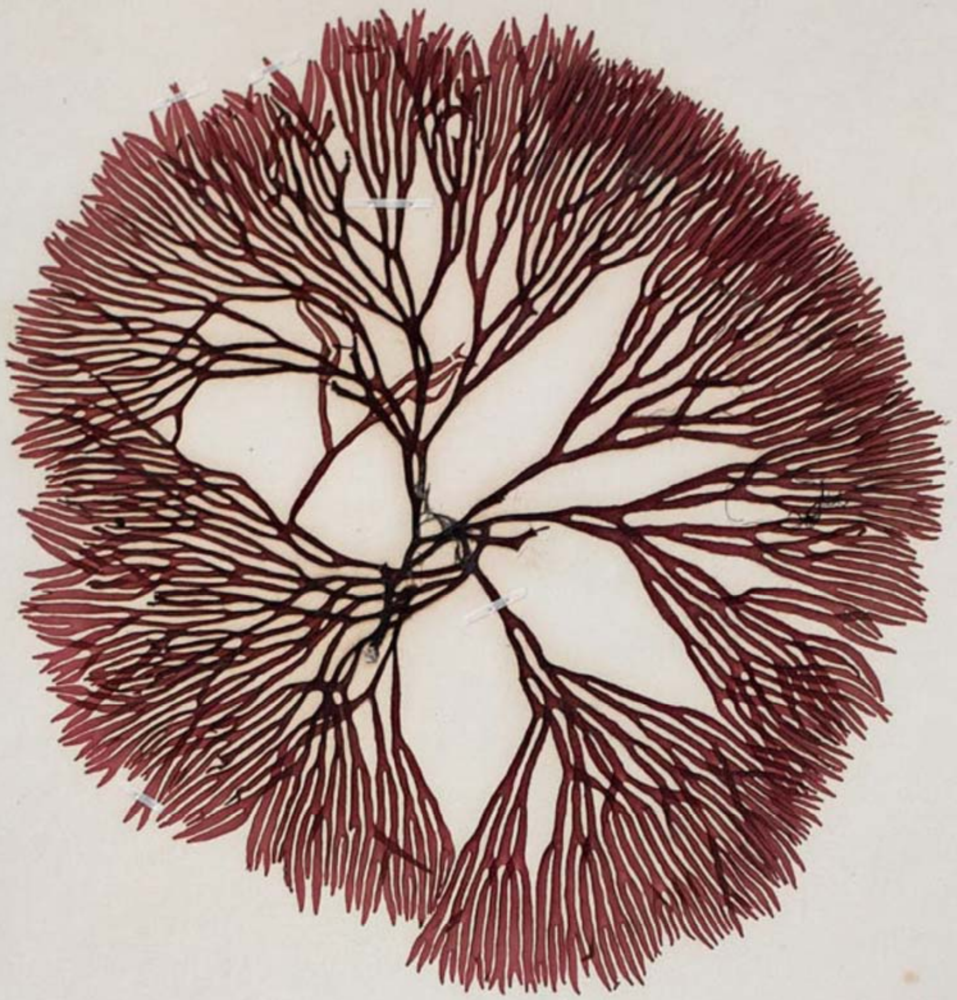

Seaweeds

for

Human Consumption, Bioactive Compounds, and Combating of Diseases

An International Interdisciplinary Symposium

Carlsberg Academy, Copenhagen August 26–27, 2010

Invited Speakers: **Louis Druehl** Canada + **Shep Erhart** USA + **Jane Teas** USA **Stefan Kraan** Ireland + **Philippe Potin** France + **Carsten Christophersen** Denmark + **Prannie Rhatigan** Ireland + **Susse Wegeberg** Denmark + **Susan Holdt** Denmark + **Annette Bruhn** Denmark + **Norishige Yotsukura** Japan

Organiser: Ole G. Mouritsen, University of Southern Denmark, Odense, Denmark
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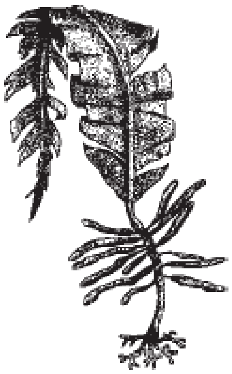
MEMPHYS – Center for Biomembrane Physics *The Royal Danish Academy of Sciences and Letters*



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PROGRAM

Thursday August 26

13.15-13.45 Welcome and introduction (Ole G. Mouritsen)

13.45-14.30 **Kelp farming in British Columbia: technology, ecophysiology, and genetics**
Louis Druehl
(Bamfield Marine Sciences Centre & Canadian Kelp Resources, Canada)

14.30-15.15 **Production of kelp in Japan: various natural resources and established aquaculture technique**
Norishige Yotsukura
(Field Science Center for Northern Biosphere, Hokkaido University, Japan)

15.15-15.45 Coffee and tea break

15.45-16.30 **Algal genomics may offer new insights into seaweed uses**
Philippe Potin
(Station Biologique de Roscoff, France)

16.30-17.00 **Potential for farming edible seaweeds in Denmark, Faroe Islands, and Greenland**
Susse Wegeberg
(National Environmental Research Institute, Denmark)

17.00-17.30 **Cultivation of *Chondrus crispus* in Denmark - production potential, quality and food safety**
Annette Bruhn
(Marine Ecology, National Environmental Research Institute, Denmark)

17.30-18.15 Refreshments and seaweed snacks sponsored by Carlsberg, Canadian Kelp Resources and Main Coast Sea Vegetables

Friday August 27

09.30-10.15	**Sustainably harvesting, processing, and marketing wild seaweeds for healthy eating** *Shep Erhart* (Maine Coast Sea Vegetables, USA)
10.15-10.45	Coffee and tea break
10.45-11.15	**Functional food ingredients in seaweeds, claims and legislation** *Stefan Kraan* (Ocean Harvest Technology Ltd, Galway, Ireland)
11.15-12.00	**Practical everyday use of seaweed for maximum health gain** *Prannie Rhatigan* (The Irish Seaweed Kitchen, Co Sligo, Ireland)
12.00-12.30	**Seaweed research and production in Denmark** *Susan L. Holdt* (Department of Environmental Engineering, DTU, Denmark)
12.30-14.00	Lunch in Pompeji
14.00-14.30	**Seaweeds – curse or blessing?** *Carsten Christophersen* (Department of Chemistry, University of Copenhagen, Denmark)
14.30-15.15	**Overview of clinical and epidemiological studies that include dietary seaweed** *Jane Teas* (University of South Carolina, USA)
15.15	Closing

Venue

Carlsberg Academy, Gl. Carlsbergvej 15, DK-2500 Valby, Denmark

Organizer

Ole G. Mouritsen, the Royal Danish Academy of Sciences
and Letters and the University of Southern Denmark

Sponsors

The Carlsberg Foundation
MEMPHYS – Center for Biomembrane Physics

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Introduction

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Seaweeds are an overlooked source of nutrition in the Western world. Seaweeds are algae and not ordinary plants. They are found in all of the world's climate belts and they display an enormous variation in terms of species. Whereas in many Asian countries, e.g. Japan and China, seaweed products are an important part of peoples' diet, we mostly think of seaweed as the ugly smelling stuff that lies rotten at the beach or which grows in our polluted waters during a hot summer day. However, seaweeds have been used by humans throughout history and across different cultures for different purposes, such as food for humans and livestock, for producing salt and iodine, for medicine and cosmetics, and for agricultural and technical purposes.

Many people encounter unknowingly almost every day extracts of seaweed as additives in food or cosmetics. However, seaweed can be used directly as tasty foodstuff that is blessed with a bounty of important minerals, trace elements, vitamins, proteins, iodine, and healthy polyunsaturated fatty acids. Moreover, seaweed has plenty of dietary fibers and hence contains few calories. Seaweeds can be harvested in the wild or grown in the sea in large amounts in a sustainable fashion. Seaweed was an important component of our ancestors' diet and part of the basis for the evolution of our brain and neural system. Seaweed is brain food. Undoubtedly, seaweed will in the future become a larger part of our daily diet. Importantly, these vegetables of the sea will help us to renew and balance our diet to combat the growth in global lifestyle diseases, in particular cardiovascular and heart diseases, cancer, obesity, as well as mental disorders.

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Kelp farming in British Columbia: technology, ecophysiology and genetics

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Canadian Kelp Resources (www.canadiankelp.com) researches novel cultivation techniques to meet new kelp uses and markets.

Kelp farming consists of "seed" production, ocean grow-out, and harvesting. The kelp farm exploits environmental conditions and facilitates new farming technologies. World production values range from 8 to 40 wet kg kelp/m cultivation rope.

Placement of the kelp farm, adjustment of cultivation depth, and time of planting are ways the growth environment can be manipulated. Near-surface cultivation results in increased phenolics and carbohydrates and deep cultivation results in increased protein and fucoxanthin production, and an elevated nitrate load. Plantings spaced over a few months provide for a larger window of optimal production. Autumn plantings result in "Forced Cultivation" for some species, where the kelp rapidly achieves second year characteristics (1).

Exclusion of blue light restricts sexual reproduction in most kelp species (2). Asexual gametophytes may be grown for over 30 years. Such gametophytes can be cloned and crossed, and successful combinations reproduced for future generations. Early results indicate a unique maternal inheritance in kelp (3) suggesting one should genetically select for features demonstrated by the females "parental" sporophyte.

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Production of kelp in Japan: various natural resources and the established aquaculture technique

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Thirty-seven species of kelp (Laminariales, Phaeophyceae) grow on the coast of Japan. Within them, *Saccharina* (formerly *Laminaria*), whose main distribution area is Hokkaido, has been harvested for 1000 years or more. *Saccharina* is an indispensable ingredient in Japanese traditional cooking. *Saccharina* species have been identified on the bases several morphological characteristics (e.g. Miyabe 1902. J. Sapporo Agric. Coll. 1: 1–50), but most of these characters are unstable. In addition, molecular analyses have shown that there is little genetic difference between the morphological species (e.g. Yotsukura et al. 2008. J. Jpn. Bot. 83: 165-176). Nevertheless, industry recognizes different forms (mostly old morphological species) from specific localities and having different values and uses.
Wild harvest has dominated in the production of *Saccharina* in Hokkaido. However, wild harvest has declined from about 30,000 dry tons per year to a low of about 14,000 tons in 2009. Meanwhile, kelp cultivation, initiated in 1970, which is technically well developed (Kawashima 1984. Jpn. J. Phycol. 32: 379-394), produces about 5,000 tons dry weight per year.

Wild Collecting

Product Name (dry weight from Hokkaido in 2009) : *L. longissima* (5113 tons) , *L. coriacea* (1352 tons), *L. japonica* (600 tons), *L. ochotensis* (600 tons), *L. angustata* (590 tons), *L. diabolica* (309 tons), others without species name such as “kelp for processing” (6,035 tons). Harvest Season: from July to October. Fishery: small scale management by unit of family; collecting by outboard using special equipments such as “hydroscope”, “Makka”, “Kama”, “Kagi” etc.

Cultivation

Hokkaido Localities: Minamikayabe, Hakodate (South), Rishiri-Rebun, Soya (North), Rausu, Shiretoko (East). Product Name (dry weight from Hokkaido in 2009) : *L. japonica* (1228 tons), *L. ochotensis* (290 tons), *L. diabolica* (189 tons), others without species name such as “kelp for processing” (3,031 tons). Harvest Season: from June to September. Cultivation: (1) collecting of wild spore-bearing kelp, (2) production of seedling line, (3) seedling culture indoors, (4) moving to sea, (5) full-scale cultivation (1-3 are done by the fisheries coop); forced cultivation (1 year) and 2 years cultivation protocols.

Algal genomics may offer new insights into seaweed uses

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As a result of their unusual metabolisms, seaweeds produce a number of molecules which attract diverse industries. They are presently used as human foods, and for the extraction of industrial gums and various chemicals used in cosmetics or in agriculture. They have also the potential to be used as a source new bioactives for human, animal or plant health. Currently, the European seaweed industry relies on macroalgae collected from the wild with the exception of carrageenan extraction plants which extract *Kappaphycus* and *Eucheuma* farmed in South East Asia and Eastern Africa. The growing demand of raw material for food, cosmetics and bioactives, raises questions surrounding the sustainability of the European industry. There is an urgent need to upscale or develop methods for mass production of native seaweeds. Regardless of the cultivation techniques, these activities require detailed information about the biology and life cycle of the algal crops and different production options.

Despite this large interest and needs, there are still only one genome of a macroalga that have been completely characterized by an international consortium headed by Station Biologique of Roscoff, the 214 Mbp-genome of the filamentous brown alga *Ectocarpus silculosus* (Cock et al., 2010). The expert analysis of this recently published genome has revealed a great deal both about the biology and about the evolutionary history of this organism. Features such as the metabolic routes for the synthesis of anionic polysaccharides and UV-sunscreens such as phlorotannins, the presence of an extended set of light-harvesting and pigment biosynthesis genes, and novel metabolic processes such as halide metabolism help explain the ability of this organism to cope with the highly variable intertidal environment. There are also some red algae for which full or near-full genome sequences have been secured; these genomes include those of the Irish Moss *Chondrus crispus*, the atlantic nori species *Porphyra umbilicalis* and the coralline red alga *Calliarthron sp*. There have also been projects developed to define algal transcriptomes as determined by cDNA analysis and now using high throughput RNAseq. These recent efforts focused on acquiring and analyzing seaweed genome sequences have generated considerable amount of data that provide an in-depth, comprehensive view of the carbohydrate metabolism of brown and red seaweeds and shine a new light on the secondary metabolism of these organisms. Marine Genomics research is generating new tools, such as functional molecular markers, as well as new knowledge about inheritance phenomena that could increase the efficiency and precision of algal crop improvement. Marker-assisted breeding and selection will be largely accelerated by these novel approaches. Among the traits which are of interest for the selection of algal crops are the defenses against stress and especially biotic stress. Improving the regulation and the production of anti-microbial, anti-herbivore or signaling compounds in maricultured algae is susceptible to yield new bioactives or to provide new bio-processes to produce these valuable molecules.

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Potential for farming edible seaweeds in Denmark, Faro Islands, and Greenland

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The interest of producing seaweeds in the Nordic countries, including Denmark, Faroe Islands, and Greenland, is rising concurrently with the growing demand for CO_2 neutral and sustainable energy. As a consequence of the recent years' focus on production of biomass for bioenergy with its derived complex of problems, and the public focus on health and healthy food, eyes have turned to the "blue biomass" for exploitation for energy and food. Furthermore, the initiation of the Danish aquaculture regulations, including compensation for increased fish production through farming of bioremediative organisms, will also push the need for seaweed farming forward.

Farming of edible seaweeds is certainly possible in all of the Nordic countries but each country possesses its specific challenges to seaweed production which have to be considered evaluating production potential. At present the development of seaweed farming in the respective countries is still in its embryo, and few productions and research projects have been initiated.

In Denmark several factors are important in controlling the natural occurrence of seaweed, some of which also must be considered in connection with seaweed farming; lack of suitable substratum and decline in salinity from northern to the south-eastern waters. Furthermore, nutrient rich waters may promote seaweed farming but may also provide a problem regarding fouling (1). Examples of seaweed cultivation in Denmark illustrate these challenges.

In the Faroe Islands cultivation of seaweed has been performed in preparation for bioremediation in connection with integrated aquaculture (2). Pilot testing of *Alaria esculenta* cultivation demonstrates conditions suitable for seaweed farming. Furthermore, the Faroe Islands possesses a rich occurrence of the edible seaweed species traditionally used for human consumption, and thereby provides sources and potential for cultivation of a number of species.

At present no tests of seaweed cultivation have been performed in Greenland. The Greenlandic seaweed flora includes several of the species traditionally suitable for human consumption, but also offers more exotic species potentially edible. However, seaweed farming in Greenland meets the challenge of long winters, which include ice cover and suboptimal light conditions for long periods of time. It may, however, be possible to identify areas which may prove to be suitable for seaweed farming. Considering the hitherto identified comprehensive seaweed biomass, which naturally occurs along the west coast of Greenland (3), a potential for seaweed farming may be present. Another, yet not tested, approach is harvest of wild seaweed stocks, as conducted in Iceland and Norway.

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Cultivation of *Chondrus crispus* in Denmark – production potential, quality and food safety

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The commercially important carrageenophyte *Chondrus crispus* Stackhouse is common and abundant in Danish waters. Harvest of natural resources of *Chondrus* in Denmark, however, is not sustainable. The potential for landbased cultivation of *C. crispus* in Denmark was investigated in a co-operation between Aarhus University, the Danish Shellfish Centre and CP Kelco Aps, one of the leading international carrageenan producers. The cultivation experiments were carried out in 1 m^2 tanks optimised according to Bidwell et al. (1985).

The average specific growth rates of the *C. crispus* were 1-2 % d^{-1}, with a maximum of 4 % d^{-1}. Four to six kilos of biomass per m^2 was defined as the optimal stocking density, giving a biomass yield of 30 tonnes DW ha^{-1} $year^{-1}$, equivalent to a carrageenan yield of 14 tonnes ha^{-1} $year^{-1}$.
The carrageenan yield of the produced *Chondrus* was up to twice as high as that of *Chondrus* imported from Nova Scotia (47 % versus 23 % of DW), and the carrageenan potency (CAM value) was up to 26 % higher. In addition, the degree of purity of the seaweed was higher than material harvested from natural resources, potentially opening for the production of a semi-refined product. Nitrogen concentrations in the tissue were inversely correlated to carrageenan content (Neish effect) (Neish et al. 1977), but directly correlated to carrageenan quality (CAM value).

Despite the production potential and high quality of cultivated seaweed, two major challenges remain to be overcome to realise a commercial production of Danish *Chondrus*: 1. Cultivation must be less energy intensive. 2. The concentration of total arsenic in Danish *Chondrus* caused the concentration of arsenic in the refined carrageenan product to exceed limit values set by food legislation. The total arsenic concentrations were higher than in *Chondrus* from Nova Scotia, but not higher than concentrations reported from other regions (i.e. Almela et al. 2006).

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Sustainably harvesting, processing, and marketing wild seaweeds for healthy eating

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This presentation will explore some principles of harvesting, processing and marketing wild seaweeds sustainably, using examples from the 40 year evolution of Maine Coast Sea Vegetables.

General principles: start small, use local species, limit capital investment, grow slowly, minimize stress, maximize enjoyment/satisfaction.

Sustainable harvesting principles — balancing extraction rates with recruitment rates. Choose the healthiest beds and plants of well populated species. Check literature for recruitment rate studies. Establish biomass baseline for each harvested species, if possible. Selectively cut in modest amounts leaving 30-50% of biomass. Watch for impacts, population changes and trends. Follow any existing regulations, develop new ones proactively, practice stewardship. Pay harvesters and yourself a living wage.

Sustainable processing principles – balancing time/energy inputs with marketable outputs. Minimize processing with fresh, salted, frozen or dried products. Minimize transport/energy costs from ocean to finished product. Grade plants for different usage/markets. Develop secondary products to incorporate lower grades. Use everything harvested – zero waste.

Sustainable marketing principles – balancing promotional costs with natural value/desirability of products. Find expanding markets, like Organics, Natural Foods, Specialty Foods. Diversify within your niche. Keep products simple, focused, convenient. Establish credibility with good information, consistency, no hype. Practice guerilla marketing by using the media, word of mouth, collaboration, and the internet.

Conclusion: maintaining balance and close connection with the plants, the people, the process, and the products – these are the sources of renewable energy for long term sustainable activity.

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Functional food ingredients in seaweeds, claims and legislation

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Strictly speaking, all food is functional, in that it provides energy and nutrients necessary for survival. But the term "functional food" in use today conveys health benefits that extend far beyond mere survival. Food and nutrition science has moved from identifying and correcting nutritional deficiencies to designing foods that promote optimal health and reduce the risk of disease. The combination of consumer desires, advances in food technology, and new evidence-based science linking diet to disease and disease prevention has created an unprecedented opportunity to address public health issues through diet and lifestyle. Functional foods can provide health benefits by reducing the risk of chronic disease and enhancing the ability to manage chronic disease, thus improving the quality of life. Functional foods also can promote growth and development and enhance performance.

Marine macroalgae have great potential for further development as products in the functional food markets and novel products based on macroalgae have entered the market in recent years. Studies have shown that marine macroalgae are unrivalled sources of compounds with the potential to maintain and improve health through inclusion in other foods or as whole foods. An overview of potential seaweed bioactives together with some aspects on the legislation of functional food products will be presented.

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Practical everyday use of seaweed for maximum health gain

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Seaweeds contain minerals, vitamins and trace elements in addition to components such as phyto-defensive compounds, specific polysaccharides and lipids but unless we actually consume them we are not going to gain much benefit. How many people can count a range of seaweeds as part of their daily 5 or more fruit and vegetables?

The cookbook “Irish Seaweed Kitchen” which is a comprehensive guide to healthy everyday cooking with seaweeds unveils what is under our feet and provides the information necessary to incorporate seaweed into sweet and savory dishes to cater for breakfast, lunch and dinner. Misconceptions abound about taste, texture and aroma. The challenge is to help people change the way they think about seaweeds and to recognize that seaweeds are as diverse as any selection of vegetables available from the garden or a shop.

What are the health gains? While we have some good evidence around nutritional values, anti viral properties and expectorant properties of the various seaweeds there is less research available to support some of the other therapeutic claims. To enable the use of seaweeds in mainstream medicine more research is needed in the areas of cardiovascular health, anti-hypertensives and lipid lowering; bone health; gastrointestinal health; anti cancer and anti inflammatory activity.

Evidence quality is often presented in hierarchical terms with RCTs at the top and anecdotal evidence at the bottom. While we are unlikely to achieve many research results from the top of the pyramid, remaining with anecdotal work will not further the acceptance of seaweeds into the world of therapeutics. In examination of the research perhaps the term “evidence-informed” can be the umbrella under which all forms of evaluated findings are scrutinized.

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Seaweed research and production in Denmark

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Recently, seaweed is attracting more attention in Denmark. All universities have interest in seaweed either because of its potential source of nutraceuticals or bioenergy. However, only few projects have been funded so far. Generally research has moved from basic towards applied science including seaweed research. But that might be moving too fast in a country with little history in seaweed research. How can we know the future product, not knowing the composition of the feedstock? A report, just released by The Ministry of Food, Agriculture and Fisheries, concludes that research within the unexploited resources of the sea, including seaweed, may create social benefits (1).

Furthermore, the authorities now see possibilities in the bioremediation capacity of seaweed, and their potential use in the trading of nitrogen quotas to fulfill the environmental plans set by the European Commission. Bioremediation by either blue mussels or seaweed are also recommended by the Danish marine farming committee. Marine fish farms will be regulated by output in the future and not by input as before. This means that marine fish farmers may need to cultivate seaweed in order to keep up the fish production (2). In addition, seaweed is now part of The Danish Aquaculture Organization regulations (3).

Can industry, universities and authorities carry out this mission? The possible future production of Danish seaweed must not be wasted, but will the researchers or consumers be ready for the feedstock? The Danish Seaweed network may be the link that makes this possible. More than 150 persons from industry, universities, authorities, restaurants, organizations, future seaweed producers, and persons that work with or have interest in seaweed have joined the network (4). This is just the beginning of the mission that is not impossible!

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Seaweeds – curse or blessing?

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In spite of the enormous number of investigations published dealing with secondary metabolites in macroalgae and their biological activities only a very limited amount of ecological, medicinal, toxicological and nutritional facts have been scientifically clarified so far. The main reason for this sad state of affairs is that investigations within this area have traditionally been performed by natural product chemists who have mainly been interested in the often highly unusual chemistry involved. By now this classic model is changing into multidisciplinary approaches involving stakeholders from a wide range of disciplines.

Brown algae

The subjects of nutraceuticals or medicine from seaweeds exemplified by the anti-obesity and satiety effects exhibited by alginates from brown algae as well as the porphyranase activity in Japanese consumers will be briefly touched upon. Geographical variation of three cytotoxic eleganolone diterpenoids in *Bifurcaria bifurcata* will be mentioned. The almost forgotten blood sugar reducing activity of sargalin (*Sargassum confusum*) and the mystery of the antibiotic sarganin complex (from a variety of marine algae) is still unresolved and will be briefly discussed. And does *Desmarestia* really contain strong sulfuric acid in the algal cells? And how about organoarsenicals in brown algae?

Green algae

Green algae have given rise to only a limited number of new structures; however, most of them have unusual chemical features. The structure of caulerpicin from *Caulerpa racemosa* will be discussed. In addition the ecological consequence of the herbicidal and insecticidal activity of charatoxin I and II and the bactericidal effect of charamin from skunkweed in the ancient order Charales will be dwelt upon as will the lachrymatoric effect of some Characean algae.

Red algae

How do red algae advance research in the concept of quorum- sensing and biofilms? Exemplified by *Delisea pulchra* and isethionic acid from *Hypnea musciformis*.

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Overview of clinical and epidemiological studies that include dietary seaweed

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A brief overview of clinical and epidemiological studies that have included seaweed will place our findings in a wider context of current knowledge about the health benefits of consuming seaweed (Hata and others 2001; Irhimeh and others 2009; Irhimeh and others 2005; Kang and others 2003; Krotkiewski and others 1991; Paxman and others 2008a; Paxman and others 2008b; Skibola 2004; Teas and others 2009a; Teas and others 2009b; Tokita and others 2010; Townsend and others 2004; Yang and others 2009). We have conducted 4 clinical trials using dietary seaweed. In our first study, with 33 healthy postmenopausal women, we found that there was a linear relationship between increasing seaweed (*Alaria esculenta*) and decreasing serum estrogen (Teas and others 2009b). Serum estrogen is a risk factor for developing breast cancer and breast cancer recurrence. Seaweed ingestion was also related to significantly higher phytoestrogen metabolism. When consumed in combination with soy, seaweed lowered homocysteine concentrations. In our second study we examined the effects of seaweed in 30 healthy adults with at least one symptom of metabolic syndrome. For both men and women, those people with high blood pressure experienced decreased systolic and diastolic blood pressure with 6 g/d *Undaria* (Teas and others 2009a). Women also had a significant decrease in waist circumference. In a study of 15 healthy postmenopausal women, seaweed was associated with a significant decrease in urinary urokinase, an enzyme associated with bc metastases, and expression of 4 proteins. These changes were reversible. The findings may help explain the 75% lower breast cancer rates for postmenopausal Japanese women in Japan. The last clinical study was of seaweed, spirulina, or the combination of both for people with HIV. None of the 12 subjects were taking antiretroviral therapies. For the 5 people for whom we had at least 6 m data, HIV viral load decreased by 38%, CD4 increased 30%, and quality of life increased. Taken together, these trials indicate that seaweeds are well tolerated in seaweed-naïve populations and are associated with health promotion.

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The Carlsberg Academy is the former private home of brewer and founder of Carlsberg, J. P. Jacobsen. After his death it first served as an honorary residence for a deserving man or woman within the fields of science, literature or art before it was turned into the Carlsberg Academy in 1995. The building was designed by J. C. Jacobsen and N. S. Nebelong and was built in 1853-54, and in 1858 a winter garden was added. In 1876 a conservatory referred to as Pompeji in the style of a hypostyle hall was added after the design of J. C. Jacobsen and architect P. C. Bønecke. The house is built in the classical Italian villa style. The house is decorated with numerous artworks by Bertel Thorvaldsen. These include 'the Alexander Frieze' below the barrel vaulted ceiling of the two-story dining hall, six reliefs on the walls and a statue of Hebe. The English-inspired park dates from 1848 and was planned by landscape gardener Rudolph Rothe in accordance with J. C. Jacobsen’s ideas. It includes many rare plants and trees which J. C. Jacobsen brought back from his many trips abroad.