▸ Experimental cultivation of sea lettuce (*Ulva lactuca*) for bioethanol production.

But as the carbohydrates in algae and seaweeds are far more complex than the starch in plants, the processes required to convert them into ethanol are complicated and have not been perfected on an industrial scale. In many instances, there is not yet any detailed knowledge of the biochemical principles involved in the breakdown of complex carbohydrates. Further studies are needed to elaborate effective, biotechnological production systems to bridge this gap. A number of research projects have shown that on a small scale one can use both microalgae and seaweeds to produce biofuels, but commercial viability has been achieved in only a single instance on small, family-run seaweed farms in the Philippines. In general, it has proven to be exceptionally difficult to scale up the results obtained in experimental pilot projects.

At first glance it would appear that the cultivation of microalgae would be most practical for the production of biofuels. They are probably better suited for conversion into biodiesel on account of their lipid content, which might be increased by growing genetically modified varieties. A drawback, however, is that their growth rate is often vastly overestimated. Just the same, there is optimism in some quarters, an optimism fueled by goverment grants. A small Florida company, Algenol, is developing a method for capturing ethanol directly from the microalgae without killing or fermenting them. Particular strains of algae, kept in special bioreactors containing seawater and added nutrients, are exposed to sunlight and carbon dioxide from the atmosphere or power plant emissions. The algae photosynthesize, leading to the formation of sugars inside the cells and these sugars, still in the cells, are turned

Food or fuel?

The global demand for energy is unlikely to decline, regardless of the degree of energy efficiency that it is possible to achieve in the developed countries. Robust, new economies in Asia are expanding by leaps and bounds and the Third World has a large, unmet demand for energy sources. At the same time, a hungry world needs more food. It is, therefore, quite possible that our deliberations about the industrial utilization of algae will be confronted by the same dilemma as the one that has arisen with respect to the growing exploitation of plants, such as corn, soya, and rapeseed, which are often the dietary staples of poor people, for the extraction of ethanol.

There are indications that rising prices and the looming global food crisis are partly due to the diversion of agricultural output from foods to energy production. This raises the fundamental question of the extent to which we should aim to dedicate marine resources to increasing the food supply or to trying to fill the world's insatiable demand for more energy. Another basic question is whether the exploitation of seaweeds and algae for energy production can be carried out in a sustainable manner, so that their capacity to fix carbon dioxide, with its inherent positive impact on the Earth's atmosphere and climate, is not diminished.

Seaweeds in medicine, health care, and cosmetics

Seaweeds in medicine

A variety of seaweed species have been incorporated into traditional Chinese and Japanese herbal medical practice in the treatment of tuberculosis, rheumatism, colds, influenza, wounds, worm infestations, and cancer. Just as it is difficult to dismiss several thousand years of experience with naturopathic medicine, it is equally difficult to establish a firm scientific basis for its beneficial effects, to say nothing of trying to shed some light on precisely which substances in the seaweeds are the biologically active ingredients and what determines their bioavailability. Over and above this, advocates of macrobiotic approaches to wellness will probably maintain that the determining factors are not the individual chemical substances, but the seaweed in its entirety and the synergy between it and the patient in a particular treatment situation.

Nevertheless, many *bona fide* researchers have come to the conclusion that various seaweed species may well contain substances that are biologically

Seaweeds in medicine, health care, and cosmetics

◂ Sea urchins eating seaweeds.

of its precursor bacteria, *Helicobacter pylori*, to colonize the stomach lining. In addition, brown seaweeds contain a long list of terpenes, an umbrella term for a large and varied class of organochemicals. Some of these terpenes exhibit anti-viral and anti-cancer properties and possibly have the potential to counteract malaria. As described earlier, some of the fats (certain glycolipids) and some of the polysaccharides (especially fucoidan) that have already been discovered have the ability to suppress the growth of tumors.

As the search for new antibiotics has intensified in the last few years due to the rapid proliferation of drug-resistant bacteria, attention is increasingly being paid to the substances found in seaweeds and algae that are natural defenses against attacking microorganisms and herbivorous marine fish. The brown algae contain specific tannins and the green and red algae have, for example, acrylic acid and bromophenols. These compounds exhibit antibacterial activity and, furthermore, discourage herbivores from eating the algae. It has been proposed that using a combination of extracts of such bioactive substances from a variety of seaweed species in connection with the aquaculture of fish, would make it possible to dispense with conventional antibiotics in the fish fodder.

A number of reports in the scientific literature suggest that extracts derived from various seaweeds can counteract fungi and mosquito larvae and, therefore, may have potential as insecticides. Currently, research is being undertaken into the use of special algae, for example, transgenic algae, which produce different substances that can serve as a type of vaccine against skin infections and sea lice on farmed salmon.

"The seaweeds have to be there, if the children return home"

Today, fewer than 30,000 Irish men and women speak Irish fluently as their principal language. They live mainly along the west coast of Ireland in small rural districts that are called *Gaeltacht* (Gaelic-speaking). The Irish language together with Scottish (Erse) and the now virtually extinct Manx make up the Gaelic branch of the Celtic language group.

As Irish disappears little by little as a living language, a whole range of words and expressions for things and relationships that have been an integral part of the Irish way of life and that reflect the habits and activities of an earlier culture are disappearing along with them. A good example of this loss involves words for seaweeds, the harvesting of seaweeds, and foods made from them, all of which played a major role in the traditional impoverished Ireland of the past. The Irish author Aidan Carl Matthews (1956-) mourns the death of the Irish language as follows: "The tide gone out for good, thirty-one words for seaweed whiten on the foreshore."

Connemara is a *Gaeltacht* in western Ireland, north of Galway; here the common language of daily life is Irish. When I had the chance to visit Connemara, I had, however, to rely on those who spoke English. Nevertheless, Dara Flagherty used the Gaelic word *cleimín* when he pointed to a large bundle of about 2–3 tons of wet seaweeds, which had been pulled up from the edge of the water in a small bay south of Cill Chiaráin. For the past 15 years, Dara has worked as the seaweed manager of a small seaweed factory, Arramara Teoranta, which was established there in 1947. The most important part of his job is keeping on-going contact with the ca. 320 seaweed harvesters who live along the hundreds of kilometers of coastline. So when Dara said *cleimín*, he meant bundle, but not just any bundle. The word is used only in relation to seaweeds and is one of the 31 Gaelic words related to algae that are on their way to extinction.

The seaweeds that I saw lying at the edge of the water were knotted wrack (*Ascophyllum nodosum*), held together with a long rope. Dara has the challenging task of coordinating the work of the individual harvesters so that deliveries to the factory are steady, regardless of the time of year and the very changeable and harsh weather conditions on the exposed

Epilogue: Seaweeds—edible, available, and sustainable for the future

In this volume, I have attempted to gather together, for the non-specialist, much of the existing knowledge about how humans have used, and continue to use, seaweeds as food, for medicinal purposes, and in a variety of practical and industrial applications.

On one level, the book is intended to show how one can, with little effort, incorporate seaweeds into ordinary dishes to create tastier, healthier, and more interesting meals. On another level, however, this volume is a reflection of my conviction that marine algae should be regarded from a broader perspective as a vital resource for the immediate future. As indicated by its title, I have paid special attention to the three characteristics that strongly support the idea of utilizing them more extensively and in a much more informed way.

Seaweeds are not only *edible*, they are full of flavor and packed with important vitamins and minerals. They make up a vast, diverse group of organisms, which are distinctly different from terrestrial plants. There are presently more than 10,000 known species of marine algae and, as they are widely dispersed all around the globe, they are readily *available* in virtually all climatic zones. In many cases, seaweeds can be exploited in a *sustainable* way, either by harvesting the algae in the wild or by farming them in very large quantities in the ocean, preferably in a sustainable multi-trophic aquaculture.

The implications of edibility, availability, and sustainability are wide-ranging. Seaweeds are a significant nutritional resource and promoting them for human consumption, in both the developed and the developing world, may be part of a solution to the world's urgent need for increased food production and, at the same time, this could result in a healthier diet and help to counteract some of the diseases related to poor eating habits. It is a historical fact that extreme conditions, such as shortage and wars, have created new opportunities for the exploitation of seaweeds.

Seaweeds may constitute an as yet barely tapped source of chemical substances for the development of new active compounds for medicinal purposes and for industrial applications. Seaweeds are also on the radar in the energy sector, where they may be a means of meeting growing global demand and of decreasing the carbon footprint that is attributable to human activities. With a view to solving some of the major problems confronting the transportation sector by finding a replacement for oil and gasoline, plans have