Color Plate 1. Guppies in a 20-gal long tank with potted plants

Color Plate 2. Bluespotted Sunfish in a 45-gal tank

Color Plate 3. Juvenile cichlids in a 20-gal long tank

Color Plate 4. 1-gal Bowls with pet shrimp

COLOR PLATES

Cover Picture.   Rainbowfish in a 55-gal Tank (2008).

The two red fish in the center are male *Glossolepis incisus*. Others are Yellow and Neon Rainbows (*Melanotaenia* sp.). I kept Rainbowfish from 1988-2017. Perfect fish for large planted tanks. Mycobacteriosis ("Fish TB") infected all 3 of my Rainbowfish tanks in 2004. Several fish died. Eventually, I got the outbreak under control without tearing down the tanks. (Details are in article on my website: www.dianawalstad.com.)

Color Plate 1.   Guppies in a 20-gal Tank with Portable Plants.

I breed guppies in 9 tanks like this. No filters. I catch guppies easily because all plants are portable. Thin gravel scattering on the bottom. Depicted guppies are from a single batch. The variety of male color patterns shows off the unique genetic trait of *Poecilia reticulata*—'color polymorphism'. I select my guppies for longevity as well as beauty.

Color Plate 2. Bluespotted Sunfish in a 45-gal Tank.

The Bluespotted Sunfish (*Enneacanthus gloriosus*) is a beautiful native fish found in lakes from New York to Florida. They are hardy, non-aggressive and get no bigger than 2-3 inches. Ideally, they should get live food. They will not eat flake food. However, I maintained mine for several years with freeze-dried bloodworms, cichlid pellets and fresh earthworms.

Color Plate 3.   Juvenile Cichlids in a 20-gal Tank.

For many years, I raised and sold Tanganyikan cichlids. They are smaller and less aggressive than Lake Malawi cichlids. I obtained juvenile fish from cichlid breeders from the American Cichlid Association. At times, I kept over a hundred juveniles in this tank with a small 'hang-on-the-back' filter. Intense lighting and rapid emergent plant growth from the depicted Water Sprite kept the fish healthy with minimal maintenance.

Color Plate 4.   1-gal Bowls with Pet Shrimp.

I set up the bowls using a little potting soil covered with sand. Light is from a window (shaded light) and an ordinary desk lamp. Plant growth was amazing. Shrimp are RCS (red cherry shrimp) of the genus *Neocaridinia davidi*. The bowls were fun for about 8 months, but they were not big enough to *maintain* a shrimp population. I now keep my shrimp either with the guppies or temporarily by themselves in a designated tank. Amazingly, the shrimp in some guppy tanks have managed to survive and reproduce.

Ecology of the Planted Aquarium

A Practical Manual and Scientific Treatise for the Home Aquarist

by

Diana L. Walstad

Echinodorus Publishing, Chapel Hill, North Carolina (U.S.A.)

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This book is dedicated to my parents

Paul and Marge Walstad

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To Robert G. Wetzel, Biology Professor and a leading authority on freshwater ecology, I owe special thanks. First, his testbook *Limnology* prompted my initial interest in the scientific aspects of aquatic ecology. Second, his enthusiastic review (‘Bravo!) of *Ecology of the Planted Aquarium* convinced me that my nascent book was worth the trouble.

Around 2020, I became one of the moderators for the El Natural forum at Aquatic Plant Central. From thoughtful interchange on this forum, I could process old and new information for this fourth edition.

TABLE OF CONTENTS

Chapter I

INTRODUCTION

Ecology of the Planted Aquarium should appeal to hobbyists who wish to set up a successful planted aquarium plus understand more about its ecology.

Most aquarium plant books simply list/describe plant species or show how to set up a planted aquarium. This book is unique. For it explains the underlying mechanisms of the aquarium ecosystem– how plants affect the ecosystem and how the ecosystem affects the plants. It shows that plants are not just decorative but can also be quite useful in keeping fish healthy and reducing aquarium maintenance.

In addition, my book presents extensive scientific information that hobbyists have never seen. This information often contradicts prevailing ideas in the aquarium hobby– ideas that are often based on antiquated books and hobbyist observations rather than experimental data.

Aquatic plants studied include those from ponds, lakes, streams, wetlands and oceans. Many of the plants, such as *Vallisneria*, Hornwort, and *Cabomba*, are familiar to aquarium hobbyists. Others such as pondweeds and marine seagrasses may not be. However, aquatic plants, whether from the ocean or a stream, have many of the same basic needs and physiology. Thus, concepts drawn from scientific studies of 'aquatic plants' can often be applied to 'aquarium plants'. In my opinion, any distinction between the two is obscured by the great diversity of species used by both aquarium hobbyists and aquatic botanists.

Although the book is directed towards aquarium keeping, many of the concepts apply equally to ornamental pond keeping. On occasion, I have noted where there might be differences.

In order to make the scientific studies more relevant to hobbyists, I have interspersed the text with typical or actual 'Questions and Answers' (Q & A). These Q & A, plus practical discussions at the end of chapters, show how the scientific information applies to hobbyists' aquaria. The last chapter describes how to keep ‘low-tech’ tanks that are inexpensive and simple to maintain.

Chapters are grouped around three goals of explaining: (1) how plants affect the aquarium ecosystem; (2) what factors affect plants; and (3) how hobbyists can use this information to maintain a successful home aquarium.

A. Chapters of the Book

1. Introduction

The introduction briefly describes the purpose and organization of the book and the characteristics of a 'healthy' aquarium.

2. Plants as Water Purifiers

In Chapter II the toxicity of water contaminants– heavy metals, ammonia, and nitrite– to fish and plants are discussed. I show how plants counteract those toxins to purify the water and protect fish.

3. Bacteria

In Chapter III, I show how bacteria relate to all living organisms in terms of generating energy and cellular structure from various chemicals. I classify different bacterial processes in terms of their positive and negative impacts on the aquarium. I explain how bacterial processes both create and destroy aquarium toxins. Topics include the generation of beneficial humic substances, CO_2 and other plant nutrients by the decomposition of organic matter by ordinary (i.e., heterotrophic) bacteria.

4. Sources of Plant Nutrients

Chapter IV compares three potential sources of plant nutrients in aquariums– fishfood, a soil substrate, and tapwater. I use a model aquarium to quantify the theoretical contribution from each source. I show that fishfood contains all elements that plants require and that soil abundantly supplies most micronutrients. I compare hardwater versus softwater as a nutrient source. In the final analysis, I discuss which of the three sources has the best potential to provide each nutrient.

5. Carbon

Carbon is briefly described in terms of water buffering, and then more thoroughly as a plant nutrient. I show that the element carbon often limits the growth of submerged plants both in nature and in aquariums. I describe multiple strategies that aquatic plants use to obtain carbon, including bicarbonate use and air CO_2 uptake via heterophylly. I show beginners how to best deal with the transition of many newly purchased plants from their emergent form to their submersed form. Finally, I explain how to provide plants with more carbon without resorting to artificial CO_2 injection.

6. Plant Nutrition and Ecology

Chapter VI describes some fundamentals of aquatic plant nutrition (e.g., substrate versus water uptake of nutrients). I present evidence showing that most aquatic plants vastly prefer ammonium over nitrates as their nitrogen source. I explain how biological filtration (i.e., nitrification) actually competes with plants for ammonium. I discuss the importance of water hardness in providing major nutrients calcium, magnesium, etc to aquatic plants.

7. Substrates

Many hobbyists do not have soil-containing substrates in their aquariums, which may explain why they have trouble growing plants. For a better understanding of this critical topic, Chapter VII discusses the general nature of soils before delving into the inevitable soil chaos that occurs after submerging a terrestrial soil. I show why soil is essential for good plant growth, particularly in a low-tech tank, and worth the trouble. Chapter VII describes how to set up a planted tank with a soil underlayer.

8. The Aerial Advantage

In Chapter VIII, I discuss the major problems that submerged aquatic plants face and why emergent plants, the mainstay of natural wetlands, are so much more productive. I describe vital gas exchange within the plant and the techniques that all aquatic plants use to keep their roots safely oxygenated. I explain how O_2 release from roots into the surrounding soil increases microbial activity that both benefits plants and the soil environment. For the hobbyist, I emphasize the importance of aerial growth and how to promote it in the aquarium.

9. Algae Control

Chapter IX focuses on a major problem that many aquarium hobbyists have– tanks overrun by algae. I evaluate common methods that hobbyists use to counteract algal problems, some of which often only make matters worse. I then discuss the inevitable competition between plants and algae for light and nutrients. I briefly touch on the possibility of allelopathic interactions. I discuss strategies that hobbyists can use to tip the balance towards plants, with algae control rather than eradication being the goal.

10. Practical Aquarium Setup and Maintenance

In my opinion, planted aquariums are much easier to maintain than those without plants. Plants control alga growth and keep the tank healthy for fish without the drudgery of frequent water changes, gravel cleaning, etc. I describe how I set up my planted tanks, which are both inexpensive and easily maintained. I also present my own notions as to the fish, lighting, plants, aeration, etc that are best suited for a low-tech tank.

B. Is the 'Balanced Aquarium' Dead?

Older aquarium books advocated the “Balanced Aquarium” in which plants and fish balance each other’s needs. Intrinsic to the idea of the balanced aquarium was the healthy growth of plants, but many hobbyists found planted aquariums difficult to maintain. Poor plant growth and unrestricted algal growth were persistent problems. Thus, over the years, the idea of having a natural, planted aquarium lost its original appeal [1]. Many hobbyists gave up on the idea and dispensed with live plants altogether.

Furthermore, many hobbyists have little interest in plants, being primarily interested in keeping and breeding fish. Often recommended methods for fish-only tanks are not conducive to growing plants. For example, optimal fishkeeping without plants often depends on enhanced biological filtration and frequent tank cleaning. Beginning hobbyists that try to adapt these methods for planted tanks often fail.

Beginning around the 1980s various experts from Europe developed sophisticated techniques (i.e., CO_2 injection and substrate heating cables) that allowed virtually any aquarium plant species to flourish [2]. Planted tanks were no longer restricted to a few hardy, undemanding plant species. Building on these advanced techniques, the Japanese aquarist Amano ushered in the age of aquascaping in 1994 with the publication of *Nature Aquarium World* [3]. The planted aquarium became an artistic expression of a three-dimensional landscape with live fish. I call both these versions of planted aquaria ‘High-tech’. Tanks require CO_2 injection, frequent fertilizer dosing, etc. The end result– healthy fish and vibrant plant growth– resemble a natural, balanced aquarium, but the means to obtain it are unnatural, expensive, and labor intensive.[1]

With this book, I would like to resurrect the old idea of the ‘balanced aquarium’ but with a much greater understanding of how it works.

C. Characteristics of a Natural, 'Low-tech' Aquarium

My 'Low-tech' aquariums have no artificial CO_2 injection. They are low maintenance for a reason. (Too much tank cleaning removes natural sources of scarce CO_2.) One essential component is a substrate containing ordinary soil. There is a much greater reliance on plants for purifying the water than filters. It differs from what hobbyists see in stores–tanks with clean gravel substrates, heavy filtration and crystal-clear water.

The Low-tech approach takes advantage of natural processes. For example, bacteria and fish– not artificial CO_2 injection– provide CO_2 to plants. Plants and soil bacteria– not biofilters and water changes– remove ammonia and protect fish. Fishfood and soil– not micronutrient fertilizers– provide trace elements to plants. Tanks are easier (and much less expensive) to set up and maintain than High-tech tanks.

Here are some specific characteristics of Low-tech aquariums:

1. pH Remains Stable

One criterion to gauge an aquarium's success is a stable pH; acid-generating reactions in the tank are matched by base-generating reactions. Tanks with water that become acidic over time are unbalanced, usually due to

[1]High-tech aquariums sponsored by the two European manufacturers Dupla and Dennerle included metal halide lighting, CO_2 injection with automatic pH regulation, trickle filters, daily plant fertilization, and substrate heating cables [2,4]. They are quite expensive. For example, two hobbyists [5] reported in 1993 that the set-up for their 90 gal 'Super Show Tank' based on the Dupla system cost more than $3,500.

excessive nitrification in a biofilter. **Table I-1** lists the biological and physical processes that affect pH in aquariums.

Table I-1. Processes that Affect Aquarium pH.

Acid-Generating Processes (pH goes down)	**Base-Generating Processes** (pH goes up)
Nitrification by biofilter bacteria	Photosynthesis by plants and algae
Fish respiration	Denitrification by bacteria
Bacterial metabolism (e.g. decomposition of organic matter)	Water and air mixing (loss of CO_2)

Nitrification in biofilters generates acidity. The greater the fish load and filtration, the greater the pH decline. In 'fish only' tanks, a gradually declining pH cannot be avoided, requiring water changes and/or the addition of pH buffering chemicals. However, in planted tanks photosynthesis is a powerful mechanism for increasing pH.

The only tanks I have had "go acid" were those from years ago that had mediocre plant growth and heavy biological filtration. Now, my planted tanks show a neutral or slightly alkaline pH. To obtain a stable pH, I shifted my focus away from filters towards encouraging better plant growth.

2. Low Maintenance

The hallmark of a Low-tech aquarium is that it is easy to maintain. Aquariums seem to do well without hobbyist adjustment, maintenance, and cleaning. For example, my own aquariums often go for six months or more without water changes. Fish get fed well, so that plants do not need to be fertilized with chemicals. Routine maintenance consists of replacing evaporated water and pruning excess plant growth. Tanks that are unbalanced need constant cleaning and adjustment.

3. Fish Behavior is Normal

Normal fish behavior is a good indicator of a healthy, balanced ecosystem. In tanks, this means that vigorous fish like Rainbows and cichlids should be thrashing over food at meals. Male guppies should be actively courting female guppies.

Abnormal fish behavior (not eating) or an inability to reproduce often indicates contaminated water. For example, fish will stop eating when water nitrite levels get too high.

Q. My Black Moor has been sick for the last two weeks. It seems to be losing its scales and has white stringy stuff on its body. I keep him in a small 2 gal tank with no plants, but it has a small box filter and I do 10-20% water changes every week. Should I try antibiotics?

A. Antibiotics might cure the immediate infection, but they won't help much to counteract an underlying problem (e.g., a toxic substrate, contaminated water, etc). I would either clean the tank or transfer the fish to a planted tank—if you have one.

Results: I put the Moor into my planted tank. Within 2 weeks his problems cleared up.

Analysis: I am delighted to hear that your Moor has regained his health. Plants are much more than decoration or hiding places for fry. They protect fish by improving water quality (e.g., counteracting ammonia toxicity, removing excess CO_2, oxygenating the water, etc).

D. How Plants Benefit Aquariums

Below are the benefits that plants– given a chance– play in the aquarium:

1. *Protect fish by removing ammonia.* Plants readily take up ammonia, which is toxic, even though there may be adequate nitrogen in the substrate or plentiful nitrates in the water. This is because aquatic plants have a decided and overriding preference for ammonia (*See* pp. 103-106).

2. *Protect fish by removing metals from the water.* Heavy metals may or may not directly kill fish, but they can inhibit reproduction and suppress normal appetite, such that the fish eventually succumb to disease. Plants rapidly take up large quantities of 'heavy metals' like lead, cadmium, copper, and zinc from the water. Also, plant decomposition produces DOC and humic substances, which bind and detoxify those metals (*See* pp. 18-20).

3. *Control algae.* Good plant growth inhibits algae, whether in nature or aquariums. Plants compete with algae for light and nutrients. Although algae have many advantages, plants have a few key ones that hobbyists can exploit. Both rooted and emergent aquatic plants have access to nutrients that are unavailable to algae. For example, rooted plants readily remove iron from the water, thereby depriving algae of an important nutrient (*See* pp. 177-180).

4. Stabilize the pH. Photosynthesis is a major acid-consuming reaction. Thus, vigorous plant growth keeps the water from becoming acidic over time.

5. Increase biological activity within the tank. Most microorganisms (bacteria, protozoa, fungi, etc) do not live freely in the water but live attached to surfaces. Plants provide attachment sites, food, and O_2 for numerous microorganisms (*See* p. 158), many of which recycle nutrients and stabilize the aquarium ecosystem.

6. Oxygenate the water. Plants give off plentiful oxygen via photosynthesis (*See* p. 193), far more than they consume by their respiration. Even at night when plants are not photosynthesizing, they may remove little or no O_2 from the water.[2]

7. Remove CO_2 *from the water.* Excess CO_2– as much as oxygen depletion– can cause respiratory distress in fish (fish gasping at the surface [8]). Normally, plants would be expected to remove all CO_2 from the water during daylight hours.

8. Prevent substrates from becoming toxic. A substrate that supports good plant growth doesn't become toxic, and it rarely (if ever) needs to be vacuumed. Plant roots keep it healthy (*See* pp. 137-138).

E. Promoting Plant Growth in the Aquarium

Many hobbyists would like to keep plants in their aquariums, but repeated failures or the expense of the High-tech systems has discouraged them. Thus, the rest of the book addresses the factors that affect plant growth in the aquarium. They are:

1. Nutrients. Tapwater, a soil substrate, and fishfood can easily provide all nutrients required by aquarium plants (*See* Ch IV 'Sources of Plant Nutrients').

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[2]During photosynthesis, O_2 accumulates rapidly within the aquatic plant's large gas storage chambers (lacunae). Plants prefer this internal O_2 for respiration compared to water O_2, which is harder to take up due to the incredibly slow diffusion of gases in water. Thus, night-time plant respiration has little effect on the O_2 concentration of the surrounding water [6,7].

2. Algae Control. Plants cannot grow if algae smother them or take all their CO_2. Practical strategies, both short-term and long-term, for controlling algae are discussed in Ch IX 'Algae Control'.

3. Fertile substrates. Theoretically, aquatic plants can get all nutrients from the water, so what's wrong with a gravel substrate? However, in practice, gravel substrates do not work very well. Plants need a fertile substrate to grow well and compete with algae. (*See* Ch VII 'Substrates'.)

4. Bacteria. Bacteria break down organic matter into CO_2 and other nutrients that plants can use. The complex and vital role that bacteria play in aquarium ecology are described not just in Ch III ('Bacteria') but throughout the book.

5. Aerial (Emergent) Growth. Plants that access air for light and CO_2 grow much better than fully submerged plants (*See* Ch VIII 'Aerial Advantage'). By using floating plants and encouraging emergent growth of amphibious plants, hobbyists can increase total plant growth in the aquarium.

6. Light. Light is essential for plants, but light intensity that is either too much or too little can encourage algae. It helps to understand the shade nature of submerged plants and the sunny nature of emergent plants. In Ch X (pp. 190-195), I discuss lighting in general and propose strategies for using light effectively.

7. Plant Species. Different plant species respond differently to lighting, substrate, water chemistry, and CO_2. Since behavior is somewhat unpredictable, new tanks set up with a wide variety of species have a better chance to do well. That said, in Ch X (pp. 195-197), I discuss plant selection and list plants that have been easy growers for me over the years.

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