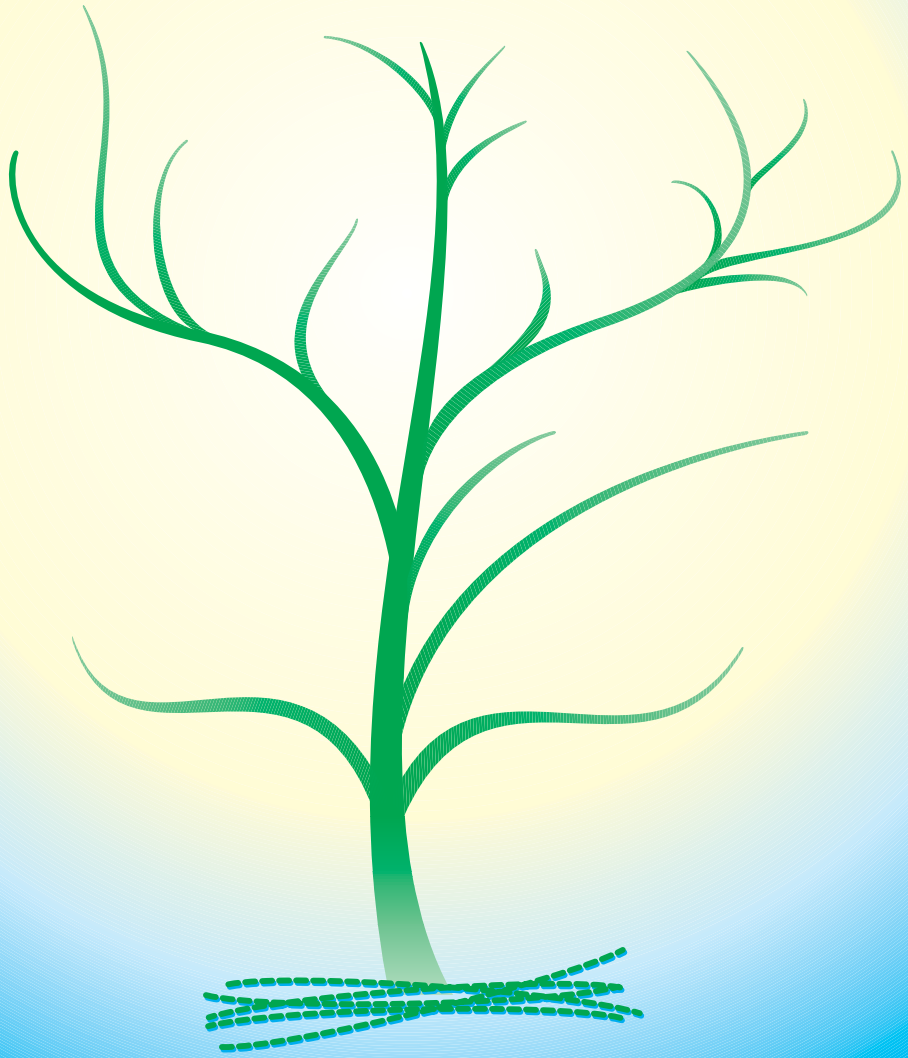
Edible Microalgae

A Review of the Health Research

Jeffrey J. Bruno, Ph.D.



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Edible Microalgae: A Review of the Health Research (Version 3.0).

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Medical disclaimer: This is a reference guide to microalgae research. It is intended to be solely educational and informational. It is not intended to be a guide to medical treatment or to substitute for any expert medical treatment.

"As above, so below."

In gratitude to one of Earth's most ancient species, the microalgae, that humanity may come to recognize the precious and interdependent nature of all sentient life. In loving thanks to Linda and Tylia, whose smiles keep me going. And in acknowledgement of my dear parents, that you may better understand why I have spent these many years devoted to working, studying, and eating little blue-green tablets. Special thanks go to Anne Stanford, Jean Adamson, Ph.D., and many other friends for editorial guidance. Finally, to John Ray and the Kollmans, who first introduced me to microalgae—to a beautiful blue-green world. Thank you.

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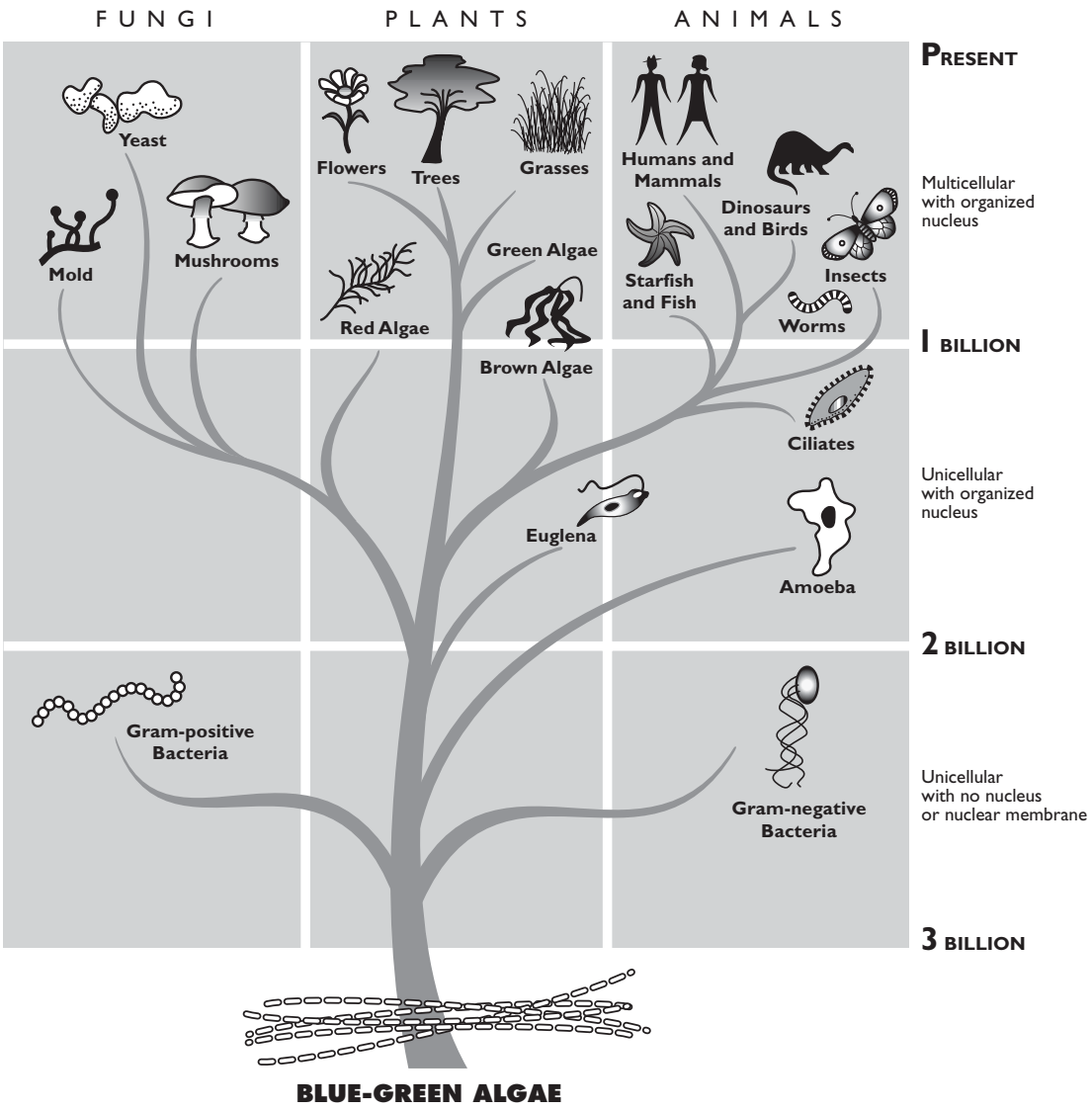

From *Algae to the Rescue!,* by Karl Abrams, Logan House Publications, 1996. Adapted with permission of author.

Introduction

It is risky business to write a review of this sort aimed at a very diverse audience. For the interested layperson, there may be too many references to scientific research, technical nomenclature, and complex biological mechanisms. For the serious scientist, there are likely to be too many questionable studies, conjectures, and hypotheses that require further research. For the medical doctor, the health benefits may appear too diverse to be credible, bringing to mind terms like "panacea" or "cure-all." In short, there is something in these pages to bother anybody!

Then why did I write this research review? My goal is to convey a sense of the enormity of the possibilities that microalgae can offer to humanity. The sheer number of studies cited—most published in peer-reviewed journals—ought to at least pique anyone's interest in the benefits of microalgae. Even among the many scientists who have studied microalgae, few appear to have taken the time to view the big picture. It is important that the full range of this information reach a broader audience.

My goals are to present the evidence in a way that (1) allows ordinary people to begin to grasp the remarkable amount of health-related evidence that supports the use of microalgae as a dietary supplement; (2) provides the kinds of scientific evidence that are required for scientists and doctors to understand the potential therapeutic uses of microalgae and thereby encourages further research and clinical application; and (3) spurs global thinking regarding microalgae's practical role in helping to solve a number of urgent problems facing humanity as we enter the 21st century.

Eleven areas of research are reviewed, ranging from algae's ability to enhance brain function to issues of safety. A few common components found within microalgae, such as antioxidants, essential fatty acids, and amino acids, are significant across a range of topics.

Perhaps one of the reasons microalgal nutrients appear to work in so many areas is that nature is conservative in its designs. Solutions that work are retained. For example, chlorophyll, an "invention" that allows organisms to capture sunlight and produce sugars, first appeared in blue-green microalgae billions of years ago and is now used as a survival strategy by all higher plants. Animals in turn depend upon chlorophyll-containing plants, directly or indirectly, as a food source.

These kinds of threads are repeated countless times throughout nature. Ancient organic molecules, such as amino acids, which were found in blue-green microalgae at the dawn of life, now act as basic building blocks for all of earth's creatures. Potent antioxidants (e.g., beta-carotene or glutathione) that originated in primitive microalgae are conserved and widely used across nature. Likewise, essential fatty acids (EFAs) are critical structural components of cell membranes and play a foundational role in our brain chemistry. Microalgae are the primary source of EFAs in the food chain! In short, microalgae at the bottom of the food chain provide an ancient biomolecular "pharmacopoeia" upon which most of cellular life now depends.

Remarkable Nutritive Qualities of Microalgae

"Gram-for-gram microalgae may be the most nutrient dense food on Earth."[1] The primitive character of microalgae's cellular organization gives it a number of advantages over higher plants and animals as a food source. For starters, practically the entire organism can be nutritious, with minimal indigestible structures. By contrast, typically less than half of the dry weight of plants and animals has nutritional value. Primitive blue-green algae are composed almost entirely of nutritionally useful and uniform cells. Furthermore, microalgae exhibit superior photosynthetic efficiency, using light approximately three times more efficiently than higher plants.[2] Microalgae are among the most productive organisms on the planet.

"*Why does* AFA [Aphanizomenon flos-aquae, *a blue-green algae]—small and simple as it seems to be—contain more micronutrients than any other known food?…*AFA *cells are about 20 to 30 times smaller than the cells within the food we usually eat. Because of this,* AFA *contains 20 to 30 times the membrane surface area.*"[3] *AFA's* smaller cell size means a larger ratio of cell membrane surface compared to the rest of the cell. In the case of blue-green algae, the cell membrane is where some of the most important nutrients are concentrated. *AFA* algae produces more cell membrane material without getting larger by creating a vast system of membrane inpouchings similar to the brain's infoldings. In other words, if the cell membrane were ironed flat, it would be many times the apparent size of the cell.

One of the most remarkable nutritional aspects of microalgae is its high content of usable protein—ranging from 50% to 70%! This is a far higher percentage than the choicest edible parts of any higher plant or animal. Algal protein has shorter and less complex polypeptide chains—making it easier to digest than plant or animal protein. Red meat has a surprisingly low net protein utilization index of 18%, compared to *AFA's* 75%.[4] The net protein utilization index is a measure of how completely amino acids are assimilated by humans. In fact, some microalgae, such as *AFA,* contain all ten essential amino acids that humans require from their diets—in a profile similar to that recommended by the National Academy of Sciences.[5]

Not least, "microalgae are considered to be the primary source of unsaturated fatty acids in the food chain."[6] Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are two relatively rare and valuable fatty acids found in microalgae.[7] The reason that fish oils are so rich in polyunsaturated fatty acids (PUFAs) is that microalgae are abundant in their food chain. Unlike seafood, microalgal oils are cholesterol free. The nutritional value and therapeutic merits of PUFAs have been widely documented.[8]

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Microalgae: A Historical Perspective

Early civilizations—including the Aztecs, certain African tribes, indigenous people of the Orient, and the South Pacific Islanders—used algae as a staple food for thousands of years. When the Spanish conquistadors discovered the Aztec empire of Mexico, *"They could not understand the passion of the Aztecs for their tecuitlatl [the blue-green algae they incorporated into their food], nor appreciate the technology of the 'chinampas'—floating gardens of [Lake] Texcoco. Never realizing that the lowly green algae of the lake produced more protein than the land could ever hope to yield."*[9] In a brief presented to the Food and Drug Administration (FDA) Select Committee on the Worldwide Use and Safety of Algae as a Food Source, the authors reported that some cultures have relied on algae for up to 25% of their diets.[10]

Yet, while a number of ancient cultures understood and used algae as a food, it wasn't until the early 1950s that the use of microalgae as a food source for humans began to gain momentum in the West. Microbiologists began to speculate that since algae have such high nutritive value (as much as 65-70% protein), large-scale production methods could lead to a revolution in agriculture. In the 1960s, this speculation fueled a sort of "algae space race" between the United States and the USSR. Dr. William Oswald of the University of California at Berkeley demonstrated a means by which algae could be used to support the entire metabolism of an adult man.[11] He called his life support system an "algatron": waste was recycled, oxygen created, and food grown on board a spaceship.[12] His results were soon supported by research in Japan and the Soviet Union that pointed to algae as an ideal food for long-term space missions.

During the 1970s, international research on the mass production of microalgae led to the early conclusion that microalgae were not cost competitive when compared to less expensive protein sources, such as soybeans. An understanding of the health benefits of microalgae would come later. The emerging "Green Revolution" turned in a different direction to feed the world's hungry, relying increasingly on the use of chemical fertilizers, pesticides, and genetic engineering to provide food for the masses. While this so-called Green Revolution did significantly increase food supplies worldwide, it has also resulted in serious problems associated with decreased seed stock, genetically engineered foods, and over-reliance on petrochemical fertilizers and pesticides.

While microalgae are generally too expensive to be considered a staple food for mass consumption, recent small-scale production advances have made one species of *Spirulina* blue-green algae affordable even to villagers in Bangladesh.[13] In wealthier countries, such as Japan and the United States, the use of microalgae as a nutritional health supplement is part of a multi-billion dollar industry that is contributing to a consumer-led health revolution in modern medicine.

The Health Revolution: For Better or for Worse?

"Vitamania," as some critics call it, is sweeping the country. Sales of supplements are soaring. Today an estimated 100 million Americans spend over $7 billion a year on nutritional supplements. That is over twice as much as the $3 billion spent in 1990, according to the Council for Responsible Nutrition in Washington, DC, a trade group for the vitamin industry. Although many Americans are convinced that vitamin supplements are effective, one large-scale, 13-year government study of 10,758 Americans found multivitamin supplements provided no long-term benefits in terms of increased lifespan or reduced cancer risk.[14] In fact, taking large doses of synthetic vitamins might even be associated with an increased risk of some kinds of chronic disease.[15]

On the other hand, the benefits of eating foods that contain a wide range of nutrients are well supported by scientific research.[16] Eating the right nutrients in the form of whole foods clearly increases life span and decreases stroke and cancer risks.[17] According to the Surgeon General, eight of the ten leading causes of death in the United States are diet related.[18]

Not surprisingly, many Americans do not get the nutrients they need. In a study of 3,172 hospitalized American patients, 58% of the patients were malnourished according to one or more objective laboratory measures.[19] Survey results published in 1995 show that of 23,699 American adults contacted during a random telephone survey, only about one in five reported having eaten the recommended five or more servings of fruits and vegetables that day.[20]

Despite the widespread use of multivitamins to fortify foods, most consumers don't realize that synthetic forms of vitamins, which are chemically manufactured, may not provide the same benefits as vitamins derived from whole food sources. Giant pharmaceutical companies (e.g., Merck and Hoffman-LaRoche) and chemical companies (e.g., Eastman Kodak) manufacture most of the vitamin isolates that are put into multivitamins and processed foods. Some of the same multinational corporations that sell synthetic vitamins later reap huge profits by selling drugs to treat diet-related diseases. This is not a small business. Alarmingly, some of these same pharmaceutical-connected companies also sell genetically modified seeds, pesticides, and petrochemical fertilizers to farmers. Obviously, such corporations have little financial incentive to spend millions of dollars to conduct clinical trials on the health benefits of organic foods and herbs, which are not patentable and are therefore less profitable. These corporations also have little incentive to make sure that the food on your table best supports and increases your health.

For the sake of bigger profits, longer shelf life, and cosmetic appearance, whole foods are robbed of their nutritional value and are then "enriched" or "fortified" with synthetic vitamins and inorganic minerals to comply with the minimum recommended daily allowances.

For the sake of bigger profits, longer shelf life, and cosmetic appearance, whole foods are robbed of their nutritional value and are then "enriched" or "fortified" with synthetic vitamins and inorganic minerals to comply with the FDA's minimum recommended daily allowances (RDAs). For example, General Mills uses a distillation process to extract vitamin E and other essential substances from soybean and cottonseed to produce vitamin E capsules. What remains is then used as margarine and cooking oil for commercial food products, so damaged by the heat and distillation process, it is no longer a health-building food. Unfortunately too, because of the distillation process the fractionated vitamin E capsule doesn't offer whole food benefits either.[21]

"Milling of whole grain to make refined flour results in loss of 85 percent of the magnesium, 86 percent of the manganese, 40 percent of the chromium, 78 percent of the zinc, 89 percent of the cobalt, 48 percent of the molybdenum, and 68 percent of the copper, in addition to comparable losses of selenium, vitamin E, and essential fatty acids."[22]

Moreover, heavy metals such as cadmium become more concentrated in refined flour, while the protective nutrients—such as biologically chelated zinc, which helps to eliminate that cadmium from our bodies—are mostly removed. To make matters worse, large amounts of sugar, saturated fats, artificial coloring, and preservatives are added to refined foods. Since a host of nutrients are required to best utilize the calories we consume, the intake of refined foods—typically nutritionally poor, but calorie rich—tends to create longer-term nutritional deficiencies that are not remedied by fortification with synthetic vitamins and minerals.

"The real test of the value of refined (fortified) foods would be to put a group of lab animals on a diet of white bread and compare them to a group fed a diet of whole-grain bread. In one such experiment, two thirds of rats kept on a diet of enriched white bread died before the experiment was finished."[23]

Meanwhile, the public remains largely ignorant about the important differences between whole-food derived nutrition versus synthetic vitamin supplements and so-called fortified processed foods.

As this changes, however, the American public will become more aware of and better informed about nutritional solutions; and people will start to demand reliable information. They will insist on evidence of scientific research to support supplement companies' claims. Currently, with 100 million consumers spending billions of dollars, thousands of companies and products are riding on the nutritional bandwagon. Yet there are signs that the public is increasingly questioning the results they experience from many so-called health supplements. On the other hand, some products have benefited from greater consumer discrimination.

St. John's wort and *Ginkgo biloba* are examples of supplements that have recently risen from relative obscurity to be among the most widely used botanical products in America. This growth was based almost solely upon strong scientific evidence of efficacy for the treatment of depression and other forms of brain dysfunction—problems that have become endemic to our culture.

By some estimates there are more than 30,000 different species of microalgae. Microalgae make up half of the plant kingdom—chiefly a separate and unexplored kingdom, as unknown and potentially valuable as the rainforests.

Microalgae Revisited

Before reviewing the extensive research on the health benefits of microalgae, it is important to consider why microalgae are so seldom mentioned in the herbal, botanical, nutritional, and alternative therapies literature. First, in Western botanical traditions herbs are by definition land-based plants, which categorically exclude aquatic algae. For all practical purposes, Western herbal medicine seldom reaches below the water's surface. Significantly, the *Physician's Desk Reference for Herbal Medicine* (1999) makes no mention of microalgae.[24] Neither does Dr. Mervyn Werback's (1993) *Nutritional Influences on Illness: A Sourcebook of Clinical Research*—one of the most comprehensive nutritional reference books to date.[25]

Second, microalgae can potentially affect many different systems in the body. This multiplicity of effects runs against the Western mechanistic search for a "magic bullet"—one treatment for a specific illness—and thus falls into the order of "panacea." Panaceas, or "cure-alls," are not widely embraced by Western medicine; such therapies might include diet, exercise, prayer, or laughter as part of the treatment. Only lately have we seen the emergence of holistic health models that better explain, for example, why the same treatments that improve intestinal function might also benefit our brain and immune systems.

Oriental medicine experts, such as macrobiotic counselors or Chinese doctors, though, do utilize algae and recognize their health benefits. However, these Eastern approaches tend to rely more upon empirical observations and tradition rather than experimental research methods.

Another area where algae are medically established is in the European health spas. Around 1867, Bonnardiere, a French physician, coined the word "thalassotherapy" (from the Greek *thalassa* or "sea"). He adapted sea therapies that had been used for centuries into a health spa regime, which included seafood and sea-vegetable diets, seawater drinks, hot seawater baths (38°C), bathing in brown kelp seawater solutions, kelp meal and seawater massages, skin fomentation with ocean bottom mud, and sunbathing.

Numerous health spas continue to use forms of thalassotherapy and algotherapy in France, West Germany, Belgium, Spain, Italy, Yugoslavia, and along the Black Sea coast. Throughout these countries and the Orient these sea- and algae-based therapies have long been used for:

"…treatment of such problems as chronic rheumatism, gout, neuralgia, asthma, wounds, eczema, hemorrhoids, scrofulosis, neuroses, stress-related diseases, and aging, as well as rehabilitation as performed by qualified specialists. [Also] In Japan, Eisenia *and* Ecklonia *added to hot bath water are supposed to prevent or cure palsy and hypertension…In Western Europe, powdered sea vegetables (*Fucus, Ascophyllum, *or* Laminaria*) are kneaded into a paste and sometimes combined with other fomentation agents for use as plasters on arthritic joints or used in combination with massage. In some instances, powdered sea vegetables and effervescent salts are added to the bath water to beautify the skin."*[26] For a more comprehensive list of medical benefits of marine algae read: Hoppe H. *Marine Algae in Pharmaceutical Science.* De Gruyter and Co, 1975.[27]

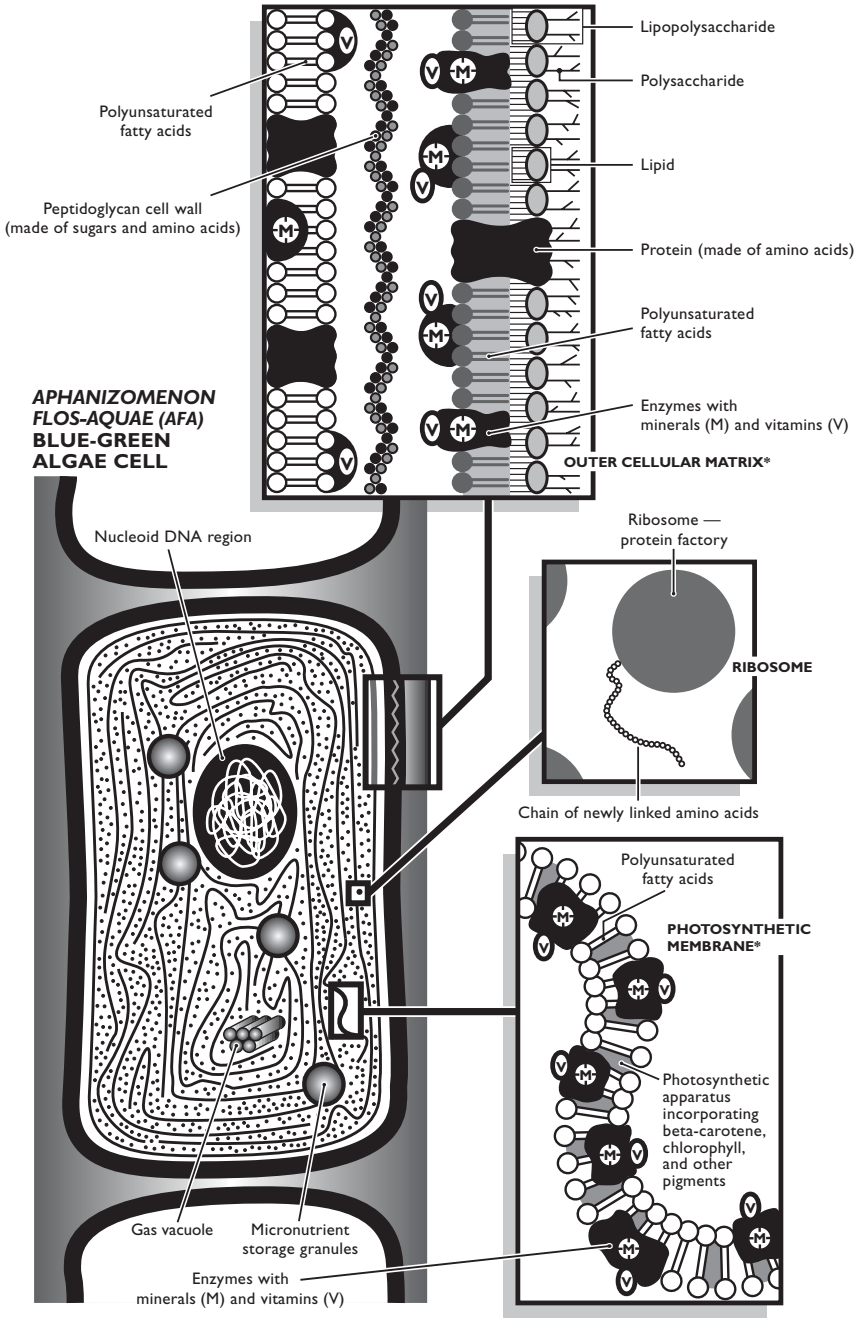
By some estimates there are more than 30,000 different species of microalgae. Microalgae make up half of the plant kingdom—chiefly a separate and unexplored kingdom, as unknown and potentially valuable as the rainforests. Microalgae can be separated into two large categories, based on their cellular organization.

The blue-green microalgae are closely related to bacteria, and are, in fact, known scientifically as cyanobacteria. All other algae, which are considered more advanced in their cellular organization, are separated into ten different phyla, which are designated by their color (e.g., brown, golden-brown, green, red). Precious few algal species have been researched for medical or nutritional usage. Many species are probably still unidentified—waiting to be discovered. The most popular edible species of algae in North America are large seaweeds, like kelp and nori, microalgae like *Chlorella* and *Dunaliella* (green), and *Spirulina* and *Aphanizomenon flos-aquae (AFA),* both blue-green.

While microalgae share some similarities, they also have important and unique differences from species to species. For example, *Chlorella* (a green microalgal species) contains more chlorophyll, less protein, and has an indigestible outer cell wall, which needs to be mechanically broken down before the cell contents can be digested. *Spirulina* (a blue-green microalgal species) has widely studied sulfolipids and readily grows in man-made ponds, especially in warm climates. *Aphanizomenon flos-aquae (AFA)* is a blue-green microalgal species, like *Spirulina,* but most *AFA* is harvested from the wild in volcanic regions, leading to high levels of trace minerals. It thrives in cold climates, resulting in higher levels of essential fatty acids. *Dunaliella* (a reddish-colored, green microalgal species) is mass cultivated and has the highest levels of beta-carotene, but also the lowest protein and chlorophyll content of the commonly eaten microalgal species. The unique health advantages of the various species are only beginning to be understood with the vast majority of microalgae still to be studied; yet many common characteristics and benefits are shared by these primitive organisms.

The environment in which algae grows—what nutrients are available, the pH, light, and temperature levels—and the manner in which it is processed, further contribute to important differences. For example, the more expensive, low-temperature freeze-dried forms of some *AFA* algae result in a higher net protein utilization. According to chemistry professor Karl Abrams, *AFA's* net protein utilization is "75%, while that of *Spirulina* and *Chlorella* are only 37% and 20%, respectively."[28] Toxins in the environment, such as heavy metals or pesticides, may contaminate microalgae; this possibility has posed a concern with some imported *Chlorella* or *Spirulina*. In other cases, contamination may occur from potentially dangerous strains of algae that may be inadvertently harvested along with the edible algae. For example, wild-harvested *AFA* algae needs to be carefully screened and tested to ensure maximum purity.

Schematic of *AFA* Cell



*These simple illustrations leave out most of the complexity and mystery of the cell.

From *Algae to the Rescue!,* by Karl Abrams, Logan House Publications, 1996. Adapted with permission of author.

Research Review

Our planet Earth has long modeled that microalgae are absolutely essential for life, but the scientific community is only now catching on. In the past two decades several hundred studies documenting the health benefits of microalgae have been published in peer-reviewed journals. This review is a compilation of many studies, most published. The health research on microalgae—their potential benefits as well as safety—may be categorized into eleven main areas, as outlined in the Table of Contents. Each of these eleven areas has either a substantial amount of research evidence to date or enough compelling evidence to warrant further investigation.

While many of the studies mentioned have been published in scientific journals, I have also included some as yet unpublished research results in cases usually where I've spoken to the researchers. In pursuit of the truth, a variety of research evidence is offered so that readers may arrive at their own conclusions. Still, it is important to recognize that even when we know something exists (e.g., gravity), we often lack a complete understanding of the causal mechanisms. For instance, Richard Smith, editor of the *British Medical Journal,* reported, "only about 15% of medical interventions are supported by solid scientific evidence."[29]

Enhanced Brain Function, Behavior, and Learning

"Blue-green algae and my new diet have helped me focus and concentrate better in school and on my homework. I am more relaxed and I don't have stomachaches anymore. I have more friends now and my mom is happier too."

—Chelsea, 8 years old

The brain contains and uses one of the highest concentrations of nutrients of any organ in the body. Oxygen consumption is the best indicator of "fuel use"—almost everyone recognizes how vital oxygen is to the brain. Unlike many organs (e.g., the liver) that have cellular fuel reserves, the brain is almost entirely dependent upon a continuous blood supply for fuel. Children's brains are even hungrier, more metabolically active, and proportionally larger than adults' brains. Per pound of body weight, children eat more food, drink more fluids, and breathe more air than adults, thereby increasing their potential exposure to toxins. Also, younger children's blood-brain barriers and intestinal linings are not as developed and are therefore less protective than those of most adults. This means that more incompletely digested foods and toxins can leak into a child's bloodstream and brain.

All these factors contribute to children's heightened susceptibility to dietary imbalances. The increased susceptibility of children to neurotoxins from what they eat, breathe, and drink, is likely contributing to the epidemic of neurobehavioral problems sweeping our country today.[30] For example, many pesticides used on food crops are specifically designed to attack the nervous system of pests. Vigorous industrialization and urbanization creates a greater discharge of hazardous environmental wastes. Given that our nervous systems are designed to be highly sensitive to environmental changes, the brain is especially vulnerable to the effects of pollution and stress.

The chemistry of the brain and nervous system is characterized by a heavy investment in lipid chemistry which accounts for up to 60% of its structural material.[31] Recent fossil evidence indicates that the rapid expansion of our species' ancestral archaic human brain took place in coastal areas, where aquatic food rich in long-chain polyunsaturated fatty acids (PUFAs), such as algae, mollusks, crustaceans, and fish, was abundant. Some brain researchers have suggested that the development of the human brain—which requires up to 10 times as much energy as that of other land-based mammals—depended on a rich source of essential fatty acids, especially DHA (docosahexanoic acid). DHA is found in marine and coastal food chains, but is not so easily obtainable on land.[32,33] As the ultimate source of essential fatty acids in the food chain, algae may have significantly contributed to the evolution of the human brain.

In addition to providing an excellent source of PUFAs, microalgae potentially offer other neurologically active substances. Researchers in Spain have described the effects of several species of algae on the central nervous system. Aqueous extracts of two species of microalgae showed antidopaminergic effects and

anticholinergic properties.[34,35] Extracts of two other microalgae species showed promise as a central nervous system (CNS) depressant and a potential muscle relaxant.[36] Certainly the CNS effects of microalgal species may vary considerably, but biologically active constituents are likely.

Male rats exposed to water immersion-induced stress (i.e., experimental near-drowning) showed significantly fewer gastric mucosal lesions when fed *Dunaliella bardawil* (whole green microalgae) as compared to an isolated synthetic beta-carotene control group.[37] Additionally, oral administration of unicellular green algae, *Chlorella vulgaris,* was found to prevent stress-induced ulcers in rats, as well.[38] Researchers hypothesized that microalgae prevents ulcer formation primarily through the "immune-brain-gut" axis, and secondarily through possible gastric mucosa protective factors.

"A test reported in the Japan Medical News in 1965 indicated that two grams of supplemental Spirulina *were able to cure all symptoms of gastric ulcers. In addition, seven out of nine cases of duodenal ulceration were completely cured, while the remaining two showed marked improvement."*[39] The anti-peptic ulcer effect of *Chlorella* was demonstrated in both human and animal studies.[40]

Beta-carotenes and antioxidants found abundantly in microalgae may contribute to protecting the central nervous system (CNS) from oxidative stress. Lipids, which comprise most of the brain tissue, are especially sensitive to oxidative damage.

In the last decade or so, medical science has determined that most gastric ulcers involve a bacterial infection, and antibiotics are often the treatment of choice. Evidently, blue-green algae may be helping through a number of different possible mechanisms: an enhancement of the immune response, direct antibacterial effects, general support for the healing process (enhancing tissue regeneration and modulating inflammation), or possibly by providing the trace mineral, bismuth, known to be effective in healing ulcers caused by the bacterium *H. pylori*. Anecdotal and experimental evidence from humans ingesting *AFA* blue-green algae is suggestive of an adaptogen, "anti-stress," effect.[41,42]

Beta-carotenes and antioxidants found abundantly in microalgae may contribute to protecting the central nervous system (CNS) from oxidative stress. Lipids, which comprise most of the brain tissue, are especially sensitive to oxidative damage. Researchers in Israel and Japan have demonstrated the protective effects of antioxidants in experimental animal brain trauma models.[43,44] Oxidative stress has been implicated in the pathogenesis of some disorders of the brain; hence antioxidants have become attractive therapeutic agents.[45] Furthermore, brain trauma and injury tends to increase whole-body oxidative stress.[46]

Scientists at the National Institute of Nutrition in Hyderabad, India, demonstrated that blue-green algae offers a cost-effective source of antioxidant carotenes for children.[47] Microalgae is one of the richest natural food sources of carotenes, including beta-carotene. Beta-carotene offers powerful anti-cancer, anti-aging, and antioxidant properties without the toxic risks of taking fat-soluble vitamin A.

Researchers at Erasmus University Medical School in the Netherlands conducted a three-year study of 5,100 people between 55 and 95 years of age and found that beta-carotene molecules acted as "tiny molecular shields" and may provide dramatic protection against the ravages of aging, memory impairment, and general brain damage.[48] These Netherlands findings suggest that beta-carotene foods, like microalgal foods, need to be further investigated with our aging population. Microalgae might also provide a cost-effective way to reduce brain-related risks of aging. As "baby boomers" turn into "senior boomers," the number of Americans with Alzheimer's disease is projected to increase by more than 300%.[49]

In 1985, Gabriel Cousens published two case studies on the use of *AFA* blue-green algae in the improvement of Alzheimer's disease. He reported "some significant return of function" such as decreased hand tremors, better balance, and improved short term memory, attention span, judgment, and reasoning in one patient; in the second patient there was no significant return of previously lost function, but there was a halting of the typical "progressive degeneration associated with Alzheimer's" along with a corresponding improvement in the patient's marital relationship.[50]

Cousens reports that, compared to *Spirulina*—the other most popular species of blue-green algae—*AFA* acts more effectively on the central nervous system, making it clinically useful for improving patients' "mental and emotional health." He recommends *Spirulina* for more general detoxification purposes and has used microalgae in his medical practice for almost two decades.[51]

Andrew Valencia and colleagues at the Neurolab Clinic associated with the University of New Mexico demonstrated that patients suffering from mild brain injury who ate *AFA* showed a 25% improvement in about half the time as patients who did not receive algae.[52] According to Valencia, in his study of more than 150 patients over two years, patients who ate *AFA* algae alone had improvements similar to those in a two-month

hospital-based rehabilitation program. However, the best results were achieved when neuro-rehabilitation was combined with eating *AFA* algae, better than *AFA* alone or the hospital program alone. Valencia's research team hypothesized that *AFA* algae seems to promote reparative neuroplasticity—or, in lay terms, rewiring of the circuitry of the brain.

Valencia also conducted electrophysiological studies of brain waves and found that the ingestion of *AFA* algae was linked with pronounced improvements in brain function, notably in the ability to focus and discriminate between various auditory signals.

At least six research studies have demonstrated the benefits of *AFA* on improving children's cognition, mood, behavior, and academic performance:

Sevilla and Aguiree's study of 1,567 students at the Monseñor Velez School in Nandaime, Nicaragua, demonstrated an 81% increase in the average standardized test scores among malnourished children eating only .5 to 1 gram of *AFA* a day over a six-month period. Subjects showed significantly increased classroom attendance and participation, as well as marked improvement in overall health. Academically, the Velez school went from having one of the lowest national scholastic test scores to achieving one of the best.[53]

Claudia Jarratt, family therapist at the Center for Family Wellness in Harvard, Massachusetts, studied 105 children given *AFA* and found a significant improvement in behavior as shown by both parent and teacher ratings. The children, who displayed a variety of behavioral problems, consumed between 0.5 and 1 gram of *AFA* daily and were observed over a ten-week period. Data from the Achenbach Child Behavior Checklists (parent and teacher versions) and extensive case histories were collected for all participants. Significant improvements were found on all 11 parent rating scales in pre- to post-test behavior. These findings were corroborated by teachers' ratings, which revealed significant improvements in seven of the ten behavioral problem areas measured. The use of an expectancy scale revealed little correlation between parents' initial expectations of treatment benefits and final outcomes.[54] Subsequently, Claudia Jarratt has continued to work with an additional 250 children, using an *AFA*-based program, with similar positive results.[55]

My own research team studied 26 students with reading difficulties, who participated in a three-month *AFA* supplement study. All were enrolled in the Stilwell Learning Center, a reading tutorial program in Sierra Vista, Arizona. Participants included 18 boys and 14 girls, ranging from 6 to 17 years old, with a mean age of 11. The children were randomly assigned to one of two groups, (1) the low-*AFA,* 1.5 grams, treatment group or (2) the high-*AFA,* 3 grams, treatment group. There was also a non *AFA* comparison group.

Both *AFA* treatment groups showed significant improvements on the following measures over the three-month trial period: attention and concentration indices, a sequential memory index, standardized academic testing, behavioral parent and teacher reports, health symptoms, tutorial attendance records, and decreased toxic levels of aluminum. Regardless of the assigned treatment group (i.e., high or low), both groups demonstrated significant improvements compared to pre-test baseline measures and a small non-supplemented comparison group.[56]

Marnee Foldoe's Sonoma State University master's thesis documented that eating *AFA* improved Attention Deficit/Hyperactivity Disorder (AD/HD) symptoms in three elementary school students. She examined the children's, teachers', and parents' attributions as to what caused the noticeable improvements in these diagnosed children. Interestingly, none of the teachers attributed the improvements to the dietary intervention, whereas the parents were convinced that eating the *AFA* made the biggest difference. Only the children reported that multiple factors were involved—their own volition, eating *AFA,* and social factors. Unfortunately, teachers in this small sample appeared to be completely unaware that diet could have any strong influence on AD/HD.[57]

A team of medical researchers headed by Dr. Krylov of the University of Illinois concluded, after examining hundreds of well-documented case histories, that *AFA* appears promising for the treatment of depression and AD/HD as well as several other health challenges.[58]

A pilot study of several thousand *AFA* consumers indicated that symptoms of AD/HD, depression, and memory difficulties improved with *AFA* consumption. This study was based on medical questionnaires similar to those used in a wide-scale health survey by the National Center for Health Statistics. In addition to specific improvements in a number of areas, the study found that people consuming *AFA* reported significantly better overall health than that reported by the general population in the larger survey.[59]

In an epidemiological study of 230 patients with multiple sclerosis in the Ukraine, it was reported that the intake of *Spirulina* increased the length of remission in patients with disseminated sclerosis.[60] Multiple sclerosis (MS) is a progressive disorder of the nervous system, where the lipid myelin sheath surrounding the nerves is gradually destroyed. Deficiencies of omega-3 oils may contribute to the syndrome of MS.

British biochemists at the Institute of Brain Chemistry and Human Nutrition in London report that any deficiency in essential fatty acids (EFAs) during early brain development in childhood can greatly increase the risk of learning disorders. Nervous tissue contains 50 to 60% lipids on a dry weight basis. Lipids play an essential role in the structure, fluidity, and function of brain membranes.[61] *AFA* blue-green algae is especially rich in PUFAs which are very important in maintaining membrane fluidity, comprising up to 10% of its dry weight.

Animal research at Massachusetts General Hospital and Harvard Medical School found that *AFA* algae dramatically raised blood levels of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). EPA and DHA are known to be important for optimal functioning of numerous organ systems, including the nervous system. They are extremely difficult to obtain in the modern American diet. The researchers found that *AFA* was far more effective than soybean oil, a good source of PUFAs, at raising blood levels of these important omega-3 fatty acids.[62]

Children with AD/HD are more likely to show deficiencies in DHA than children without attention problems, and EFA supplementation has shown initial promise in the treatment of AD/HD.[63] Gamma-linolenic acid (GLA), a powerful fatty acid found in *AFA,* may be helpful as well.[64] GLA has been linked to the release of neurochemicals that improve mental attitude, increase alertness, and reduce depression.

Attention deficit/hyperactivity disorder is our nation's leading mental health problem in children. Depression is one of the leading causes of disability in the world today.[65] Both of these brain-related problems are associated with difficulties in arousal.

Attention deficit/hyperactivity disorder is our nation's leading mental health problem in children. Depression is one of the leading causes of disability in the world today.[65] Both of these brain-related problems are associated with difficulties in arousal. While AD/HD children appear hyperactive, many scientists believe this is actually a problem of under-arousal, which increases symptoms of self-stimulation, risk-taking, and poor attention. This helps to explain why amphetamines (stimulant drugs) are prescribed to many children with AD/HD. Depression in children may sometimes even appear like AD/HD. Are there any links between the epidemic of hyperactivity in children (with acute arousal symptoms) and depression in adults (with chronic arousal symptoms)?

Although these two brain-related problems are usually diagnosed and treated as different "disorders," Larry Christensen in his survey of research on diet and behavior found evidence that depression and AD/HD are the two types of behavioral disorders most likely to respond to dietary intervention.[66] Interesting? Given that these two conditions appear to be increasing, what might this suggest about the standard American diet (SAD)?

Two expert opinions:

John Taylor, Ph.D., psychologist, author, and AD/HD expert states, *"I have been in a position to talk with thousands of parents and professionals very frankly about AD/HD. And blue-green algae is consistently mentioned to me by parents as being of help for children with AD/HD."*[67]

Edward Hallowell, M.D., is the author of the *New York Times* best seller, *Driven to Distraction,* and a leading authority on learning disabilities, particularly AD/HD. In an appearance as a keynote speaker at the 1998 Pacific Region Learning Disabilities Drug Treatment Conference in Honolulu, Hawaii, Dr. Hallowell reported that blue-green algae appears to offer a promising non-drug alternative for people with AD/HD.[68]

Improved Immune Function

"We may be different in gender, color of hair and skin, religion, and job. But we have a common bond—we are survivors. Our parents survived long enough to conceive us. Grandparents had the same claim for your parents. The thing that made this possible is that precious commodity—the immune system."

—Schmidt, Smith, and Sehnert
Beyond Antibiotics, 1993

Nutritionally acquired immune deficiency syndromes (NAIDS) are found primarily in Third World, malnourished countries. Yet while *"NAIDS is seen most frequently in children throughout the world, it is often seen in elderly individuals, and it is an all too common complication of severe medical or surgical diseases, malignancies, burns and other forms of trauma being treated in our most modern hospital centers. …Children are highly susceptible to infection and each febrile infection causes them to lose vital body nutrients. Multiple, closely spaced, or severe infections are the most frequent cause of childhood malnutrition."*[69]

"Deficiencies in any of a large number of single essential nutrients can produce dysfunctions in the immune system and other host defensive mechanisms…Single nutrients that impact importantly on protein synthesis [can] influence every aspect of immunity… Deficiencies of essential amino acids can also depress the synthesis of proteins, including those that contribute uniquely to host defenses…Trace [mineral] elements that function as the key component of metalloenzymes are also known to have some effects on the internal structure and function of lymphocytes."[70]

From a clinical point of view, important individual nutrients that support immunological functions include vitamin A, beta-carotene, zinc, iron, B-vitamins, amino acids (especially arginine and glutamine), polyunsaturated fatty acids, and nucleotides—that are found abundantly in microalgae.

School records of children eating *AFA* blue-green algae showed a dramatic improvement in class attendance in two studies. Both research teams, along with school personnel reports, suggested that the increased attendance of students who ate blue-green algae was related to decreased sick days.[71,72]

In a study of 100 children diagnosed with a zinc deficiency and given either zinc sulfate or blue-green algae tablets, those given blue-green algae demonstrated a superior immune response. The zinc found in blue-green algae may be about three times more effective than zinc from mineral sources.[73]

In a study of 100 children diagnosed with a zinc deficiency and given either zinc sulfate or blue-green algae tablets, those given blue-green algae demonstrated a superior immune response. The zinc found in blue-green algae may be about three times more effective than zinc from mineral sources.

The immunological effects of zinc are many, well studied, with a variety of possible mechanisms. Zinc is required for nucleic acid metabolism and essential to over 100 metalloenzyme activities. Also, zinc is a fundamental component of thymic hormones, helping to stimulate the activities of T-lymphocytes throughout the body and to increase antibody production.

Chemistry professor Karl Abrams describes how the carotenoids in *AFA* enhance the immune system by protecting the thymus gland and offering antioxidant protection to immune cells (e.g., white blood cells). *"Beta-carotene and the other carotenoid compounds of* AFA *biostimulate our immune system by increasing the number, activity, circulation of antiviral thymus helper cells.*[74] *And once beta-carotene has been biochemically transformed into vitamin A, white blood cells may use it to increase their abilities to kill invading viruses. This vitamin A precursor is also known to increase B-cell activity, thus increasing antibody production, especially IgA, when necessary."*[75] However, beta-carotene's immune-enhancing effects are maximized only in cases when it occurs in combination with a wider family of carotenoids, such as with microalgae.[76]

Microalgal carotenoids, such as beta-carotene, canthaxanthin, and astaxanthin have demonstrated immunomodulating activities using *in vitro* ("test tube") cell culture experiments.[77]

Researchers have found increased antibody production and enhanced immune function in animals supplemented with blue-green algae.[78, 79] Several studies, animal and human, have demonstrated the ability of microalgae to increase macrophage movement.[80-82] The dietary use of blue-green algae is reported to enhance

the immune response in laboratory mice, by stimulating macrophage functions, phagocytosis and enhanced interleukin-1 production.[83, 84]

In a study of 463 calves, kept under the same conditions of tending and feeding, the experimental groups fed supplemental algae were the least likely to contract any disease. The experimental conditions were as follows: Group 1 received *Chlorella* microalgae and a hyperimmune antibovine rabbit serum. Group 2 received either a) microalgae or b) hyperimmune antibovine rabbit serum. Group 3 received vaccines for both mucosal disease (MD) and infectious bovine rhinotracheitis (IBR). Results showed that Group 1, treated with the microalgae and the hyperimmune serum contracted the least diseases, only 20% infections; Group 2-a and 2-b treated with either algae or hyperimmune serum had similar results, with only 27% infections; Group 3 with vaccines had the worst results, with 42% of the calves contracting a disease.[85]

Gitte Jensen, Ph.D., an immunologist at McGill University, working with a team of researchers at the Royal Victoria Hospital in Montreal, demonstrated improved trafficking of immune cells to be among the effects of *AFA* algae on the human immune system. Many immune cells (e.g., natural killer [NK] cells) do their primary work outside of the bloodstream in the tissues. *AFA* algae increased the number of white blood cells that moved from the bloodstream into the tissues to do their search-and-destroy mission.[86]

In a follow-up double-blind study, Jensen's team replicated the initial results and also found that longer-term consumers of *AFA* demonstrated greater benefits than those taking algae for the first time. Yet even short-term consumers showed some benefits. Dr. Jensen's team found that within two hours of eating *AFA* there was a significant migration of natural killer cells from the blood into the surrounding tissues. Natural killer cells play a key role in our defense system as they "patrol for invading microbes and infected or transformed precancerous cells." This gentle immune boost was rapid, short-term, and cell-type specific.[87]

According to Dr. Jensen, these milder, killer-cell specific, episodic effects are preferable to a stronger, prolonged, and more global immune activation. For example, it is possible to put something into the bloodstream that will provoke a hyperactivation and a more global immune response. There are, however, substantial drawbacks to over-stimulation, including undesirable levels of inflammation. A more moderate, specific immune response is much preferable.

It is also noteworthy that high doses of *AFA* are not required to realize these benefits. The positive immune effects were seen with low amounts of *AFA* algae (1.5 grams), available in food supplementation.

In a retrospective review of medical cases, researchers found positive evidence that *AFA* blue-green algae might be useful in the treatment of chronic fatigue, Epstein Barr infection, fibromyalgia, and AIDS. These diseases all involve significant immune system, and sometimes viral, components. Such anecdotal evidence suggests that at least some autoimmune diseases may respond favorably to blue-green algae.[88] Some species of microalgae, *AFA* in particular, have been shown to be rich sources of polyunsaturated fatty acids (PUFAs), which increase cell membrane fluidity and enhance immune function. Our immune system depends on optimal cell membrane fluidity. For example, when white blood cells in our immune system develop more rigid cell membranes, it becomes more difficult for them to maneuver through tissues to attack viruses, bacteria, and unhealthy cells. Additionally essential fatty acid (EFA) deficiency is known to substantially lower the number of thymus suppressor cells and thus impair overall immune function.[89]

Lipopolysaccharides and C-phycocyanin in blue-green algae have been shown to stimulate macrophage activation and stem cell differentiation potential.[90,91] Also, cell wall fragments of lipopolysaccharide, lipid A, and glycolipoproteins are known to have immune-enhancing effects that strengthen the entire immune system.[92,93] When blue-green algae, such as *AFA*, is freeze-dried and encapsulated, such complex polysaccharide compounds of the cell wall are broken down into easily absorbable fragments. *AFA* microalgae, like human breast milk, contains a peptide known as substance P, which also acts as an immune booster.[94]

Antiviral, Antibacterial, and Antifungal Effects

"We have given too much attention to the enemy and have to some extent overlooked our defenses."

—M. Behar,
World Health, *February-March, 1974*

Microorganisms, bacteria, and fungi have been exploited for almost a century to provide useful drugs, antibiotics, and other pharmacologically active compounds.[95] Antibiotics, active against bacteria, fungi, and even viruses, have been isolated from marine algae, especially macroalgae.[96] Microalgae as well as macroalgae are able to produce a wide variety of pharmacologically active compounds.

Beneficial effects in leprosy were first observed in the 1940s. "Jorgensen and Convit fed a soup made from concentrated *Chlorella* to eighty patients at a treatment colony in Venezuela. The improvement in those patients' physical condition was the first documented evidence of the potential of microalgae as a health supplement."[97]

Subsequent positive results in the treatment of leprosy were documented in India with the use of *AFA* blue-green algae.[98] Leprosy is a bacterial infection; in some as yet unknown way microalgae appears to improve that condition.

Antibacterial, antiviral, and antifungal properties have been found in dozens of microalgae species.[99-101] A variety of unique and different biochemical properties might be involved. The antibacterial agents of blue-green algae often appear different from known cyanotoxins as well as known antibacterial substances. While some microalgal species extracts show specific and targeted antiviral or antibacterial effects, extracts of other species demonstrate an inhibitory effect across a wider range of viruses, fungi, and bacteria. A few of the species used in research are known to be toxic, while other species are edible.[102-104]

In 1989, the National Cancer Institute (NCI) announced that a number of extracts from blue-green algae were found to be "remarkably active against the AIDS virus."[105]

In 1989, the National Cancer Institute (NCI) announced that a number of extracts from blue-green algae were found to be "remarkably active against the AIDS virus."[105] NCI has searched the world for natural plants and organisms that display active anticancer, antiviral, and immune-enhancing effects. A relatively high percentage (about 15%) of aqueous extracts from freshwater and marine algae, cyanobacteria, marine invertebrates, and terrestrial plants have exhibited activity in the National Cancer Institute's primary AIDS-antiviral screening program.[106]

Numerous studies indicate that cultured or harvested blue-green algae may represent a novel source of compounds that inhibit reverse transcriptase viral activity, including that of HIV-1.[107,108] For instance, naturally occurring sulfolipid portions of glycolipids in blue-green algae have demonstrated powerful antiviral properties. Through *in vitro* and *in vivo* experiments, a sulfated polysaccharide derived from blue-green algae was demonstrated to be superior to dextran sulfate (DS) against human immunodeficiency virus type 1 (HIV-1).[109-111]

Extracts of microalgal polysulfates appear to: (1) block HIV replication in cell cultures at low concentrations without toxicity to the host cells; (2) inhibit cell-cell adhesion of HIV at its primary binding sites; (3) possibly act synergistically with anti-HIV drugs; (4) be very slow to cause virus-drug resistance and show activity against HIV mutants that become resistant to reverse transcriptase inhibitors, such as AZT and others; and (5) have the potential to be effective in a vaginal formulation to protect against HIV infection.[112] The efficacy of microalgal polysulfates in therapy or prevention of retroviral and opportunistic infections needs to be further demonstrated in animal models and humans.

Compounds and extracts from blue-green algae, as well as other microalgae, showing HIV inhibitory activity are often active against other retroviruses such as *Herpes simplex* virus types 1 & 2, simian immunodeficiency virus (SIV), cytomegalovirus, measles virus, mumps virus, and influenza A virus.[113-117]

Because of the affinity of some bacterial species for sulphated glycoconjugates exposed on the epithelial cells of susceptible host animals, researchers have hypothesized that sulphated exopolysaccharides of microalgae can be used in anti-adhesive therapies against certain bacterial infections, both in cold- and warm-blooded animals.[118]

Marine microalgae were screened for *in vitro* inhibition of viral replication for African swine fever virus and viral hemorrhagic septicemia virus of salmonid fish. Two out of ten species of marine microalgae tested produced a significant inhibition of both viruses in a dose-dependent manner. These two viruses were used

because of their major economic importance. Thus, extracts from marine microalgae may have prophylactic utility against fish and mammalian viral disease.[119]

A team of medical researchers reviewed over 200 documented medical cases and concluded that *AFA* blue-green algae may be helpful in the treatment of chronic fatigue, Epstein Barr infection, chronic ear infections, AIDS, and other conditions involving viral infections.[120] An earlier retrospective study (1996) documented numerous improved case outcomes related to viral mononucleosis and *Candida albicans* (yeast) infection.[121]

AFA blue-green algae shows an inhibitory effect on the growth of *Salmonella* bacterial strains, in amounts greater than 2 mg.[122] A hot water extract of the green alga, *Chlorella,* given to mice infected with *Listeria monocytogenes,* significantly increased the survival rates of mice, as well as demonstrating an increased immune cellular response.[123,124] Unicellular green algae have also been shown to increase resistance against *E. coli* and cytomegalovirus infections.[125-128]

According to Kenneth Bock, M.D., beta-carotene affects the immune function by: *"Enhancing lymphocyte production; increasing macrophage cytotoxicity and cytotoxic T cell activity; helping detoxify pollutants; enabling the growth and development of cells; maintaining the membrane receptors that are essential for immune function; and modulating the release of prostaglandins and leukotrienes."*[129] Microalgae provide the richest source of the best quality and most easily absorbed beta-carotene.

Beta-carotene, which is plentiful in microalgae, may also decrease susceptibility to respiratory infections. As beta-carotene is transformed into vitamin A, deficiencies associated with vitamin A—such as increased risk of respiratory disease—might be reduced.[130,131]

Chlorophyll, for which microalgae constitutes a rich source, appears to have antibacterial components.[132] Traditionally, before the advent of modern antibiotics, chlorophyll was often used to prevent infections and accelerate wound healing.[133]

Improved Cellular Repair

"The cell is immortal. It is merely the fluid in which it floats that degenerates. Renew this fluid at intervals, give the cells what they require for nutrition and, as far as we know, the pulsation of life may go on forever."

—Alexis Carrel, 1924

[Carrel, winner of two Nobel Prizes, kept the cells of a chicken alive for 38 years. The cells eventually died because of a custodial error made by his lab technician.]

"On the one hand, immortality releases us from the biological push to survive, which is the basis of egotistical struggle. On the other hand, mortality lends life a time-limited sweetness and preciousness. How interesting that we mortal organisms are composed of 75 trillion cells which have some connection with immortality? How possible is it to connect to both sides of this polarity by embodying both the human and the cellular levels of consciousness?"[134]

—Susan Aposhyan, 1999

Blue-green algae, scientifically called "cyanobacteria," like other bacterial forms, lack a nucleus. In other words, its genetic material is not surrounded by a nuclear membrane, like that of higher plants and animals. As Earth's first photosynthesizers, cyanobacteria had to depend on sunlight for their food supply, yet were also vulnerable to damage from that same energy source. *"Ultraviolet (UV) radiation has provided a challenge for the evolution of life on Earth. On the one hand, UV radiation is a mutagen, arguably the most important naturally occurring mutagen. Genetic novelties, the result of mutations, are the raw material of evolution. On the other, UV radiation is a selective agent because it affects metabolic processes from photosynthesis to vitamin D formation, and causes DNA damage."*[135]

The effects of solar radiation were especially powerful around 2.5 to 3.8 billion years ago—when blue-green algae were one of Earth's only living inhabitants—and the protective atmospheric ozone levels were less than 1% of present levels. Without today's protective "ozone shield," blue-green algae had to develop a host of powerful antioxidant pigments and protective agents, including carotenoids, and phycobilins. Today, all plants can trace their chloroplast genetic structure—their ability to photosynthesize—back to cyanobacteria.[136] However, while solar radiation in the visible region is critical for photosynthesis, UV radiation is present as well, and is damaging to life, especially to unprotected DNA close to the membrane's surface. The amazing thing is how effective microalgal antioxidant pigment solutions have proven to be!

Paleobiologists, such as J. William Schop, describe how some blue-green algal species have changed little in the last few billion years. Fossils of blue-green algae from central Australia, dating back more than 3.5 billion years, reveal early forms that are quite similar to living species today. It appears that blue-green algae achieved a sort of biological perfection—with perhaps little need to evolve—accompanied by strong protective mechanisms that minimized genetic mutations.[137] A surprising variety of important biological mechanisms found in microalgae are characteristic throughout the entire animal kingdom. For example, the energy-producing mitochondria of animal cells are hypothesized by some scientists to share common characteristics with cyanobacteria. Furthermore, primitive molecular mechanisms for vision, movement, circadian rhythms, and even human polypeptide hormone-like substances, such as acetylcholine and melanin, can be found in microalgae species.

As in all bacteria, the DNA of blue-green algae forms a simple loop, without chromosomes or a nuclear membrane. Thus, unlike nucleic acids in more advanced plant and animal species, cyanobacterial nucleic acids can constitute from 4 to 7% of the microalgae's dry weight and, without a nuclear membrane, are more orally available.

The absorption and metabolism of dietary nucleic acids has received little attention compared to that of other organic nutrients, largely because of methodological challenges in tracking cellular utilization. Conventional wisdom was that nucleosides played no useful nutritional role and were unable to survive the digestive tract. However, this old perspective is rapidly changing.

Scientists at the University of Goettingen in Germany have found that significant quantities of orally ingested nucleic acids are capable of surviving the digestive process and are absorbed intact in specific cell tissues, as demonstrated by radioactive-tagging studies.[138] Most importantly, orally consumed nucleic acids displayed a strong tissue-regenerative effect. Might algal nucleic acids offer a sort of "bioregeneration effect" that operates at the genetic level?

Additional proof is found in hen and mouse experiments conducted at the Stable Isotope Laboratory in Baylor College of Medicine. Poultry and rodent food rations were supplemented with radioactively labeled blue-green algae. Labeled isotopomers of algal dietary nucleosides, pyrimidine and purine, were detected in the experimental animals' isolated hepatic RNA. The researchers observed that large quantities of dietary pyrimidine nucleosides and minimal quantities of dietary purine nucleosides were incorporated into the animals' hepatic nucleic acids, without hydrolytic removal of the ribose moiety.[139] In other words, these laboratory results support the potential nutritional role for nucleosides and suggest that pyrimidines are "essential organic nutrients" that can be genetically incorporated at a cellular level.

Two studies by Devi and his team demonstrated the ability of algal diets to stimulate the regeneration of blood serum and liver proteins in rats.[140,141] Because microalgal protein is composed of shorter and less complex polypeptide chains—with an abundance of all essential amino acids—it can be more readily utilized at the cellular level. One can think of it as supplying the foundational building blocks for cellular repair in easily usable form.

Might algal diets be able to confer to other cells some aspect of protection from genetic mutations? Researchers at the Institute of Molecular and Subcellular Biology in Slovakia found that freeze-dried *AFA* blue-green algae demonstrated anti-mutagenic effects on bacterial cells exposed to a mutagen [a substance that disrupts DNA/RNA transcription, causing mutations] using the standard Ames test. When the algae powder was added to the cell culture at the same time as the chemical mutagen, there was no benefit. However, if the algae powder was added to the cell culture medium 2 to 24 hours before exposure to the mutagenic agent, a significant anti-mutagenic effect was evident.[142] The most intense suppression of mutagenic activity was achieved when the algae powder was mixed in the cell culture medium 24 hours before the addition of the mutagen. This suggests that the algal phytochemicals were utilized by the cell culture as a protective cellular influence rather than neutralizing the chemical mutagen directly.

Beta-carotene derived from the microalga *Dunaliella* demonstrates anti-mutagenic effects on human lymphocytes, as shown in a Chinese study using *in vitro* micronucleus and chromosomal aberration tests. The inhibitory effect of microalgae-extracted beta-carotene on mutagenesis induced by both gamma-rays and mitomycin, a known mutagenic agent, was demonstrated.[143]

New research provides evidence that dietary flavonoids (i.e., pigments) may help repair a range of free radical damage in DNA and offer protection against strand breaks and base alterations in our cells' genetic material. Scientists at the University of Auckland, New Zealand, demonstrated that antioxidant flavonoids can reduce the incidence of single-strand breaks in irradiated solutions of double-stranded DNA, *in vitro*. Using advanced pulse radiolysis measurements, scientists found that electron transfer from the flavonoids to free radical attack sites on DNA appears to result in a faster chemical repair, lessening the oxidative damage to DNA.[144]

New research provides evidence that dietary flavonoids (i.e., pigments) may help repair a range of free radical damage in DNA and offer protection against strand breaks and base alterations in our cells' genetic material.

Steve Gagne, a macrobiotic counselor and author of *The Energetics of Food* (1990), reports that "Algae are the masters of regeneration—they probably are the most highly regenerative foods on the planet."[145] In support of this empirical observation, it is noteworthy that microalgal extracts added to culture mediums dramatically increase human cell survival rates. In 1984, a U.S. Patent (no. 4,468,460) was granted to S. Kumamoto for "A Method of Human Cell Culture," described as follows: *"A method of culture of human cells is disclosed which comprises effecting the cultivation in a culture medium containing an extract of microalgae…said method permitting the normal successive cultivation of human cells to be maintained efficiently without any morphological and genetic mutations over a greater number of successive generations than has hitherto been possible."*[146]

Dr. John Apsley states, *"I have spent nearly 20 years focusing on the places within biology where the Regeneration Effect appears the strongest. In my opinion, the most rewarding places to study surround undenatured chlorophyll and raw nucleoproteins."* Drawing from the Nobel Prize-winning work of Dr. Alexis Carrel, Apsley notes that regenerative food is best obtained from young, "embryonic" cell cultures. Microalgae can be considered an embryonic cell source, since in a suitable environment they may undergo rapid and massive cellular replication within a single day or two. Furthermore, according to Carrel, avoiding excessive heat is essential as most "regenerative effectors" are destroyed when heated above the body's physiological temperatures. Finally, optimal regenerative foods contain a wide and balanced spectrum of trace minerals, vitamins, all 10 essential amino acids, and essential fatty acids, as found in freeze-dried *AFA* microalgae.[147]

Chlorophyll is considered to be a cell regenerator because its central magnesium atom plays an important role in so many (325) different enzyme systems. Also, as an antioxidant, chlorophyll may help to protect our DNA during cell division, a very vulnerable time in the life of any cell. Unfortunately, most of the published research on the regenerative properties of chlorophyll is found in older or foreign medical journals, which rely more upon natural therapies.[148-151]

Might a diet supplemented with algae increase life-span? *"In extensive traveling, beginning in 1927, Professor S. Kondo, of Tohoku University, discovered that geographic region and especially diet play a determining part in life-spans of the Japanese people…On islands and in fishing villages, people eat less rice and salty food and more sea vegetables, with the result that they live longer. The village of Oki Island, in Shimane Prefecture, where the people eat plain food and soybeans and sea vegetables—of which they are very fond—has the highest incidence rate of longevity of any…place in the nation…"* and one of the highest in the world.[152]

Radiation Protective Effects

"The transfer of energy that is produced by radiation is similar to that caused by other forms of acute injury such as an automobile crash or a bullet wound…The difference between a bullet and an X ray lies principally in the size of the particle. While a bullet destroys tissues and entire organs, a particle of radiation collides with single atoms or molecules deep within the cells."[153]

—H. Needleman and P. Landrigan,
Raising Children Toxic Free, 1994

High doses of radiation destroy cells directly, while lower doses of radiation can damage cellular DNA replication and thus lead to cell mutations. Radiation effects may be countered by increasing the cell's protective antioxidant defenses, by enhancing the repair mechanisms that fix genetic base code damage or by increasing the body's ability to identify and eliminate mutant or damaged cells. Many natural antioxidants have antimutagenic properties that may prove useful in reducing long-term radiation effects. Furthermore, nutrients that help modulate endogenous antioxidants, such as superoxide dismutase, may be useful in some radiotherapy protocols.[154]

Beta-carotene and other carotenoids, found abundantly in microalgae, are known to be potent free-radical quenchers and lipid antioxidants. Natural beta-carotene (50 mg/kg diet), obtained from the unicellular alga, *Dunaliella,* was fed to rats exposed to a single high dose of whole-body radiation (4 Gy). Radiated control animals, not fed algal carotenoids, suffered a significant loss of body weight and decreased liver concentrations of beta-carotene and retinol, compared to algal beta-carotene supplemented rats. Normal increase in body weight and the absence of ill effects were noted in the groups of rats whose diet was supplemented by beta-carotene before and after irradiation. Furthermore the effect of irradiation was "partially cured" by supplementation with beta-carotene after irradiation in sub-group controls. These results suggest that beta-carotene (especially 9-cis isomers) and retinol protect *in vivo* against the cellular damage by free radicals induced after whole body irradiation.[155]

However one possible contraindication of using beta-carotene extracts, versus giving the whole algae, is that high doses of beta-carotene treatment may markedly lower concentrations of vitamin E in tissues.[156] The use of megadoses of beta-carotene, like any isolated (pro-) vitamin extract, may contribute to other nutritional imbalances.

Foods rich in chlorophyll have been shown to offer radiation protective benefits. *"Tests performed by the U.S. Army showed that chlorophyll-rich foods may also be effective in decreasing the effects of radiation. In one controlled study it was found that a chlorophyll-rich diet doubled the life span of animals exposed to fatal doses of radiation."*[157] Again, microalgae —in this instance, *Chlorella*—are cited as particularly rich sources of chlorophyll.

Chlorophyllin, a water-soluble derivative of chlorophyll, has demonstrated an ability to protect DNA against gamma-radiation-induced strand breaks exposing plasmid DNA *in vitro.* Researchers discovered that chlorophyllin effectively protected plasmid DNA against ionizing radiation, independent of DNA repair or other cellular defense mechanisms, revealing direct evidence of free radical-scavenging properties of chlorophyll.[158]

Extracts of phycocyanin (the blue pigment) from blue-green algae helped to restore the efficiency of antioxidant defenses, dehydrogenase activity, and energy-rich phosphate levels in rats exposed to X-rays (dose of 5 Gy).[159]

Several animal and *in vitro* studies using microalgae have demonstrated remarkable radioprotective effects.[160-164] When microalgae was administered orally to mice, radio-protective effects of microalgae were shown to occur both before and immediately after exposure to sub-lethal gamma-rays.[165] Significant benefits were observed in the number of bone marrow cells and the spleen weight.

Numerous animal and in vitro *studies using microalgae have demonstrated remarkable radioprotective effects.[160-164] When microalgae was administered orally to mice, radio-protective effects of microalgae were shown to occur both before and immediately after exposure to sub-lethal gamma-rays.[165]*

According to Dr. John Apsley, "*AFA* has no less than 20 potent nutrients that limit and reverse the most common forms of radiation injury and may help to partly reverse genetic damage as well."[166] For example, *"research has shown that salts of aspartic acid, which are present in* AFA *as potassium aspartate and magnesium aspartate, are useful for protection against radiation damage."*[167] The cyanophycin storage granules in blue-green algae are made of aspartic acid and arginine, which act to stimulate the thymus gland, promoting white blood cell activity.

As part of an attempt to evaluate and treat 709 children who had suffered long-term exposure to different doses of radiation during and after the Chernobyl accident and subsequently moved to Israel, all of them underwent a medical examination. Of these children, 99 were provided with a beta-carotene powder of *Dunaliella* microalgae to take twice a day. The researchers found that irradiation increased the susceptibility of lipids to oxidation overall in the Chernobyl children. Yet they observed that microalgal beta-carotene may act as an *in vivo* lipophilic antioxidant or radioprotector in the supplemented group of children.[168]

Victims of the Chernobyl incident living in Russia and exposed to the long-term effects of radiation poisoning reported to medical relief workers that they experienced positive benefits after eating *AFA* blue-green algae.[169]

Cancer Protective Effects

"At present we have overwhelming evidence…(that) none of the risk factors for cancer is…more significant than diet and nutrition."

—B. Reddy,
Committee on Diet, Nutrition and Cancer, *1992*

"Today, treating cancer is a huge business. Every 30 seconds another American is diagnosed as having the disease. Typical cancer patients spend over $25,000.00 to try to treat their condition…Every 55 seconds, another American dies of cancer."

—J. Robbins,
Diet for A New America, *1987*

Cancer, defined as cellular replication that has gone awry, is the second leading cause of death in America. The same factors within algae that optimize cellular regeneration and help to protect genetic replication and transcription may likewise offer cancer-protective effects. Despite the "war on cancer," involving decades of research and many billions of dollars spent, the incidence of a number of cancers has continued to increase. Environmental factors and diet appear to play significant roles in certain forms of cancer. An important watershed was an article by Doll and Peto (1981) estimating that 35% of cancer incidence was related to nutritional factors.[170]

Notwithstanding an ongoing debate—with an increasing recognition of multi-causal factors involved with the etiology of cancer—the role of diet remains a strong one. In these last few decades researchers have increasingly begun to focus on foods, vitamins, and plant chemicals to provide protective factors that lower the risk of cancer.[171, 172] Beta-carotene is one of the best-known anticancer substances found in food.

Dozens of large-scale studies have disclosed evidence that eating vegetables rich in beta-carotene reduces the risks of cancer.[173-176] It is important to note, however, that isolated beta-carotene (sold as a supplement on its own or in multivitamin formulas) does *not* provide the same benefits. In fact, the large-scale study referred to as "CARET" (Carotenoid and Retinol Efficacy Trial) found that synthetic beta-carotene supplements were correlated with increased—not decreased—morbidity and mortality from cancer.[15]

Because microalgae are the foods richest in natural beta-carotene, several species, notably *Dunaliella* and *Spirulina,* have been extensively tested for anticancer effects and these effects have been well documented.[177-185]

Researchers at the Harvard University School of Dental Medicine demonstrated that algal extracts rich in beta-carotene applied to cancerous tumors in the mouths of hamsters reduced the number and size of tumors or caused them to disappear.[186] In a further study, when an algal extract was administered to 20 hamsters pretreated to develop mouth cancer, none of the animals developed the disease. By comparison, two pretreated

control groups that did not receive any algal extract (40 animals) all developed mouth cancer. Interestingly, when beta-carotene alone was given (provided by Sigma Chemical Company) fully half the animals developed cancer.[187] This research team has continued to replicate these effects, repeatedly demonstrating the ability of blue-green algal extracts to inhibit and prevent tumor growth and cancer.[188-190]

Additionally, there is evidence that blue-green algae can make a significant contribution to the prevention of oral cancer in humans. Researchers at Maryland's Human Nutrition Center administered a single gram of algae a day to tobacco chewers in Kerala, India, who had pre-cancerous mouth lesions (oral leukoplakia). After one year, the sores had vanished or shrunk significantly in more than half of the people, with complete regression in 45% of the human subjects (N = 40). Lesions disappeared in only 7% of the people in the placebo group. Within one year of discontinuing algae supplements, about half of the experimental subjects developed recurrent lesions. There was no experimental intervention to change the carcinogenic behavior of their tobacco chewing.[191]

Beta-carotene is not the only cancer-protective substance to be found in microalgae. Cancer researchers at the University of Hawaii isolated a blue-green algal pigment, called cryptophycin, that demonstrates powerful anticancer properties—especially useful in the chemotherapy of drug-resistant tumors.[192, 193] Other new algal protein compounds have also exhibited "multidrug-resistance reversing activities" that may be useful in the treatment of difficult, drug-resistant tumors.[194-196]

Unicellular algae have some compounds in their cell walls that are similar to those found in bacteria and yeast. Scientists discovered that these algae protected mice against experimentally grafted sarcoma in much the same way as the other microorganisms.[197] Bacteria and yeasts are able to induce, when inoculated into laboratory rodents, a general stimulation of defenses through an immune process. Glycoproteins extracted from algae demonstrate potent anti-tumor properties in animal studies.[198-202] Initial human trials with these anti-tumor peptidoglycans from microalgae have shown promising effects.[203]

Several components of chlorophyll have shown tumor-suppressive activities.[204, 205] A study published in the journal *Cancer Research* reported that chlorophyll, abundant in microalgae, is a "potent inhibitor of hepato-carcinogenesis (the development of liver cancer) …and may have important implications in intervention and dietary management of human cancer risks."[206]

Numerous studies with unicellular green algae have demonstrated anti-tumor and cancer inhibitory effects in laboratory rodents.[207-213] These anti-tumor effects appear mainly to be mediated by an increased host immune response. In some cases the survival rates of algae-treated mice increased nearly 80% over control groups.[214] Such findings suggest that presurgical treatment with extracts of microalgae might decrease or prevent metastasis or tumor progression.[215]

In some cases the survival rates of algae-treated mice increased nearly 80% over control groups.[214] Such findings suggest that presurgical treatment with extracts of microalgae might decrease or prevent metastasis or tumor progression.[215]

Marine unicellular algae, diatoms, have displayed antiproliferative effects against solid human tumor cell cultures—lung carcinoma, kidney carcinoma and melanoma—and have been shown to inhibit non-small-cell bronchopulmonary carcinoma in *in vitro* cell studies.[216, 217] However no clinical research has been done on humans as yet.

"In research in Japan, phycocyanin (the blue pigment of blue-green algae) was extracted and…[given] orally…[to] mice with liver cancer. The survival rate of the treatment group was significantly higher than the control group not given phycocyanin. After five weeks, 90% of the phycocyanin group survived, but only 25% of the control group were still alive. After eight weeks, 25% of the phycocyanin group still survived, yet none of the control group was alive. This suggests eating phycocyanin may increase the survival rate of cancer stricken organisms."[218]

Researchers at Dainippon Ink and Chemicals Company have a patent pending for using phycocyanin as an "anti-tumor agent." They base their claim on a study demonstrating that after two weeks the levels of white blood cells of a cancer group treated with phycocyanin were significantly higher than those of the untreated cancer group and equal to or higher than those of the normal group without cancer. This suggests phycocyanin may raise lymphocyte activity.[219]

Another patent claim filed by Dainippon Ink and Chemicals and Tokyo Kenkyukai is for "Anti-tumor agents containing phycobilin—also used to treat ulcers and hemorrhoid bleeding."[220] This patent application documents that taking a small dosage of algal extract daily maintains or accelerates normal cellular control functions that prevent generation of malignancy or inhibit its growth or recurrence. "Radiation and chemotherapeutic

"Whole body irradiation" animal studies suggest there may be a potential benefit for cancer patients given algal beta-carotene before and after radiation treatments to protect against cellular damage caused by free radicals induced from irradiation.[222]

treatments of cancer often result in undesirable reduction of defensive white cells. Studies published in *Medication and New Drugs* in 1966 reveal that 2 to 3 grams of *Spirulina* [blue-green algae] will slow this loss of white blood cells. In addition, patients reported less nausea and lassitude from cancer treatment when *Spirulina* was added to their regimens."[221]

"Whole body irradiation" animal studies suggest there may be a potential benefit for cancer patients given algal beta-carotene before and after radiation treatments to protect against cellular damage caused by free radicals induced from irradiation.[222] Additionally, Japanese researchers using an animal model found that components of unicellular algae may be beneficial in the alleviation of cancer chemotherapy side effects (e.g., immune suppression) while supporting the anti-tumor activity of the chemotherapeutic agents.[223]

Detoxification Support

"Since 1950, at least 70,000 new chemical compounds have been invented and dispersed into our environment through new consumer commodities, industrial products, and food. We are by default conducting a massive clinical toxicological trial. And our children and their children are the experimental animals."

—H. Needleman and P. Landrigan,
Raising Children Toxic Free, *1994*

"Toxic substances are everywhere – in the air we breathe, the food we eat, and the water we drink. Even our bodies and the bacteria in the intestines produce toxic substances. It can be strongly said that the health of an individual is largely determined by the ability of the body to detoxify."

—Murray and Pizzorno,
Encyclopedia of Natural Medicine, *1991*

"Methionine was probably one of the first amino acids available in Earth's ancient primordial seas billions of years ago. This amino acid was (and is still) used by primitive bacteria and blue-green algae to biosynthesize glutathione, possibly Earth's first antioxidant (protection) tripeptide molecule. Methionine in this form has been shown to help humans detoxify lead and copper contamination in the blood."[224]

Methionine's most useful metabolite, glutathione, is a peptide made of three amino acids—glycine, cystine, and glutamic acid—all present in microalgae. Also, methionine can be restored from homocysteine—its alter-ego, sister form—with the help of B vitamins, especially folic acid in conjunction with B-6 and B-12. Elevated blood homocysteine levels are a risk factor for heart attack, the number one killer of adults in America.[225]

Blue-green algae are one of the richest food sources of detoxifying polypetides, including methionine and glutathione, along with B-vitamin precursors. Once ingested, these molecules are modified as needed. Such polypeptides are essential in the protection of DNA, the family jewels, and are essential in the chemistry of detoxification.[226] Also glutathione, along with ascorbate, may help to protect against polyunsaturated fatty acid (PUFA) oxidation.[227]

Glutathione is the most important worker in the body's detoxification department. In fact, detoxification is the most important activity in the body's entire biochemistry and the biggest consumer of energy for making new molecules. Biochemically, the glutathione reductase enzyme present in blue-green algae shows amino acid sequence similarities to human reductases.[228] Among prokaryotes, only two groups, the purple bacteria and the cyanobacteria—also known as blue-green algae—produce glutathione.[229]

Detoxification of harmful substances from the body is a life-long process. Our ability to effectively detoxify and eliminate toxins (e.g., heavy metals, solvents, pesticides, microbial toxins) shapes and determines our state of health. Two major organ systems, the kidneys and liver, are primarily involved in detoxification. Additionally, healthy intestinal bacteria and a healthy mucosal lining are essential to reduce the absorption of toxins into the blood through the intestines. Microalgae can support, directly and indirectly, these primary detoxification pathways to better eliminate toxins.

The liver acts as a major organ for detoxification. All blood returning from the stomach, intestines, spleen, and pancreas is "detoxified" by the liver, reducing and helping to eliminate many toxins. Blue-green algae have multiple liver-protective factors, including amino acids (e.g., methionine, arginine, and isoleucine), chelating trace minerals, and potent antioxidants, such as phycocyanins and superoxide dismutase (SOD).[230-232]

When microalgal supplementation was given to rats consuming a high fructose (60%) diet, a preventive effect on the liver triglyceride level was observed, along with lowered plasma cholesterol. The researchers reported that the microalgae helped reduce liver fats that were elevated by the excessively fructose-rich diet.[233]

Blue-green algae have multiple liver-protective factors, including amino acids (e.g., methionine, arginine, and isoleucine), chelating trace minerals, and potent antioxidants, such as phycocyanins and superoxide dismutase (SOD).

Chlorophyll, which microalgae contain in abundance, can help to stimulate liver function, increase bile secretion, and protect cellular functions.[234] Also, "chlorophyll appears to promote regeneration of damaged liver cells."[235]

Researchers from the National Institute of Oceanography in Haifa, Israel, reported that the increased absorption of essential fatty acids (EFAs) found with consumption of certain microalgae can support healthier liver function.[236] Additionally, experimental animals fed oxidized (i.e., rancid) oil combined with a *Dunaliella* algal extract were better able to maintain their hepatic stores of beta-carotene and vitamin A than control animals given a synthetic all-trans beta-carotene. The control group showed significant liver (pro)vitamin losses, likely due to a greater utilization of their antioxidant vitamin reserves. Beta-carotene helps to reduce hepatic and erythrocyte peroxidation associated with the consumption of oxidized oils.[237] Exposure to air naturally oxidizes the oils in our food; light and heat both speed up the process.

In the Orient algae has a long tradition as a master cleanser. Macrobiotic counselor Steve Gagne reports, *"When ingested, algae begin to go to work like a janitor, cleaning, purifying and strengthening the internal environment."*[238] Japan has been subject to several tragic incidents of severe chemical poisoning. The use of algae has stimulated the excretion of some contaminants, notably cadmium, at an accelerated rate in test patients. Lead and mercury are also excreted, without the detrimental effects associated with conventional chelation therapy.[239]

Japanese researchers from Chiba University found that blue-green algae effectively reduces kidney toxicity from high doses of mercury and pharmaceutical drugs administered to laboratory rats.[240] These scientists used two indicators for kidney toxicity, blood urea nitrogen (BUN) and serum creatinine. They checked levels of both indicators before and after administering various toxic doses of mercury, para-aminophenol (a common pain-killer), gentamicin (an antibiotic), and cis-dichloro-diamino-platinum (an anticancer drug). In all cases, rats fed blue-green algae (up to 30% of their diet) exhibited significantly reduced BUN and serum creatinine levels that returned back to near normal levels after the experimental poisoning. This was not the case with the poisoned, untreated, control animals.

Medical researchers have demonstrated that green microalgae increase the detoxification of harmful chemicals like chlordecone, dioxin, and PCBs.[241] In a study of chlordecone poisoned rats, ingested algae decreased the half-life of the chemical toxins from 40 to 19 days.[242]

Several grams of *AFA* blue-green algae eliminated excessive aluminum from children in a three-month study. Also, parents reported significant decreases in negative health symptoms, suggestive of improved detoxification pathways.[243] Aluminum exposure in humans is unavoidable. Some aluminum absorption occurs with the ingestion of food and medicines. Greater amounts of aluminum are present in antacids.[244] Blue-green algae may be helpful for dialysis patients, who have a greater risk for aluminum accumulation and an increased risk of neurotoxicity.

Blue-green algae have been shown to reduce lead toxicity, as well.[245] The beneficial effects of blue-green algae may be due to the presence of the abundance of antioxidants, including beta-carotene and SOD enzymes. Numerous studies have demonstrated a strong relationship between childhood learning disabilities and body stores of heavy metals, particularly lead.[246, 247]

Andrew Valencia reported that *AFA* significantly reduced "leaky gut syndrome" in patients, based on functional test measures.[248] Compromised intestinal permeability increases the uptake of toxic compounds and macromolecules that can exhaust the detoxification capability of the liver. A combination of leaky gut and dysfunctional liver detoxification may lead to increased tissue stores of toxic compounds and depressed immune status.

Treatment with both reduced glutathione and selenium-enriched *Spirulina* algae helped to normalize the intestinal permeability of rats exposed to an experimental anaphylaxis reaction. Reduced glutathione administered by itself did not help normalize the intestinal permeablility of these sensitized rats.[249]

Chlorophyll, the green pigment in algae, was found to be helpful in controlling body and fecal odors in 62 geriatric patients.[250] Chlorophyll may help to restore intestinal balance by reducing toxic bacteria and fungi in the walls of the intestines. In natural therapies, chlorophyll is considered a "detoxifying agent."

Anti-inflammatory and Antioxidant Effects

"Many of the elderly in the United States—and quite a few of the not-so-elderly—experience terrible pain in their joints. Their fingers may become twisted and swollen, and they may be unable to button a coat without large doses of anti-inflammatory drugs…Many come to feel crippled and useless. By the age of 35, 35% of Americans have diagnosable arthritis in their knees. At least 85% of those over the age of 70 have it, and many have it severely."

—J. Robbins,
Diet for A New America, ***1987***

Fossilized samples of algae show that these organisms have remained virtually unchanged for several billion years. Scientists describe blue-green algae as having reached a sort of "evolutionary perfection," as some species show little evidence of mutation or genetic damage. The success of ancient microalgae depended upon their developing powerful antioxidant pigment shields. Because there was little atmospheric protection from the harmful rays of a much brighter sun, antioxidant shields were vitally important to protect sensitive molecules—especially exposed nucleic acids and lipids—from the damaging effects of solar radiation. By producing oxygen and converting inorganic carbon and nitrogen into organic forms, ancient microalgae helped to transform our planet from an inhospitable world into a life-sustaining one over billions of years. So effectively did microalgae develop antioxidant and genetic survival codes that they provided a foundational blueprint copied by many higher species that arrived later.[251]

Prokaryotes, organisms without a nuclear membrane (e.g., blue-green algae), display a more diverse array of antioxidant pigments and a broader selection of carotenoids than terrestrial plants and most green algae. Scientists at the University of Wisconsin, Department of Food Microbiology, report that because of the remarkable health benefits of algal and microbial carotenes, there will likely be a substantial increase in the world-wide demand for a full range of these important antioxidants.[252] Carotenoids represent one of the most widely distributed and structurally diverse classes of natural pigments, with important functions in photosynthesis, nutrition, and protection against photo-oxidative damage.

Rats and chickens fed a natural algal form of beta-carotene showed at least a tenfold higher accumulation of overall beta-carotene in their livers than those control animals fed equivalent amounts of synthetic all-trans beta-carotene supplement. The higher accumulation of the natural algal carotenoids, over the synthetic isolated beta-carotene, likely indicates a greater therapeutic value, according to the researchers.[253]

Researchers have reported that natural algal beta-carotene is superior to a synthetic beta-carotene supplement in terms of raising lipophilic antioxidants (protecting PUFAs) in human serum.[254] Also, natural algal extracts of 9-cis beta-carotene are shown to have a higher antioxidant potency compared to synthetic all-trans beta-carotene with *in vitro* experiments.[255]

Pigments, phytochemicals, vitamins, and trace elements from algae and higher plants can help boost the human body's antioxidant defenses.[256, 257] *AFA* has an unusually wide variety of antioxidants, such as tocopherols, beta-carotene, flavonoids, superoxide dismutase, glutathione, taurine, tryptophan, phenolic acid, and vitamins C, E, B5, and B2. Antioxidants are biomolecules that protect organisms from the damaging effects of reactive oxygen species (free radicals) that are constantly formed in biological systems.

Free radicals are molecules that lack one electron—a highly energetic particle—in what is usually a pair. To stabilize, free radicals randomly grab electrons from normal (i.e., healthy) molecules. This creates new free radicals, and like a row of falling dominoes, the damaging free radical cascade continues to spread. Free radicals are by-products of normal metabolism and form as a result of exposure to radiation and some environmental pollutants. Because they are highly reactive, they can damage cellular components, a particular concern with brain, vascular, and connective tissues and nucleic acids. They have been implicated in a variety of diseases and even in the acceleration of the aging process itself.

"The more complicated the life form, the more sophisticated its handling of the oxygen molecule. In higher life forms, oxygen can be converted into several toxic oxygen species (free radicals) that are lethal to most potential pathogens. Then the host must also be capable of protecting itself from these toxic oxygen species; hence, antioxidant defenses were born…The pathogens, on the other hand, possess inadequate antioxidant defenses against this sophisticated handling of oxygen."[258] For example, leukocytes can generate and launch toxic free radical attacks against pathogens, but they must also have their own effective antioxidant defense system.

Essential fatty acids, especially the omega-3s found in coldwater microalgae and fish oils, can be helpful in a variety of inflammatory conditions, such as rheumatoid arthritis.

Researchers at Oregon State University in Corvallis are starting to recognize that pigment particles in blue-green algae may have an antioxidant effect in humans, preventing unstable compounds from damaging healthy cells. Balz Frei, director of OSU's Linus Pauling Institute, speculates that perhaps algae might one day be commonly eaten to help lower the risk of cancer, perhaps becoming as popular as taking vitamin C.[259]

Blue-green algae contain a wide range of antioxidants in the form of specific trace minerals, amino acids, vitamins, and especially pigments – an impressive variety of carotenes along with potent green and blue pigments. Depending on the source of blue-green algae, the amount of phycocyanin can range up to 15% of its dry weight.

Replicated studies with a range of experimental animal models have established the potent antioxidant and anti-inflammatory effects of phycocyanin. In rodents, experimentally-induced colitis as well as edemas of the paw and ear all responded positively to C-phycocyanin.[260-264]

"Bi-indoles isolated from a number of blue-green algae have anti-inflammatory and anti-allergenic properties."[265] Additionally, a chlorophyll-related compound, pheophytin, derived from an edible green alga, has potent anti-inflammatory effects in both *in vitro* and *in vivo* experiments. Both human and mouse immune cells showed an inhibited response to experimentally induced inflammation. Pheophytin has exhibited a significant suppression against edema formation in a mouse ear that was inflamed by toxic means.[266]

Gitte Jensen, an immunologist from McGill University, and her team at the Royal Victoria Hospital in Montreal report that *AFA* algae may help to inhibit and to reverse inflammatory conditions. The researchers observed that small dilutions of *AFA* algae tend to dampen the release of reactive oxygen species from certain phagocytic cells in human blood.[267]

Scientists at the University of Padova, Italy, found that diatoms, golden brown unicellular algae, produce anti-inflammatory chemicals that are the main active ingredients in mud-pack treatments. In European health spas the use of mud-packs for the treatment of rheumatic and osteoarthritic patients has a long and relatively successful history. The maturation of thermal mud is dependent upon the full colonization of the mud by thermophilic microorganisms, with diatoms producing anti-inflammatory sulfoglycolipids (SGL), similar to those in blue-green algae. A typical cycle of treatments requires 12 packs of thermal mud.

"On this basis we calculated the amount of SGL taken up by each patient in a cycle of treatments, and found a figure not far from the recommended dose of non-steroid anti-inflammatory drugs utilized for the same pathology. However, unlike pharmaceutical preparations, the amount of SGL taken up by the patients after the mud-packs does not exert any adverse gastrointestinal effect on these patients," reported the scientists.[268] Additionally, the anti-inflammatory action of SGL is consistent with the decrease of serum interleukin-1 observed in arthrosic patients treated with mud-packs.[269]

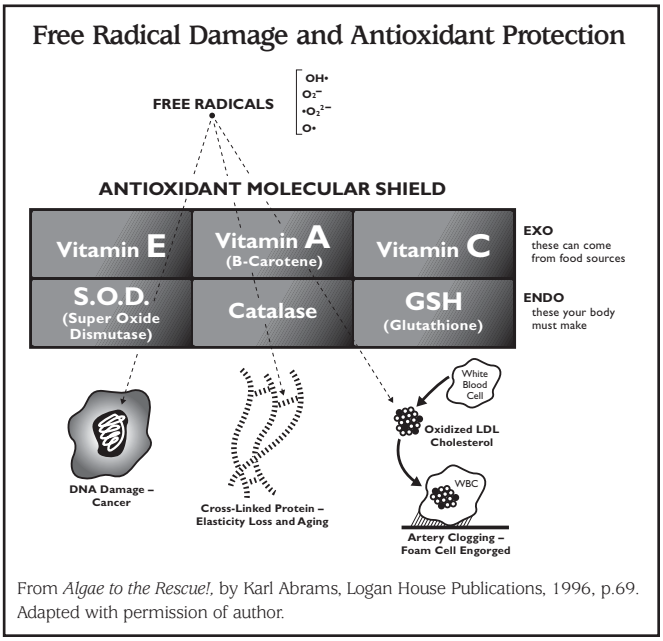
Biologists at Israel's National Institute of Oceanography fed blue-green algae to animals and discovered that the high levels of the important fatty acids EPA and DHA in blue-green algae reduced the levels of arachidonic acid in the blood and liver.[270] Arachidonic acid increases brain cell oxidative damage and impairs the flexibility of cell membranes. It is a precursor of the inflammatory prostaglandins—the molecules people are trying to suppress when they take anti-inflammatory drugs.

Essential fatty acids, especially the omega–3s found in coldwater microalgae and fish oils, can be helpful in a variety of inflammatory conditions, such as rheumatoid arthritis.[271] Fish oils are essentially derived from the consumption of aquatic algae-derived PUFAs, either directly or indirectly. Cold-water fatty fish are good sources of these health-promoting fatty acids because of the cold-water algae in their food chain.

In a retrospective study of 208 documented cases, medical researchers found positive evidence suggesting that *AFA* (a coldwater blue-green algae) may be helpful in the treatment of fibromyalgia, a painful inflammatory condition with multiple etiologies.[272]

Overall, evidence suggests that microalgae demonstrate at least four antioxidant properties:

1. Scavenging of reactive oxygen species (free radicals).
2. Regeneration of endogenous antioxidants, such as SOD and glutathione reductase.
3. Chelation of heavy metals.
4. Repair of oxidation-damaged proteins.



From *Algae to the Rescue!,* by Karl Abrams, Logan House Publications, 1996, p.69. Adapted with permission of author.

Improved Circulation and Heart Function

"The human heart so far surpasses all known motors in functional capacity that we can hardly hope to improve on it, even with the most ingenious machine produced by man…It beats 100,000 times per day, approximately 40 million times in a year…It pumps two gallons of blood per minute and 100 gallons per hour, through a vascular system of about 60,000 miles in length—2½ times the circumference of the earth."

***—Bircher-Benner,* Nutrition Plan for High Blood Pressure Problems, 1973**

Albert Sanchez, Ph.D., a public health expert who examined obesity and heart disease risk factors in 249 high school students, reported, *"We are appalled at the horrendous diet that 80 to 90% of our children are eating,"* to physicians at the 49th annual conference of the American College of Cardiology in Anaheim, California, in March, 2000.[273] More than 80% of the students ate diets that exceeded the recommended levels of total fat and saturated fat, with more than a third having elevated levels of LDL ("bad") cholesterol. Furthermore, the presence of an early buildup of fatty deposits in the carotid artery, as revealed by ultrasound images, was not uncommon. All these risk factors are predictive of heart disease and serious health problems only a few decades down the road.

Microalgae's potent range of antioxidants, in addition to its healthy balance of EFAs, offer top-quality cardiovascular support. *"A high consumption of fruit and vegetables, which are good sources of antioxidants, is associated with a lower coronary risk. More specifically, there is evidence of a reduced coronary risk in populations with high blood levels of the antioxidant nutrients, vitamins C and E. Evidence is also accumulating that diabetes and microvascular complications associated with diabetes involve oxidative stress and compromised antioxidant status…evidence is sufficiently compelling to suggest that antioxidants are potential therapeutic agents in the above conditions."*[274]

Dietary supplementation with algal beta-carotene may normalize the elevated LDL oxidation in patients with diabetes, and thus delay the onset and further development of atherosclerosis in these patients. Twenty patients with long-standing non-insulin-dependent diabetes mellitus were studied in comparison with age- and sex-matched control subjects. Diabetic patients showed overall greater LDL oxidative effects compared to the controls. An algae-derived beta-carotene supplement (60 mg daily dose) was given for 3 weeks. Upon supplementation, a marked reduction in oxidative effects was seen in the patients. Supplementation with algae naturally rich in beta-carotene appears to normalize the diabetic-enhanced LDL oxidation levels and consequently may be of importance in delaying the accelerated development of atherosclerosis in these patients.[275]

Researchers at the University of California - San Francisco found that children with an inherited tendency for high cholesterol levels benefited from antioxidant vitamins. Antioxidants seem to improve the condition of blood vessels by helping to neutralize the free radical molecules or "reactive oxygen species" (ROS) that may prevent endothelial cells lining the blood vessels from releasing nitric oxide. Nitric oxide is responsible for the dilation of blood vessels.[276]

One animal study suggests that a blue-green alga, "Spirulina maxima, *may decrease vascular tone by increasing the synthesis and release of both a vasodilating cyclooxygenase-dependent product of arachidonic acid and nitric oxide, as well as by decreasing the synthesis and release of a vasoconstricting eicosanoid from the endothelial cells.*"[277]

AFA algae has high concentrations of polyunsaturated fatty acids (PUFAs) which account for almost 10% of its dry weight. Even more important, it has a high percentage of the omega-3 fatty acids, comparing extremely favorably with most plants, seeds, nuts, and other microalgae. The reason *AFA* has more concentrated amounts of valuable PUFAs than tropical algae like *Spirulina* is that it thrives in a much colder environment. *AFA* compensates for the cold by manufacturing more of the flexible omega-3 and cis-unsaturated fatty acids. (Cis-unsaturated forms of fatty acids are healthier than the trans-fatty acid forms, because their curved shape further contributes to cell membrane flexibility.) Tropical algae appear not to be as good a source of these particular nutrients.

While both omega-3 and omega-6 forms of EFAs are important, omega-3s are seriously lacking in the standard American diet. *AFA* algae contain an ideal ratio of essential omega-3 to omega-6 fatty acids and are especially high in the essential omega-3 fatty acid, alpha-linolenic acid (3-5% by weight). Greenland Eskimos, whose traditional diet was high in cold-water fish that eat blue-green algae, had little cardiovascular disease.[278]

"EFAs have lubricating qualities and increase cell membrane flexibility. They are known to reduce blood cholesterol and thus help to prevent cardiovascular disease…EFAs are especially useful because of the efficiency with which they increase the solubility of cholesterol deposits and wash these deposits away from our artery walls…As the consumption of fish oils or essential fatty acids found in AFA *increases, the tendency for blood platelets to aggregate decreases and blood pressure goes down."*[279]

Natural algae-rich beta-carotene supplementation appears to normalize the diabetic- enhanced LDL oxidation levels and consequently may be of importance in delaying the accelerated development of atherosclerosis in these patients.

Algae-derived omega-3 fatty acids may support heart function, reduce blood viscosity, decrease arteriosclerosis (a disease of hardened arterial walls) and lower high blood pressure, according to research of Zvi Cohen at the Laboratory for Micro-algal Biotechnology in Israel and Helen Norman at the United States Department of Agriculture.[280] The flexibility of any cell membrane is directly proportional to the amount and type of polyunsaturated fatty acids (PUFAs) it contains. Research reveals that algae supplementation can significantly reduce high levels of arachidonic acid (AA) in the blood and liver lipids and cause a significant increase in the percentages of the omega-3 polyunsaturated fatty acids (PUFAs).[281]

Dr. Rafail Kushak and colleagues demonstrated that *AFA* essential fatty acids are more easily assimilated than those of soybean oil and offer superior cardiovascular benefits. While both soybean oil and blue-green algae contain the essential omega-3 fatty acid, alpha-linolenic acid (LNA), the scientists found that rats required triple the amount of soybean oil in their diets to achieve the same level of circulating LNA as rats fed algae. Also, *AFA* significantly increased both eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) blood plasma levels far more effectively than did soybean oil.[282] Both EPA and DHA are essential for optimal cardiovascular and brain function and can be synthesized in the body from LNA.

Other studies suggest not only that blue-green algae provide an excellent PUFA source, but also that algae oils might help the body to better utilize other vegetarian sources of PUFAs. For example, while flaxseed oil offers high levels of omega-3s, many people have difficulty assimilating them from this source. Yet when microalgae is combined or taken with vegetable oils, like flaxseed oil, blood levels of omega-3s are significantly

increased. Thus, microalgae's ability to raise PUFA levels might be a two-fold action: both acting as a superior source of PUFAs and helping to aid the assimilation of other dietary PUFAs.

Microalgae-derived DHA supplements markedly enhanced the DHA status levels in serum and platelets of healthy vegetarian subjects. Researchers also found a substantial increase of EPA and a lowering of total and LDL-cholesterol: HDL-cholesterol ratios, suggestive of a decreased risk factor for heart disease in the DHA algal supplemented group.[283] Microalgae supplementation may be especially important for vegetarians who have a limited intake of fish and eggs.

Vegetarians, especially vegans who eat no animal products (i.e., no fish, eggs, or dairy), tend to have lower serum and platelet phospholipid levels of DHA and EPA than omnivores.[284] DHA is found in high levels in the brain and retina, where it functions in mental performance and visual acuity, respectively.[285] EPA and DHA may help to reduce the risk of developing cardiovascular diseases. Although vegetarians tend to have a lower risk for cardiovascular disease, due partly to their lower serum cholesterol levels, their thrombogenic (stroke) risk factors may be significant.[286]

The ability of *AFA* algae to lower blood cholesterol in animals was also reported by Kushak's Massachusetts General Hospital research group. Rats fed diets supplemented "with 10% and 15% algae decreased their blood cholesterol level to 54% and 25% of…[the levels of the] rats fed the standard diet." The researchers concluded that the cholesterol-reducing effect of *AFA* is probably influenced by something other than just its fatty acid content, because both experimental and control diets were rich in PUFAs. They propose that microalgal pigments, such as chlorophyll, might contribute to this cholesterol-reducing effect.[287] Several prior studies had demonstrated lower blood cholesterol levels with the dietary intake of microalgae.[288-290]

Japanese White rabbits fed on a ten-week load of high-cholesterol diet and powdered *Chlorella,* showed a significant suppression of total and beta-lipoprotein cholesterol levels, along with less aortic atheromatous lesions. However, rabbits in the control, with no algae in their diet, showed a dramatic increase in serum total cholesterol and beta-lipoprotein cholesterol levels, with resulting symptoms of atherosclerosis.[291]

Chlorella, both in powder form and in glycolipid (GL) and phospholipid (PL) extracts suppressed the increase of serum cholesterol levels caused by the administration of a high-cholesterol diet to rats. There was no significant difference between using the algal powder form or the extracts in terms of effect on the serum lipid. But the algal extracts were more effective in increasing the fecal excretion of steroids (mostly cholesterol, deoxycholic, and lithocholic acid). It was concluded that algal extracts inhibited the absorption of exogenous steroids and promoted the turnover of bile acids in the liver, which suppressed the increase of serum cholesterol levels caused by the high-cholesterol diet.[292]

Scenedesmus (a green microalga) powder fed to rats on a cholesterol-enriched diet prevented the excessive deposition of cholesterol in their livers. The algae-supplemented rat livers weighed about one third less than the control rats. Also the levels of plasma cholesterol and triglycerides were significantly improved in the algae-supplemented rats.[293]

The docosahexaenoic acid (DHA) and alpha-linolenic acid (LNA) in certain microalgae support heart function and may help prevent heart attacks.[294] Also, the carotenoids that are so plentiful in microalgae may reduce the risk of heart disease.[295]

Homocysteine blood levels are a significant predictor for risk of heart attack, the number one killer of adults in America.[296] Importantly, homocysteine can be transformed into the amino acid methionine—its beneficial alter form—with the help of B vitamins; especially folic acid in conjunction with B-6 and B-12. Microalgae contain a variety of B-vitamins and methionine.

Dietary hyperlipidemia caused by a high-fructose diet in rats was improved by blue-green algae supplementation. Male rats fed on a high-fructose diet (68%) showed heightened hyperlipidemia, while experimental, algae-supplemented rats had increased lipoprotein lipase enzyme activity, along with suppressed levels of hyperlipidemia.[297]

Hawaiian scientists have developed a way to grow and extract heart-healthy substances from microalgae. Currently a randomized, double-blind trial is underway in association with Michigan State University, to evaluate whether astaxanthin, a natural antioxidant from microalgae, reduces blood serum levels of C-reactive protein (CRP). CRP is an indicator of low-grade arterial inflammation and one of the single strongest predictors of risk of future heart problems in apparently healthy men and women.[298]

Dr. Krylov (University of Illinois) and colleagues concluded, after examining case histories of patients with hypertension who had consumed *AFA* blue-green algae, that this particular algae appears promising for the treatment of hypertension.[299]

Allergy and Asthma Relief

"If you are sitting on a tack, it takes a lot of aspirin to make it feel good. If you are sitting on two tacks, removing just one does not result in a 50 percent improvement."

—Sidney Baker,
Detoxification and Healing, ***1997***

According to James Breneman, former chairman of the Food Allergy Committee of the American College of Allergists, *"The incidence of food allergy is greater than the incidence of any other type of illness affecting mankind. By some estimates, 60 percent of the population have unknown food intolerances or allergies."*[300]

A daily dose of beta-carotene, from an algae extract, demonstrated a protective effect against exercise-induced asthma.

Pediatric studies published in the Japanese journal *Pediatric Clinics* in 1962 reported the use of decolorized green algae in the diets of infants sensitive to milk and soybean formulas. The algae reduced allergic sensitivity and provided a range of nutritional factors found in ordinary milk products. Algae powder has also been used in the United States to reduce seasonal pollen allergies.[301]

Two studies have found that the inclusion of blue-green algae in the diet contributes to a reduction of anaphylactic and immune-type allergic reactions in animal studies. Serum histamine levels are significantly inhibited in rats administered *Spirulina*. These results suggest that blue-green algae may contain compounds that act to inhibit mast cell-mediated, immediate-type allergic reactions.[302, 303]

In another study when *Spirulina* was ingested by mice along with a known antigen (a crude shrimp extract), enhanced IgA antibody levels in the intestines were evident. According to the scientists, these significantly enhanced IgA antibody levels might protect against allergic reaction. Positive effects were found in both *in vitro* studies with lymphoid cells from the spleen and mesenteric lymph nodes, and *in vivo* studies with live animals. The researchers concluded that, "Spirulina *may at least neither induce nor enhance allergic reaction such as food allergy dependent on an IgE antibody, and that when ingested both concurrently with antigen and before antigen stimulation, it may significantly enhance the IgA antibody level to protect against allergic reaction."*[304]

Researchers at Massachusetts General Hospital, affiliated with Harvard Medical School, found that algal oils significantly reduced blood levels of arachidonic acid in rats.[305] Arachidonic acid produces molecules (leukotrienes) that trigger allergic reactions and contribute to water retention (edema) and puffiness. These molecules may be 1,000 times more problematic than histamine in contributing to asthmatic bronchial constriction.[306]

A daily dose of beta-carotene, from an algae extract, demonstrated a protective effect against exercise-induced asthma. Of thirty-eight patients given 64 mg of algal beta-carotene extract daily for one week, 53% were protected from exercise-induced asthma. All of the patients in the placebo condition showed a significant post-exercise reduction of breathing in a forced expiratory volume test.[307]

A pilot study that used a survey developed by the National Center for Health Statistics (1996) reported fewer allergies, skin problems, and asthma among *AFA* consumers. The algae eaters scored significantly better than average on numerous measures of health, when scores were compared to normative baseline data.[308]

In my own research a significant reduction was observed in parents' reports of their children's allergy-type symptoms during a three-month trial on *AFA* supplementation. This study included 26 children and used a standardized health symptom checklist as well as a number of other test instruments.[309]

In Japan blue-green algae is reported "to forestall pancreatic exhaustion and return balance to the flow of enzymatic secretions."[310] Good digestion requires that the body secrete sufficient hydrochloric acid and pancreatic enzymes into the stomach to process foods. Certain food allergies can be traced to poor digestion combined with "leaky gut syndrome" that allows undigested proteins to enter the blood; the immune system reacts to these large molecules as foreign invaders. "*AFA* blue-green algae contains carotenes and chlorophyll, both of which are able to dramatically stimulate specialized cells around the intestinal walls to secrete lubricating material and thus help to prevent this type of allergic reaction."[311] The omega-3 fatty acids are likely to be helpful as well.

Safety Issues

"Since 1950 small amounts of arsenic as arsanilic acid have been incorporated into poultry feed to stimulate early maturation, increase efficiency of feed utilization, produce more eggs, "improve" skin coloring and feathering, and yield more profits…Currently 90 per cent of all commercial chickens are raised with arsenic in their feed…The arsenic-containing feed must be discontinued long enough before slaughter for the birds to eliminate most—but not all—of it from their meat."

—B. Hunter
Consumer Beware*, 1971*

Industrial chemicals and microbial pathogens can contaminate any food. In recent years, the news media have broadcast many stories of illness and death related to bacteria-contaminated poultry, mercury in fish, aflatoxin in moldy peanuts, and viruses in uncooked shellfish. The Food and Drug Administration reports that food-borne infections caused by *Salmonella* alone are responsible for an estimated 6.5 million cases of human illness and 9,000 deaths annually in the United States.[312]

The primary safety concern with wild-grown algae comes from contaminant algal species that, under certain conditions, may grow in the same lake and thus be harvested along with the food algae. Known toxins that could potentially contaminate edible algae are amenable to regulatory assessment, using reliable laboratory analysis for signs of toxins, along with safety guidelines and consumption rates for the food.[313,314] A reputable microalgae company will guarantee that accurate and independent tests are done on each batch of harvested algae to ensure purity and safety.

Another concern is how fresh or nutritionally intact the final product is. One of the best freshness indicators for microalgae is the amount and kind of chlorophyll breakdown products it contains. In one comparison of five companies that harvested wild microalgae the percentage of intact chlorophyll ranged from 0 to 65% (average of 21%).[315] Breakdown products of chlorophyll include pheophytins and, potentially, pheophorbides. The latter are known to be toxic. Careful harvesting and avoidance of heat will minimize these breakdown products. The same is true of any species of microalgae and also of all chlorophyll-rich "green" foods.

Other species of microalgae, such as *Spirulina* and *Chlorella,* are typically grown in man-made ponds where the environment is subject to control. However, *"Growing just one kind of algae in a pond is not an easy feat. Hundreds of aquatic organisms can flourish in pond water…Unlike a garden, weeding out unwanted algae becomes a difficult task since this algae is microscopic…An algae farm can keep out weed algae by balancing the pond ecology, without resorting to poisons used by conventional agriculture. Each farm has its own trade secrets."*[316]

Unlike *AFA,* which flourishes only in highly alkaline water unfriendly to most other algae, *Chlorella* grows in normal water conditions where other undesirable weed algae easily grow. Also because its cell size is so tiny—only 2 to 8 thousandths of a millimeter in diameter—it cannot be harvested using screens the way blue-green algae can be. Instead, each pond is harvested all at once using centrifuges. Because *Chlorella* has a hard cellulose cell wall, an elaborate drying process is used to crack open the cell wall or mechanically crush it. Though *Chlorella* can only be farmed in a highly controlled environment, strict procedures and safety testing are still required.

Likewise, while *Spirulina,* a blue-green alga, is the most easily domesticated and farmed commercial algae, the need for rigorous growing, testing, and processing standards also applies. *Spirulina* is grown worldwide and the standards and purity of harvested microalgae vary considerably.[317] In 1982 US Customs and FDA agents blocked *Spirulina* harvested from Lake Texcoco (the location of the original Aztec floating gardens) due to persistent quality and contamination problems. Additionally, traces of microcystins are also present in *Spirulina* products.[318] It is important to know where any microalgae comes from and the manner in which it is harvested, tested, and processed.

Harvesters of wild algae need to take extra precautions to ensure that the surrounding environment and the microalgae are safe from external sources of contamination. For example, Cell Tech International, the largest and oldest harvester of *AFA,* has its own in-house testing and quality assurance program. Furthermore, the company also uses independent laboratories to conduct purity analyses on every batch of algae it harvests. These tests include heavy metal assays, pesticide assays, extraneous substance detection, and moisture content analysis, as well as toxicity analyses for algal-toxins from dangerous species, bacterial analysis, and pigment

analysis to measure chlorophyll intactness. "Redundancy testing" by two independent laboratories is used to compare each finding on every batch, to help ensure greater reliability. Finally, the Oregon Department of Agriculture regularly tests algae-harvesting companies for the presence of microcystins in their products.

Risk assessments have been performed by researchers at the University of Illinois; by Dr. Gary Flamm, former head toxicologist at the Food and Drug Administration (FDA); and by the Oregon Health Division. The proposed safe levels varied between 1 and 15 parts per million (ppm). Because a thousand-fold "uncertainty factor" is used to establish conservative safety limits, the levels where microcystin-LR actually demonstrates any harmful cellular effects are around 10,000 to 15,000 parts per million. Still "the health risk posed by exposure to cyanotoxins is difficult to quantify, since the actual exposure and resulting effects have still not been conclusively determined, especially for the human situation."[319]

The current legal limit for microcystin is based on the "no adverse effects limit" determined in a 1994 study, and then further reduced by a "safety factor" of 1,000 by the ODA. This conservative limit—similar to that in force for Canadian public drinking water—was determined using a procedure in which mice were tube-fed with pure microcystin extract in water. However, the toxic effects of food-borne microcystins are further reduced. In a recent study published in Ecotoxicology and Environmental Safety, researchers re-examined the toxicity issue, but instead of using microcystins in a water solution, they used a diet of ordinary rodent food combined with *AFA* that was contaminated with twenty times the legal limit of microcystin.[320] That would be at least 20 parts per million.

Even at extreme concentrations—the equivalent of a human ingesting 15,000 capsules of AFA *per day—Dr. Jensen found no toxic effects on human blood cells.*[324]

This method of combining microcystin contamination with algae and ordinary food more closely approximates the way humans would be exposed if they were to eat contaminated algae. The mice tested at the highest consumption rate were fed a quantity of algae that corresponds to a human eating over 2.3 pounds of *AFA* (4,600 capsules or 1150 grams) per day. Yet no adverse effects were seen at these extreme levels. To put this into a larger perspective, if aspirin were used instead of algae tablets, all the rats would have died the first day. Still the researchers felt that a conservative safeguard would be limiting microcystin food consumption to 10 parts per million, daily.

Three other studies have also determined that the regulatory limit for microcystins in the *AFA* harvesting industry is many thousands of times (ppm) below the acceptable safe limit for humans.[321-323]

Dr. Gitte Jensen, an immunologist affiliated with McGill University, sought to establish a level at which uncontaminated *AFA* algae might exert a toxic effect on human blood cells. She created various dilutions of live blood mixed with *AFA* algae and observed the reactions. Even at extreme concentrations—the equivalent of a human ingesting 15,000 capsules of *AFA* per day—Dr. Jensen found no toxic effects on human blood cells.[324]

Furthermore, she also collected blood from long-term *AFA* algae consumers to look for any signs of liver enzyme impairment. Her concern was to detect any signs of liver damage due to possible contamination with microcystin, a known liver toxin. Dr. Jensen discovered that long-term *AFA* algae consumers showed no signs of liver enzyme impairment. As a further precaution, Dr. Jensen looked for any signs of increased cellular inflammation, which is also associated with microcystin toxins, but found none. Instead she discovered that *AFA* algae exerted an inhibitory effect or even reversed inflammatory conditions.[325]

Yet, there are a few reported cases of allergies to microalgae, typically in mold-sensitive individuals.[326, 327] Because molds and some microalgae grow in very similar conditions, individuals sensitized to mold may likewise show a similar symptom pattern of response to microalgae, as is occasionally reported with *Chlorella*. Yet these researchers concluded that *Chlorella* is a "weak" allergen even in atopic children with multiple sensitivities. Overall, most children exposed to *Chlorella* do not show any signs of allergic reactions.

Finally, low grade processed microalgae may pose a risk to photosensitive individuals. Japanese medical researchers noted that five patients who consumed *Chlorella* developed photosensitization with swelling and "erythematopurpuric lesions" on sun-exposed areas of their body. The scientists believe that pheophorbides and their esters in the *Chlorella* tablets are photosensitizing agents.[328] It is interesting, in this regard, to note that pheophorbides are toxic breakdown products of chlorophyll and have been found in some brands of less carefully processed algae. St. John's wort, a popular herb used to relieve mild depression, is also known to contain potential photosensitizing agents.

Conclusion

"In blue-green algae…we find three and one-half billion years of life on this planet encoded in their nucleic acids (DNA). At the same time, all microalgae supply that fresh burst of primal essence that manifested when life was in its birthing stages. At a moment in history when the survival of the human species is in jeopardy, many people have begun instinctively to turn to these original life forms for nutritional support."

—Paul Pitchford
Healing with Whole Foods, *1993*

By this point anyone who has taken the time to read this extensive collection of microalgae health research must realize that a vast, relatively untapped biological resource is available. Comprising a hefty share of the world's biomass, algae have an enormous effect on the biosphere. It is humbling to consider that many of the challenges humanity is currently struggling with—trying to develop sustainable sources of food and energy, restoring the environment, as well as protecting ourselves from harmful toxins, infections, and cancer—are ones the lowest species on Earth have long since resolved.

It would be irresponsible on my part not to recommend more research and not to temper my enthusiasm with the reminder that we know far less about the benefits of microalgae than we need to know. Some of the early research promises will not prove robust, reliable, or useful, while many more microalgae benefits are likely to be discovered. We have only begun to uncover the many gifts of algae and to learn how we may best align with these extraordinary partners to help restore our health as well as our planetary home.

The following are some predictions about where microalgal health research might be headed over the next few decades:

1. A critical mass of research on microalgae's benefits will tip the scale and draw worldwide scientific and public interest. Similar to what occurred with St. John's wort and *Ginkgo biloba,* once microalgae's health benefits are well documented, they will be sought. This industry will shift from its current reliance on anecdotal "testimonials" to the use of scientific research to capture the public's interest and demand.
2. As the "baby boom" generation becomes the "senior boomers," microalgae will be used to combat critical problems associated with aging and to increase life span. For example, age-related digestive problems have already created a multibillion-dollar industry out of antacids, which merely mask symptoms and can exacerbate underlying health problems (as well as increase risk for food-borne illness). Algal antioxidants will increasingly be relied upon to prevent cellular breakdown from occurring in the first place.
3. Further research is anticipated on the brain and mood enhancement effects of eating microalgae, especially *AFA*. Microalgae appears to offer the brain-protective benefits associated with herbs such as St. John's wort and *Ginkgo biloba.* Most promising areas are mood disorders like depression and anxiety, learning disabilities, problems of attention, brain injuries, and developmental disorders.
4. Research is needed on the use of microalgae in substance abuse and addiction programs. Nutritional support can help substance abusers better detoxify, recover from injuries to the liver, kidney/adrenals, gastrointestinal system, and brain. The mood enhancement benefits of microalgae may help recovery, as well. Algae's ability to support the body in detoxifying from exposure to many commonly found heavy metals, pesticides, and industrial chemicals will also become more valued and recognized.
5. Identification, extraction, and standardization of active algal ingredients, like phycocyanin, carotenoids, sulfolipids, and algal oils will result in microalgae products becoming more recognized in the emerging nutraceutical industry as well as better accepted and more widely prescribed by physicians. This result will be in part due to increased public and professional demand for high-quality standardized nutraceuticals,

along with a need to reduce confusion arising from the barrage of herbal and nutritional product claims.

6. A range of human clinical trials will be conducted in promising areas that animal research and retrospective case studies have already identified. Research on microalgae's anti-cancer, as well as antiviral effects, and its immune-enhancing benefits will certainly grow. Additional clinical research will likely include: diabetes, hypoglycemia, cardiovascular disease, fibromyalgia, rheumatoid arthritis, chronic fatigue, brain injury and Alzheimer's disease, to name a few.

In conclusion, the remarkable multi-billion year journey of microalgae is not yet over. There are many more volumes of information that we will learn and unravel from these most primitive of species. In microalgae there exist relatively "undiscovered kingdoms" that will eventually yield numerous health benefits. Survival codes found in ancient lineages of microalgae offer a biochemical pharmacopoeia that will increasingly be valued and used in the twenty-first century. Potent antioxidants, trace minerals, essential fatty and amino acids are readily available in microalgae, along with novel biomolecules that still await discovery. As humanity collectively reaches into this primal matter, many new surprises and applications will surely be found.

Appendix

Human health, the primary concern of this research review, is not the only arena in which microalgae show promise for solving some of humankind's more pressing problems. I would like to present here a few areas in which the potential application of microalgal technologies seems most promising.

Global Hunger Reduction and Ecological Restoration

"The possibility of cultivating crops of vegetation on the vast areas of the open ocean…has gripped the imaginations of a growing number of technicians and planners throughout the world. If successfully realized, this technology would enable the planet's oceans to become a huge new source of feeds, foods, fuels, and chemicals—fixed carbon and fixed nitrogen—for the benefit of humanity."

—H. Wilcox,
The Ocean as a Supplier of Food and Energy, *1982*

"As we enter the new millennium, nearly 800 million of the World's population will remain chronically malnourished…Eradication of nutritional deficiencies among woman and children on a global scale are needed to ensure improved quality of life for the next generation of citizens."

—Iyengar and Nair,
Science Total Environment, *April 17, 2000*

The major advantage of algae as a source of protein is in terms of economical land and water use. A one-quart jar may hold billions of microalgae cells that can double on a sunny day. Best yet, microalgae can be sustainably cultivated on marginal (agriculturally poor) land or in the ocean.[329] This ability is significant, as the UN Environmental Program (UNEP) reports that "11 billion acres—35% of the earth's land surface—are threatened by desertification and, with them, fully one-fifth of humanity."[330] Furthermore, it is estimated that the world population will increase by nearly 30% in the next two decades, while fertile crop lands are decreasing.

One of the greatest challenges facing humanity in the 21st century will be addressing the imbalance between increasing food production and restoring a healthy environment. The loss of prime agricultural lands will continue as population pressures increase and the rising "greenhouse" atmospheric effect remains unchecked. In the equatorial regions where malnutrition, over-population, and climate change are most intense, microalgae cultivation for food and fertilizer is most promising. As cheap oil, water, and land resources are depleted over the next few decades, food prices may dramatically rise. Modern agriculture is highly dependent on cheap petrochemical fertilizers, topsoil, and groundwater. In comparison to beef, microalgal protein is hundreds of times less wasteful in terms of topsoil, water, and land use. Another alternative is the increasing use of genetically modified food species that pose unknown and potentially huge risks to our environment.

Land management studies suggest that it takes hundreds of times more land and water to make a pound of beef than a pound of vegetables.[331] But when vegetables are compared to microalgae still greater gains are realized. *"Algo-culture systems can produce up to 15,000 kilograms of proteins per acre per year. This is almost 20 times the per-acre yield of soybeans, which is the highest yield obtainable through conventional agriculture. Through algo-culture, in theory, a protein supply adequate for the entire planet could be produced in an area the size of the state of Maine…From the standpoint of food energy, our algal cultures have yielded dietary energy on an area basis at rates 8 times as great as that of sugar beets, 22 times as great as that of corn, and 45 times as great as that of potatoes…[and could supply] up to two thirds of the protein supplied by fish for adult humans, without impairment of nitrogen retention."*[332]

"Once scientists better understand how to cultivate microalgae in seawater, new food producing areas can open up on the more than 10,000 miles of accessible desert coastline in hot climates. Coastal farms could produce food and support new ecological industrial zones, recycling industrial carbon dioxide and mineral wastes into food. Marine algae farms could be built along the coastline of Baja California, Peru and Chile, West Africa, Mediterranean North

Africa, Indian Ocean coasts of East Africa, Egypt and the Arabian Peninsula, India and Australia. Many of these coastlines are close to famine threatened areas with millions of people."[333]

Given our current course, the time will come when microalgae cultivation will play an essential role in meeting the food needs of a protein-hungry world. Much of the developing world currently depends upon fish as a protein source. However, our global fish reserves are being rapidly depleted, while animal protein is too inefficient and environmentally wasteful. Though people can exist on algal protein exclusively for long periods of time, it is unlikely that microalgae will be eaten in the same way as wheat or rice. The best dietary results are achieved when algae is used to supplement a varied diet. Used in this manner, even a single gram or two of microalgae daily goes a long way.

Microalgae and the Greenhouse Effect

"Life in the Earth's biosphere depends on the balance of gases in the atmosphere… with two-thirds of the world's biomass, algae has an enormous effect on the biosphere."

—R. Henrickson,
Earth Food Spirulina, ***1989***

Because algae were the first organisms to extract oxygen from water, they undoubtedly played a central role in the oxygenation of the air. "Photosynthetic carbon fixation by phytoplankton [microalgae] is a key component of the global carbon cycle."[334] Algae and higher plants produce sugar and oxygen photosynthetically through a process of carbon-dioxide assimilation. Acre for acre, algae are the most efficient transformers of CO_2 and producers of oxygen—much more efficient than trees or other life forms.

Preliminary studies report that a photosynthetic artificial lung could be developed, using micro-algae technology, as a human life support system. Microalgae might effectively be used to catalytically convert blood CO_2 to O_2 directly across a semipermeable membrane device, needing only an adequate light source.[335]

Microalgae's photosynthetic efficiency has led some pioneers to suggest that our current dangerous rise in CO_2, which contributes to the escalating greenhouse effect, might be reversed by creating numerous algae ponds throughout the world, especially in poor soil and hot climate conditions. Futhermore, during glacial periods, low atmospheric carbon dioxide concentrations have been associated with increased oceanic carbon uptake, particularly in the southern oceans.[336]

Phytoplankton, such as diatom microalgae, are capable of drawing huge amounts of atmospheric CO_2 and transporting it to the ocean depths. In the Arctic waters near the poles, the factor limiting phytoplankton algal blooms appears to be a lack of trace minerals, such as iron. It has been proposed that by adding ferric iron to the oceans or stirring up nutrients from the bottom, it might be possible to stimulate enormous ocean microalgae blooms and significantly reduce atmospheric CO_2 levels.[337, 338] However, much controversy exists regarding the effectiveness or even the wisdom of trying such an approach. First, no reliable models exist to predict the influence of microalgae oceanic uptake of atmospheric carbon dioxide (CO_2) as related to global warming. Secondly, there could be unforeseen dangers to the ocean environment. Thirdly, small pilot projects have yielded mixed results.[339, 340] Still, a few scientists who advocate this approach say the main risk in trying larger scale experiments would likely be an increase in the population of the whales that would feed off these phytoplankton blooms.

Microalgae as Fertilizer and Animal Feed

"We have noticed already that the dogs and cats are not shedding nearly as much since we started them on microalgae."

—C. Peterein, D.V.M., 1993

Algae has been used as a fertilizer for thousands of years in Japan. In fact, the initial domestication of rice and the use of algae as a fertilizer occurred close together. "Nitrogen-fixing blue-green algae have been cultivated in Southeast Asian rice paddies for a thousand years to increase rice production. A 1981 UN FAO [Food and

Agriculture Organization] report, "Blue-Green Algae in Rice Production," documented the possibilities of blue-green algae replacing chemical fertilizers and rebuilding the structure of depleted soils."[341]

"In Europe for a number of years people have been feeding domesticated animals on seaweeds when regular fodder is insufficient. They probably got the hint for this policy from watching wild animals feed on sea vegetables. Incidentally, sea vegetables stimulate animal appetites…The history of seaweeds, especially kelp, as fertilizer is very old. In Europe, kelp meal was effectively put to this use in the twelfth century."[342]

"Prior to 1960 most animal feeding research with algae was performed on rats and chicks. The Grain Processing Corporation of Muscatine, Iowa produced about two million pounds of algae (grown on corn liquor) and fed it to chickens to enhance formation of yellow pigment in egg yolks. [Currently one company is supplementing chicken feed with algae to increase DHA levels in eggs]…Dr. Combs fed chicks a diet containing Chlorella *as a substitute for soybean meal. He found that when algae were substituted for 10% of the soybeans in the diet, a more efficient utilization of protein resulted and led to a significant improvement in growth."*[343]

Numerous studies have documented the effectiveness of algae as a high-quality feed for animals. Microalgae have proven to be an effective animal feed supplement, providing higher quality protein and better trace mineral uptake than many conventional foods. Benefits have included more rapid weight gain, enhanced immunity, and larger litter sizes.[344-351] The variety of animals successfully given algae feed are many, including, fish, rodents, birds, cats, dogs, pigs, horses, and cows.

"Most raw powdered algae was not very palatable to livestock [in high amounts]. This problem was almost entirely overcome by a University of California at Davis research group, which included Drs. Harold Hintz, Hugh Heitman, James Meyers, Bill Wein and Dick Grau, when they made pellets from processed algae and steam-rolled barley. The cost of pelletizing algae is about ten dollars per ton of final feed or about one dollar per ton of algae."[352]

Algae is also useful in waste treatment, both directly and in conjunction with its role as animal feed. In a simple waste treatment system, such as the one used in the town I live in (Pacifica, California), the municipal sewage treatment plant uses marsh plants and algae to help treat the discharged water. In an integrated biological system, algae is used to break down fecal waste and is later collected and used for animal feed. In other words, in the latter system algae plays two roles—one as a direct means of waste treatment, the other as a commercially valuable by-product. The first effective prototype of this kind of system was designed by Dr. Oswald at the University of California at Berkeley (of "Algatron" fame) in cooperation with the Davis campus research team. They cultivated algae in a one-million-liter-production pilot pond and then fed large animals with algae grown on waste products.[353]

Microalgae as an Aid in Water Purification and Conservation

"If Americans reduced their meat consumption by only ten percent for one year, enough grain would be freed up that we could feed everybody who will starve to death this year [were methods of equitable food distribution available]."

—B. Resenberger,* The New York Times, *October 25, 1974

A few facts make clear the relationship between meat production and the threat to our water: First, modern beef production both pollutes our water and wastes it. *"Every 24 hours, the animals destined for America's dinner tables produce 20 billion pounds of waste. That is 250,000 pounds of excrement a second (more than enough to fill a typical family's home). The livestock of the United States produce twenty times as much excrement as the entire human population of the country. Over half this staggering production comes from confinement operation from which it cannot be recycled…the result is their waste tends to end up in our water."*[354]

Second, animal "farm/factory" manure accounts for over ten times as much water pollution as the entire human population's fecal wastes. It is also important to note that *"over half the total amount of water consumed in the United States goes to irrigate land growing feed and fodder for livestock. Enormous additional quantities of water must also be used to wash away the animals' excrement…It takes up to a hundred times more water to produce a pound of meat than it does to produce a pound of wheat."*[355]

North Americans are headed for an ecological and economic disaster based on the inefficient use of water wasted for raising livestock. Huge drops in the groundwater tables are occurring. Wells are going dry. The great Ogallala Aquifer may be depleted in 35 years—13 trillion gallons of water used mostly to produce meat each year. It is estimated that the water that goes into raising a 1,000-pound steer would float a Navy destroyer.

"Reports by the General Accounting Office, the Rand Corporation, and the Water Resources Council have made it clear that irrigation water subsidies to livestock producers are economically counterproductive. Every dollar that state governments dole out to livestock producers, in the form of irrigation subsidies, actually costs tax payers over seven dollars in lost wages,…most of the water goes to produce livestock, either directly or indirectly. Thus, current water use practices now threaten to undermine the economies of every state in the region."[356]

Our choices appear simple. First, mandate that sizable animal factory farms use integrated wastewater treatment systems, such as microalgae to: (a) better recycle waste water, so less new water would be needed; (b) minimize water pollution run-off that is tainted by animal excrement; and (c) use far less land and irrigation to grow feed-crops for animals, as algae by-products could supplement their food. Second, children and adults need better education as to the wastefulness and the environmental impact of current animal factory farming practices. If this program were the only contribution microalgae made to global restoration that would be valuable enough.[357, 358]

Microalgae aquaculture wastewater treatment system efficiencies vary, but have reached as high as 100% in their removal of phosphorus, nitrogen, and ammonia by the end of the treatment period. Additionally, applied aquatic systems have demonstrated a reduction of heavy metals in the range of between 52.3% and 100% in the batch system and 64.2% and 100% in continuous system designs.[359]

Microalgae Technology and Toxic Clean-Up

"Some things are clear. We must begin by understanding that there are real costs that we pay for pollution, even if they are not printed on each object's price tag."

—H. Needleman, P. Landrigan,
Raising children Toxic Free, *1994*

Industrial and human waste steadily pollutes our world. The amount of toxic by-products discharged into our air, water, and landfill is staggering. Unfortunately, it appears that the task of clean-up is being left for future generations. Take just one example, *"Today there are about 15,000 publicly owned wastewater treatment works in the United States, discharging approximately 26 billion gallons per day of treated wastewater into lakes, streams and waterways…[about] fourteen percent—approximately 28 million pounds per year—winds up in sewage sludge… Over 60,000 toxic substances and chemical compounds can be found in sewage sludge, and scientists are developing 700 to 1,000 new chemicals per year."*[360]

Bioremediation generally uses microbes (bacteria, fungi, yeast, and algae) to remove heavy metals and break down chemical toxins. New bioremediation techniques are emerging based on dramatic advances in biotechnology. Algae will be increasingly relied upon as environmental garbage collectors in the new millennium.[361-364]

Bioremediation is the favored approach for processing biological wastes and may play an increasing role in concentrating metals and radioactive materials to reduce toxicity and to recover metals for reuse.[365-371] Microalgae and bacteria used to degrade organic chemicals can then be used in waste-site cleanup operations, as well as in pollution management.[372-374]

Bioremediation methods have already proven themselves to be cost-effective and beneficial additions to chemical and physical methods of managing waste and environmental pollutants.[375] Recently developed rapid-screening assays may help in the future to identify organisms, like strains of microalgae, that are capable of degrading specific wastes. Advanced biotechnology techniques can potentially be used to increase these particular algal metabolic pathways. Of course, a danger implicit in using biologically modified organisms for environmental clean up is that their release into the environment may inadvertently upset other life forms.

Yet, because microalgae readily grow inside isolated, controlled bodies of water, environmental factors could be created that are quite different and more easily regulated than those in the world at large. For example, a culture might be produced that only grows in water with a high level of cadmium. Conceivably, use of microalgae can avoid problems associated with higher plant sources. Because higher plants spread pollen over many miles, as part of their reproductive cycle, they can be extremely hard to control once released into the environment. But microalgae are less likely to present this particular problem. Finally, because microalgae rapidly regenerate, they offer a novel biosorbent that may even be repeatedly used.

The Future of Microalgae as a Sustainable Energy Source

"Low-level plants like the algae are a greater source of natural fuel energy than more elaborate, sophisticated plants. Coal, which is produced largely from ferns, is a better fuel than firewood. And petroleum, which is formed from living organisms, including unicellular, low-level algae…is superior to coal as fuel…the potential power of the lower-level plants is greater than that of higher-level plants; but, only after much scientific investigation, was it discovered that this potential in the form of petroleum can be turned into kinetic energy…Probably the utilization of sea vegetables [algae] can have the same revolutionizing effect…that the use of petroleum has had on human industry and civilization."

—Arasaki S, Arasaki T,.* Vegetables from the Sea, *Japan Publications, 1983

A most important difference between fuels derived from fossilized sunlight (oil reserves are the ancient remains of organic matter) and those created from current sunlight (e.g., algae) is that one is limited and the other is renewable. Also, when fossil fuels are burned they release CO_2 that has been stored for millions of years. Algae, or any biomass fuel, merely recycles current CO_2, adding no additional greenhouse gases to the atmosphere. Furthermore, a suitable climate to grow microalgae fuel is along the equator, the location of most of the world's poorest countries. The great gap in wealth between the richer and poorer countries might be somewhat reduced by utilizing algae-fuel technologies.

"Recently several methods have been developed to use Chlorella *as a source of energy. One of these (developed in Canada) grows* Chlorella *in conjunction with a yeast or bacterium which feeds on the* Chlorella. *The yeast then develops fat cells which contain a hydrocarbon oil almost identical to crude oil. Another method produces algae which is almost 50% oil (by dry weight). This oil is then extracted to form a fine grade crude from which gasoline as well as all the other products derived from petrochemicals can be produced. (Petrochemicals are the source of all plastics, many dyes, paints, pharmaceuticals, etc.)"*[376]

While a special oil-rich microalga, *Botryococcus braunii,* occasionally contains up to 85% hydrocarbons of its dry weight under natural conditions, considerable basic research will be needed to reliably achieve these levels in mass-production.[377] As yet there has not been a suitable method developed for microalgal hydrocarbon production on a commercial-scale.[378] However, with increased biotechnology and understanding of the genetic regulation and environmental parameters that control hydrocarbon-producing capacities, the day may come when the commercial production of microalgal hydrocarbons becomes a reality.

"The exploitation of photosynthetic microorganisms affords the only feasible approach to bioproduction of hydrocarbon oils. Photosynthetic microalgae: (a) use sunlight as energy for biochemical synthesis from inorganic compounds; (b) can be intensively cultivated in bodies of water generally considered unusable for domestic purposes; and (c) accumulate trace metals and synthesize proteins, carbohydrates and vitamins thereby making excellent livestock feed or fertilizers. Particularly important is the fact that the cultivation of microalgae for the purpose of producing fermentation products is unlike other biomass programs in that all endproducts increase our biomass rather than decrease it. Such rewards make the search for the hydrocarbon producing algae a most exciting one."[379]

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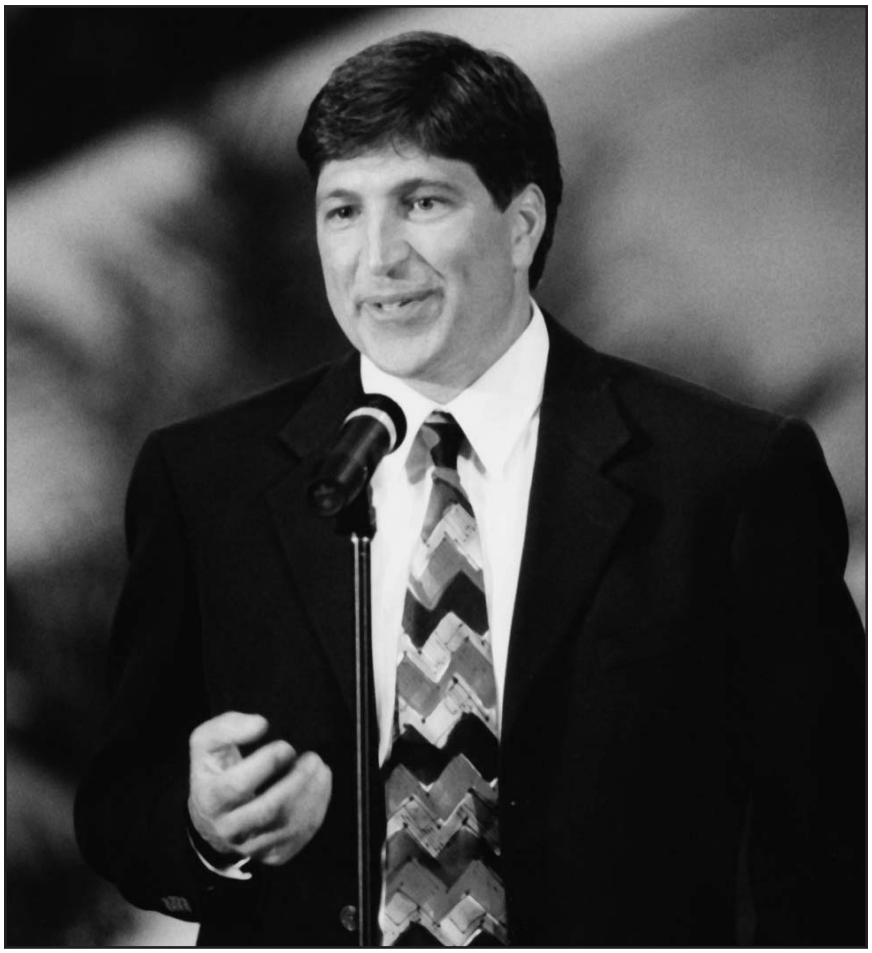
When I was a child I often dreamed of becoming an oceanographer. Now as a psychologist I dream of how these tiny "living flowers of the water" offer keys to open a treasure chest of optimal health, longer life, and a green sustainable future. Where some see an ugly primal slime, I see a beautiful reminder that if we but take the time to appreciate nature's web, we will see simple patterns that can inform our hearts and minds and raise our humanity.

—Jeffrey J. Bruno, Ph.D.
Pacifica, California



Jeffrey Bruno, Ph.D., director of the Peninsula Child & Youth Assessment Clinics, has a doctorate in clinical psychology and a master's degree in experimental psychology. A licensed psychologist experienced in child and adolescent assessment, he provides in-depth evaluation services for a wide range of psychological, educational, and neurodevelopmental problems. Dr. Bruno is also a published author and lectures nationwide on brain development and diet-behavior relationships. He has conducted several independent studies on the use of blue-green algae with children experiencing learning, mood, and behavior problems.

Dr. Jeffrey Bruno can be reached at:
The Peninsula Child & Youth Assessment Clinics
(Pacifica and Burlingame, California offices)

650-738-0807

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—Jeffrey J. Bruno, Ph.D.