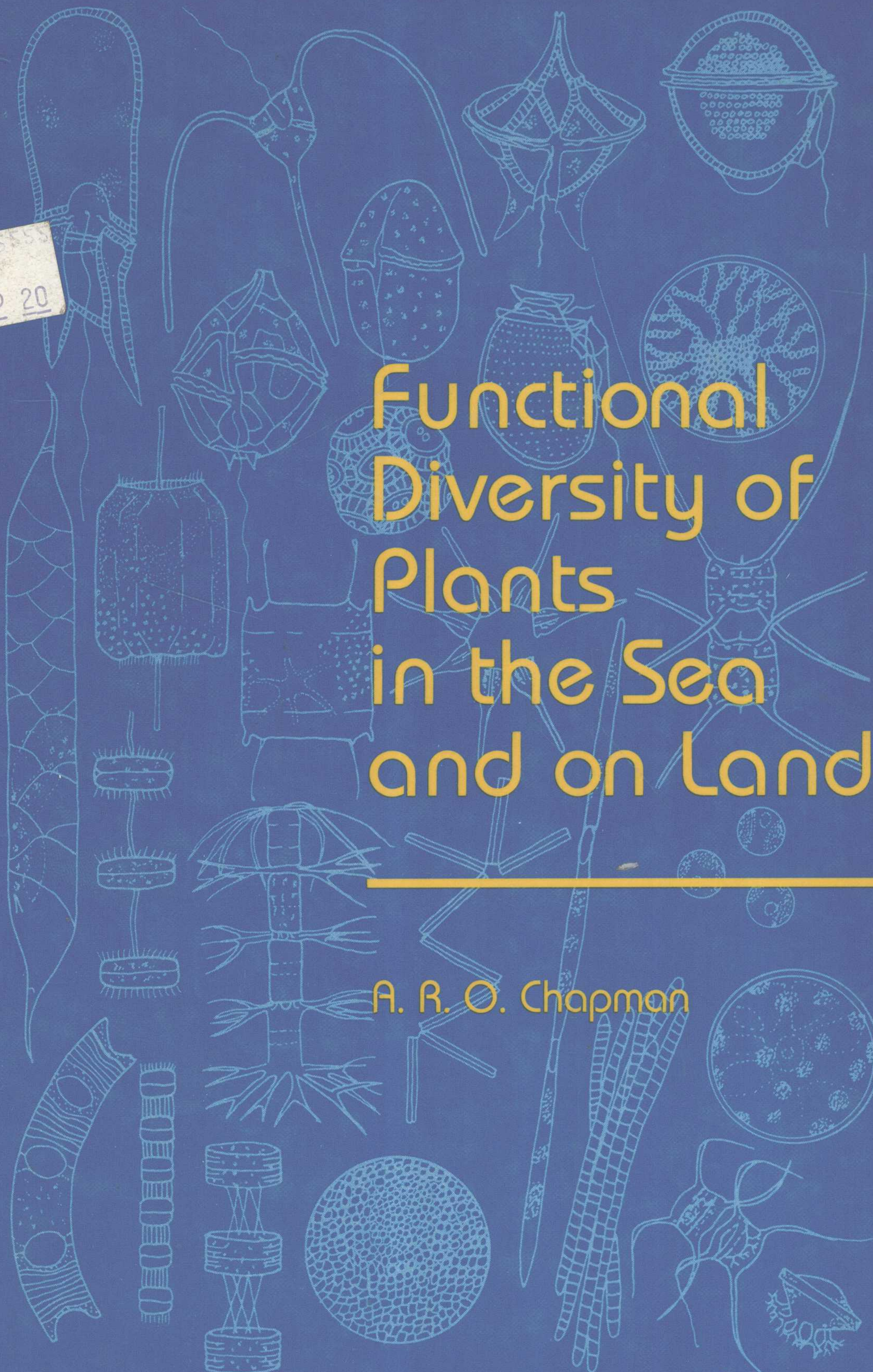
Functional Diversity of Plants in the Sea and on Land

A. R. O. Chapman



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To Jan, Paul, Lin and Hanah

Preface

This book is intended to introduce first and second year university students to major groups of plants within the context of the environments that they live in. Most of the plants that live in the sea are algae, and most of the plants on land are vascular plants. It is, therefore, possible to present systematic diversity of algae with reference to the aquatic mode of life. Similarly, vascular plant diversity can be presented in terms of the problems of life on land. My experience over more than ten years of teaching a biological diversity course is that students find this approach inherently appealing. The students learn about plant diversity, but they also learn about how plants function in diverse habitats.

I am especially grateful to Pat Evans-Lindley who prepared all of the illustrations. I would also like to thank all of the authors and publishers who have allowed me to use their illustrations. Pat Harding provided an in-depth critique of the manuscript which made me explain some of my ideas much more clearly. I am very grateful to her. The major part of the manuscript was prepared during a sabbatical year that I spent at the University of Bristol. I would like to thank Professor Frank Round for making arrangements for my stay and also for his permission to use the illustration shown in Figure 6 and on the cover of this book.

A.R.O. Chapman
Dalhousie University, Canada
September 1985

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1

Introduction

Botanical diversity encompasses all photosynthetic plants and all of the fungi. The diversity within and among these groups is overwhelming and difficult to systematize taxonomically or phylogenetically. However, it is necessary to review the taxonomic and historical relationships of plant groups before embarking on a consideration of the functional relationships between plants and their habitats (which is what this book is about). In this introduction a short and elementary treatment of plant systematics will be presented from a phylogenetic perspective.

Plant Taxa

The diversity of living organisms is classified in a taxonomic hierarchy. The base point of this hierarchy is of the myriad **species** in the world. Species mean different things to different people, but the **morphological species** concept seems most appropriate in the present context. Members of a morphological species are similar to one another in most respects and have correlated morphological characteristics which are not shared with members of other species. Groups of species are agglomerated in the next highest category known as the **genus** (Fig. 1). Genera are grouped into **families**, families into **orders**,

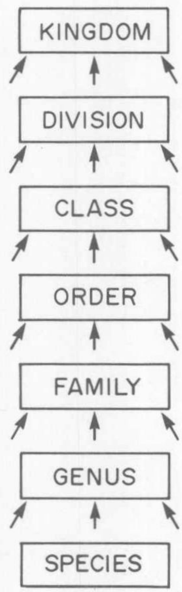


Figure 1. Hierarchy of taxonomic categories. Taxa at lower levels are grouped into higher level taxa.

orders into **divisions**, and divisions into **kingdoms**.

There is considerable controversy over the way in which kingdoms of living organisms are to be separated from one another. Plants and Animals are often regarded as separate kingdoms, but although antelopes and daffodils are clearly easy to differentiate, the separation of single celled plants from single celled animals is well nigh impossible. In fact, diversity in the biological world falls clearly into two kingdoms known as the **Prokaryota** and the **Eukaryota**. The differences between these two groups are tabulated in Table 1. In Table 2 the divisions of living organisms considered in this book are partitioned between the Prokaryota and the Eukaryota. There is no confusion. Each division is either prokaryotic or eukaryotic and thus we recognize two kingoms of living organisms.

Where do we find botanical diversity among the two kingdoms? This is not an easy question to answer. Botany has traditionally comprised a study of the groups listed in Table 2 (bacteria other than Cyanobacteria are not included here, but are considered in some botanical texts). In colloquial terminology these groups are known as **blue-green algae**, **algae**, **bryophytes**, **vascular plants** and **fungi**. The blue-green algae and the algae are mostly aquatic; bryophytes, vascular plants and fungi are mostly terrestrial. The aquatic and terrestrial modes of life comprise the theme of this treatment of botanical diversity. However, the historical development of the modes of life must first be considered.

Table 1. Some important differences between cell types in the Kingdoms Prokaryota and Eukaryota.

Characteristic	*Prokaryota*	*Eukaryota*
Nuclear membrane	Absent	Present
Chromosomes	Composed of nucleic acid only	Composed of nucleic acid and protein
Cytoplasmic organelles	Absent	Present
Flagella	Lack 9+2 fibril organization	Have 9+2 fibril organization
Cell wall	Contains peptidoglycans as supporting polymers*	Does not contain peptidoglycans

* Peptidoglycans are built up of N-substituted glucosamines and muramic acid (3-0 lactylglucosamine). The archaebacteria have a pseudo-peptidoglycan constructed on the same general plan, but with different chemical components.

Table 2. Distribution of divisions (dealt with in text) among two kingdoms.

Kingdom	*Division*	*Common Name*
Prokaryota	Cyanobacteria	Blue-green algae
Eukaryota	Rhodophyta	Red algae
	Chlorophyta	Green algae
	Euglenophyta	Euglenids
	Chrysophyta	Golden algae
	Pyrrophyta	Dinoflagellates
	Cryptophyta	Cryptomonads
	Phaeophyta	Brown algae
	Tracheophyta	Vascular plants
	Bryophyta	Mosses, liverworts, hornworts
	Chytridiomycota	Water molds, chytrids
	Oomycota	Water molds, downy mildews
	Zygomycota	Pin molds
	Ascomycota	Sac fungi
	Basidiomycota	Club fungi
	Deuteromycota	Imperfect fungi

History of Plant Life

The earth is about 4.5 billion years old. When it first condensed there was probably no atmosphere, and no life. The first atmospheric gases came from volcanic activity and probably consisted of CH_4, NH_3, H_2 and H_2O vapor. Free oxygen was almost certainly absent from this primitive atmosphere.

The gases in the atmosphere of the primeval world would be noxious to most modern life forms. Furthermore, for most of its history the earth was bombarded with lethal ultra-violet radiation (UV) from the sun. Life on earth is now protected from this radiation by the layer of ozone gas in the high atmosphere. The ozone is derived from the oxygen produced in the lower atmosphere by plant photosynthesis. The development of an oxygen rich atmosphere has been a very slow process. Because of UV radiation early life was confined to aquatic habitats where water screens out the harmful rays. Initially the radiation was harmful to perhaps 10 meters depth. Presumably life was then restricted to deeper water. Since water rapidly attenuates light in the visible range (as well as UV), photosynthetic production must also have been restricted by inadequate illumination. Because the rate of photosynthesis determines the release of oxygen into the atmosphere, the development of an oxidizing atmosphere must therefore have been very slow. Oxygen in the atmosphere reached 1% of present levels about 600-650 million years ago (MYA). It took perhaps a billion years of photosynthesis for this level to be achieved.

Who were the first photosynthesizers and who were their ancestors? There is some consensus in the view that the first living organisms on earth were not photosynthetic or autotrophic in any respect. Most probably they were fermenting heterotrophs. All of these terms need explanation, and it will be necessary now to embark on a discussion of the ways in which organisms obtain energy .

Organisms obtain some or all of their energy by the oxidation of an organic compound:

$$\underset{\text{Organic hydrogen donor}}{AH_2} + \underset{\text{Hydrogen acceptor}}{B} \rightarrow A + BH_2 + \text{Energy}$$

If the molecule B (hydrogen acceptor) is oxygen, then the process is aerobic respiration, and BH_2 is water. If molecule B is organic, then the process is fermentation and BH_2 is organic:

$$AH_2 \bullet B \rightarrow A + BH_2 + \text{Energy}$$

Here B is part of the substrate.

In fermentation there is no requirement for free oxygen in order to obtain energy from organic substrates. Fermentation is thought to have been the nutritional mode of the first living organisms on earth.

Fermenting anaerobic bacteria are common today. Two common groups are called **lactic acid bacteria** and **clostridia** and these are thought to be very primitive in their life styles. Lactic acid bacteria sour milk and ripen cheeses. Clostridia belong to the genus *Clostridium* and are found in soil, dust, water and animal guts wherever oxygen is absent and an organic substrate is present.

Apart from fermentation, anaerobic respiration can occur when the hydrogen acceptor is an oxidized inorganic substance like sulfate:

$$4AH_2 + H_2SO_4 \rightarrow 4A + H_2S + 4H_2O + \text{Energy}$$

This is called sulfate respiration. *Desulfovibrio* is a modern sulfate respirer (Fig. 2) that lives in oxygen free sediments containing sulfate and organic matter. The organisms ferment organic compounds to acetic acid and they convert sulfate (SO_4^{2-}) into sulfide (S^{2-}) which may be released as hydrogen sulfide (H_2S) or dimethyl sulfide (H_3CSCH_3).

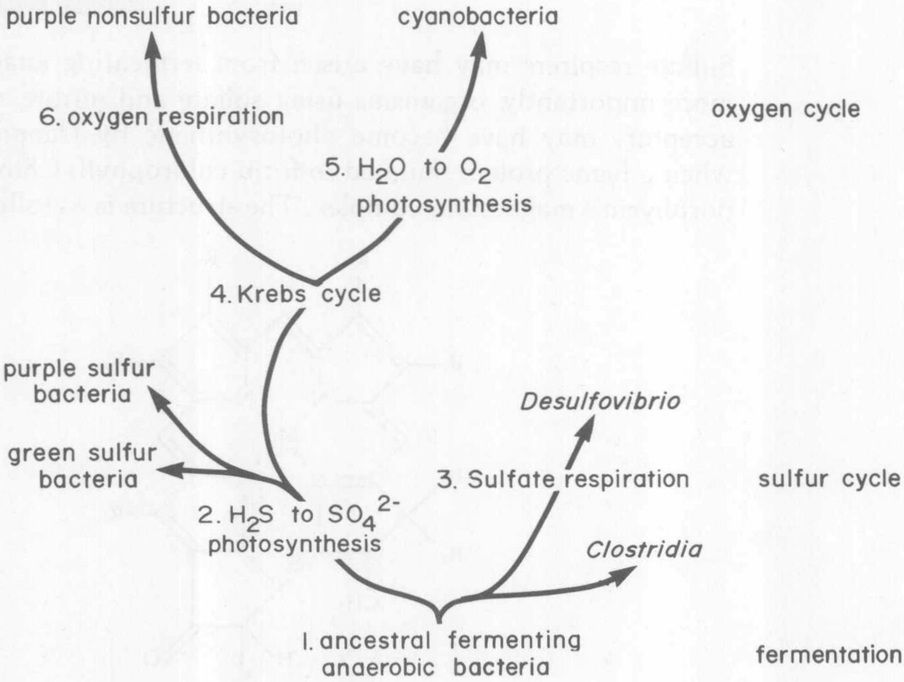
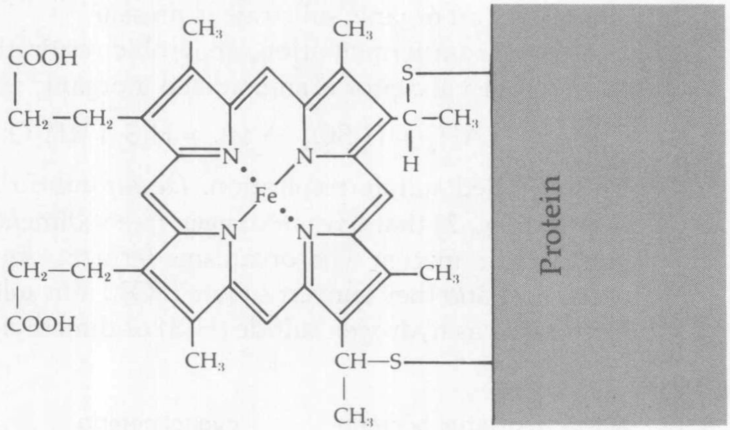


Figure 2. A hypothetical evolutionary diversification of prokaryotes leading to Cyanobacteria and the development of an oxygen-rich atmosphere (modified after Tappan, 1980).

When the organic compound is oxidized in sulfate respiration, hydrogen atoms (or electrons) are transferred to sulfate via a chain of chemicals called the **electron transport chain**. The **cytochromes** (proteins) are major components of the electron transport chain. The electron carrying capacity is conferred by a ring shaped compound called a porphyrin. At the center of a cytochrome porphyrin ring is an iron atom and the porphyrin-metal complex is called a **heme** group. The structure is as follows:



Sulfate respirers may have arisen from fermenting anaerobes, and more importantly, organisms using sulfate and nitrate as hydrogen acceptors may have become photosynthetic by trapping photons when a heme protein mutated to form chlorophyll. Chlorophyll is a porphyrin – magnesium complex. The structure is as follows: