on the microbial communities they contain. An important distinction needs to be made at this stage – between lentic and lotic systems. Freshwater environments can be grouped into standing waters (lentic systems – including ponds, lakes, marshes and other enclosed water bodies) and flowing waters (lotic systems – rivers, estuaries and canals). The distinction between lentic and lotic systems is not absolute, and almost all water bodies have some element of through-flow. Key differences between lentic and lotic systems in terms of carbon availability and food webs are considered in (Alongi, 1991).

With the exception of viruses (which constitute a distinct group of non-free living organisms), the most fundamental element of taxonomic diversity within the freshwater environment lies in the

separation of biota into three major domains – the Bacteria, Archaea, and Eukarya. Organisms within these domains can be distinguished in terms of a number of key fine-structural, biochemical, and physiological characteristics (Purves et al., 1997) (Table 2).

Size is an important parameter for all freshwater microorganisms, affecting their location within the freshwater environment, their biological activities, and their removal by predators. The importance of size and shape in planktonic algae is considered in some detail in Section 3.4, and includes aspects such as predation by other organisms, sinking rates, and potential growth rates. In the case of free-floating (planktonic) organisms, the maximum linear dimension ranges from 200 mm, with separation of the biota into five major size categories (Table 3), from femtoplankton to macroplankton (Battarbee 1999)

Freshwater microorganisms may be divided according to their feeding activity (trophic status) into two major groups:

Autotrophs – synthesize their complex carbon compounds from external CO2. Most also obtain their supplies of nutrients (e.g., nitrogen and phosphorus) from simple inorganic compounds. These phototrophic microorganisms include microalgae and photosynthetic bacteria and are the main creators of biomass (primary producers) in many freshwater ecosystems. This is not always the case, however, since photosynthetic microorganisms are outcompeted by larger algae and macrophytes in some aquatic systems, particularly wetland communities (Begon et al. 1996).

Heterotrophs – use complex organic compounds as a source of carbon. By far the majority of freshwater microorganisms (most bacteria, protozoa, fungi) are heterotrophic. Even within the algae, various groups have evolved the capacity for heterotrophic nutrition and many organisms currently included in the protozoon assemblage have probably evolved from photosynthetic ancestors (Bell et al. 1974).

Heterotrophic nutrition involves a wide diversity of activities (Table 4) with microorganisms obtaining their organic material in three main ways saprotrophy, predation, and in association with living organisms.

This book explores the diversity, interactions and activities of microbes (microorganisms) within freshwater environments. These form an important part of the biosphere, which also includes oceans, terrestrial environments and the earth’s atmosphere.

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