Australian Government

Rural Industries Research and Development Corporation

Using Algae in the 21st Century

—*Novel Opportunities in a Changing World*—

A report from the 11th International Conference on Applied Phycology

RIRDC Innovation for rural Australia

Australian Government

Rural Industries Research and Development Corporation

Using Algae in the 21st Century

- Novel Opportunities in a Changing World-

A report from the 11th International Conference on Applied Phycology

Galway, Ireland, 2008

By Pia Winberg

RIRDC Publication No 08/159
RIRDC Project No PRJ-002840

© 2009 Rural Industries Research and Development Corporation.
All rights reserved.

ISBN 1 74151 748 6
ISSN 1440-6845

Using Algae in the 21st Century - novel opportunities in a changing world - A report from the 11th International Conference on Applied Phycology

Publication No. 08/159
Project No. PRJ-002840

The information contained in this publication is intended for general use to assist public knowledge and discussion and to help improve the development of sustainable regions. You must not rely on any information contained in this publication without taking specialist advice relevant to your particular circumstances.

While reasonable care has been taken in preparing this publication to ensure that information is true and correct, the Commonwealth of Australia gives no assurance as to the accuracy of any information in this publication.

The Commonwealth of Australia, the Rural Industries Research and Development Corporation (RIRDC), the authors or contributors expressly disclaim, to the maximum extent permitted by law, all responsibility and liability to any person, arising directly or indirectly from any act or omission, or for any consequences of any such act or omission, made in reliance on the contents of this publication, whether or not caused by any negligence on the part of the Commonwealth of Australia, RIRDC, the authors or contributors.

The Commonwealth of Australia does not necessarily endorse the views in this publication.

This publication is copyright. Apart from any use as permitted under the *Copyright Act 1968*, all other rights are reserved. However, wide dissemination is encouraged. Requests and inquiries concerning reproduction and rights should be addressed to the RIRDC Publications Manager on phone 02 6271 4165.

Researcher Contact Details

Pia Winberg
Venus Shell Systems Pty. Ltd.
30 Victor Ave
Narrawallee NSW 2539

Tel: 61 2 4455 5518
Mobile: 0429 33 88 46

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

Published in February 2009

Contents

Tables

Figures

Executive Summary

What this report is about

This report summarizes the latest research and industry trends through conference sessions that were of relevance to the potential seaweed industries in Australia. These sessions included algal culture, algal products (especially biofuels), health and nutrition and integrated multi-trophic aquaculture systems.

Key themes from the conference

Applied phycology generally implies that there are industry applications related to the culture of seaweeds; although seaweed industries in Ireland, Asia and Africa still rely on wild harvest of seaweeds. The various culture technologies of seaweed in both macro and microalgal forms was therefore a key theme. A variety of culture methods exist, and research efforts focused on optimising yields using different lighting, nutrient, water supply and flow regimes.

A most dominant and controversial topic was that of algae and biofuels, the viability of which is strongly linked to costs of production, harvest and oil extraction (microalgae) or fermentation to ethanol (macroalgae). The controversy relates to many “grossly overstated” claims about the productivity and yields achieved in culture, the feasibility of scaling up culture, or the costs to extract and produce fuel.

There was also a strong focus on the health and nutritional applications of diverse seaweeds, and the benefits are as broad as the range of species is large. Health applications ranged from skin and beauty products, to functional whole foods, nutrient supplements, as well as bioactive ingredients with the potential for pharmaceuticals. Health benefits included anti-viral, anti-bacterial, anti-tumoral, gut health and micro and macronutrient delivery. A range of commercial products were on display.

Integrated Multi-Trophic Aquaculture (IMTA) was also a dominant theme as many countries now face the challenge of developing environmentally sustainable practices to improve the viability of aquaculture farms in the long term, most notably nutrient removal where seaweed can play a major role. IMTA developments included investigation of a range of new and more valuable algal species for culture, as well as optimising productivity and yield.

Finally some seaweed industries in Ireland were visited, and of note was that health and beauty treatments using seaweed were of great interest with many new companies marketing products based on claims of health benefits of seaweed. The Irish government was also funding the development of a seaweed recipe book by a nutritionist and medical doctor, who also had a background and cultural knowledge of the diverse Atlantic seaweed species, their uses and health benefits.

Introduction

The 11th International Conference of Applied Phycology was held in Galway on the west coast of Ireland; an appropriate location considering the historical use of seaweed and recent efforts in further research and development in seaweed related industries. The conference title, “Applied phycology in the 21st century; novel opportunities in a changing world”, and the large number of delegates (>400) from many (>43) countries, also reflected the growing global interest in the culture technology and diverse applications for multiple microalgal and macroalgal species. Delegates represented phycological research organisations, engineers, contractors, manufacturers, biotechnology scientists and companies, biofuel industries, policy makers and venture capitalists, and demonstrated the current level of effort in research and development towards the commercial applications of algae.

The main themes of the conference included:

- *culture technology* (Photosynthetic efficiency, Photobioreactors and upscaling, growth and physiology, Open versus closed: the great photo bioreactor debate)
- *algal products* (Polyunsaturated Fatty Acids and carotenoids, Chemical ecology, Algal products, Vaccine application)
- *biofuels* (Biofuels, energy and production, Algae for biofuels and CO_2 bioremediation, Bioenergy CO_2 and methane,
- *Algae and health* (Algae as food and feed (posters), Algae in plant, animal and human nutrition; health, quality and safety issues)
- *aquaculture* (Micro and macroalgae as feed ingredient, Integrated multitrophic aquaculture (IMTA), Harvesting and aquaculture for large scale production)
- *Biology* (Growth and physiology, Charales: from stoneworts to molecular tools, Algae and genetics)
- *Environment and bioremediation* (Harmful algae, Bio-deterioration of artificial substrates by terrestrial microalgae, Algae and the environment, Algae as biomonitors and use in bioremediation and environmental protection
- workshops around issues common to industry and research (industry and academia working together, algae and health)

Workshop sessions held at the conference facilitated the exchange of experiences relating to the interaction of science with industry. In the workshop “industry and academia working together; success and pitfalls”, the benefits from collaboration between industry and researchers were discussed. These included intellectual stimulation, personal and financial satisfaction for researchers, benefits for research organisations (funding and reputation), socio-economic and environmental benefits; while pitfalls included ineffective communication of science to industry, protecting the interests of scientists in research contracts, complicated legal frameworks that are poorly understood by academics, and research outcomes that are irrelevant to industry application. The second workshop held was related to algae and health, and this topic is further discussed in section 3.4 of this report.

With over 300 posters and presentations at the conference, a summary of the dominant themes, with relevance to current research and development in Australia (integrated primary production systems and new algae plant products for Australia (Cordover 2007, CSIRO 2007, Lee 2007, Lee and Momdjian 1997, Qin 2005, RIRDC 2002, Winberg *et al.* 2008)) is presented in this report. These include culture technology, algal products, biofuels, algae and health and integrated aquaculture. A special edition of the Journal of Applied Phycology that will include contributed papers from the conference is currently being prepared for publication later this year, and further and technical details will be available there.

Irish Seaweed Industry

A keynote opening address by Professor Michael Guiry provided an enlightening overview of the historical and recent developments of the seaweed industry in Ireland. Historically, Irish civilisations have had a strong association with the abundant and diverse seaweeds along the coast (Fig. 2-1); many folk stories and records exist about life with seaweed. Importantly, seaweed was used to create arable land from poor and rocky soils and was considered highly beneficial for growing potatoes. In addition, seaweed was used for human food for the high nutritional value, eg “slawk” (*Porphyra* sp.), *Ulva* sp. and “Dulse” (*Palmaria* sp.) (Fig. 2-2), *Chondrus crispus* and *Fuscus* sp. were eaten fresh, dried and used in breads and stews. Seaweed was also fed to livestock for improved animal health and meat production. Some species were used for their carrageen (from the Gaelic language) and agar content, and kelp was commercially burnt for ash production.

Figure 1 A collection of algal (seaweed) species washed up along the west coast of Ireland at Coral Beach, County Connemara.

The export of seaweed and seaweed ash from Ireland began in the 1600’s, and reached 5000 tons by the 1800’s. The hard manual labour required for this industry was a demonstration of the value, and today over 20,000 tons has been harvested sustainably and annually since the 1940’s. This export species is dominantly *Ascophyllum nodosum* (Fig. 2-2) which is used for alginates in foods, and Australia currently imports close to 2000 tons per annum from Ireland (Winberg *et al.* 2008).

Figure 1 Irish seaweed products “Dulse” (Palmaria palmata) and Ascophyllum nodsum used as human and animal food products respectively.

In addition there is renewed interest in the application of seaweed in the health industry. In particular, a range of existing cosmetic products and new brands are being marketed on the seaweed content, and make statements about the health and wellbeing seaweed can provide (Fig. 2-3). An old tradition of seaweed baths is being adopted in modern facilities for locals and tourists alike, and seaweed body wraps are also provided in salons.

A number of research and development projects in Ireland are currently being driven and coordinated between government, academic and industry organisations, with an applied focus for developing industries. One outcome of this is the Irish Seaweed Centre at the National University of Ireland, Galway, with a number of collaborative projects in the fields of algal culture technology for aquaculture, biofuels and the health and nutraceutical industries.

Figure 2 A range of modern Irish seaweed products for the beauty/health industry.

Conference Themes

Many of the conference symposia were relevant to multiple themes, for example, the culture technology of algae for biofuels, food and biotechnological applications have many things in common, but there are also unique issues relevant to the different applications. Therefore, the following structure includes a summary of symposia with broad applications (eg. culture technology, algal products), but also summarises the dominant and most relevant themes for this report (eg. biofuels, algae and health and aquaculture). Further information on other symposia at the conference can be found in an up and coming edition of the Journal of Applied Phycology, where selected papers from the conference will be published.

Culture Technology

One of the limiting factors for the viability of any commercial algal culture system is the cost of production versus the productivity of the system and the value of products. To date, culture systems produce algae at costs that are competitive only for high value products such as food, aquaculture and biotechnology applications. Culture technology already exists for these applications and has been commercially adopted in many viable industries. However the current interest in producing biofuels from algae requires that production costs can be significantly reduced and occur at a very large scale. One of the biggest problems in achieving commercially viable algal production is that a high areal rate of productivity is required, however at large scales, either reliable control of the culture production is reduced (i.e. riskier business), or the cost of controlling environmental factors (eg. light and temperature) at a large scale is very high. Therefore the culture technology symposia at the conference had a strong focus on technologies that attempt to achieve high algal productivity and/or reduce the costs of production.

Photosynthetic Efficiency

One of the strategies towards boosting production rates of algal culture is to get plants to use the sun's energy in the photosynthetic process more efficiently. Theoretically, a photosynthetic efficiency using 10% of solar irradiance (or 20% of photosynthetic active radiation (PAR)) to fix 125g Carbon / m^2 day would be the maximum possible, and produce an estimated biomass of 110g/m^{-2} day^{-1} under warm temperate conditions (Grobbelaar 2008, Tredici 2008, Weissman 2008). However this greatly exceeds actual yields which are considered good if they are around 20-39g/m^{-2} day^{-1}. Achieving increased production and photosynthetic efficiency is complicated by the optimal light being a tricky factor, as well as surface to volume ratios, temperature, pH, stocking density and the concentration of carbon dioxide.

A number of papers at the conference addressed these issues, demonstrating that photosynthetic efficiency can be improved by careful selection of species (Tredici 2008), manipulating temperature or irradiance (Grobbelaar 2008, Weissman 2008), increasing the surface to volume ratios (eg. panels or tubular biocoils) (Rodolfi et al. 2008), optimising light and dark cycles (not less than 10secs) and production increase. High density culture of algae is desirable for commercially viable rates of production and pure cultures, however, a high density of algae reduces the light available to each algal cell and it's chloroplasts, and cells use high light with low efficiency in dense cultures (Tredici 2008). Therefore technology that increases the surface to volume ratio of culture systems at large scales, and optimum environmental variables for maximum productivity, were key topics to address the often prohibitive costs of production per area of land or culture system unit.

In addition to maximising photosynthetic efficiency to boost productivity, carbon sequestration is also a goal of algal biomass culture that can boost the productivity of algae. This can also be costly, but in certain situations the resources are available and systems can be developed that make this logistically feasible (Beardall 2008). Integration of algal culture with existing CO^2 producing industries will be the most economical way to achieve CO^2 fertilized algal production. It has been demonstrated that microalgal culture on the CO^2 rich flue gas from coal-burining plants can be highly productive (Acien et al. 2008, Ben-Amotz 2008). It is clear that CO^2 fertilization of nitrogen rich waste water can make waste-treatment systems more efficient too, and integration of waste water with waste CO^2 streams would be ideal if in close proximity to each other (Lundquist and Benemann 2008).

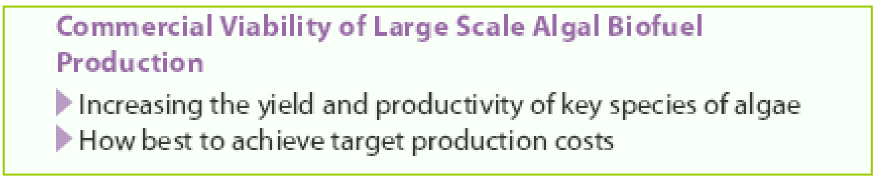
Upscaling

Although photosynthetic efficiency and production rates can be improved at small scales in laboratories under very controlled conditions, the leap to a pre-commercial or commercial scale is regarded as the greatest factor limiting high areal yields (Borowitzka (in press) 2008, Grobbelaar 2008). In particular for microalgae, it is hard to maintain the desired species for extended periods in the least costly systems, raceway ponds (Rodolfi et al. 2008). Therefore cost, system stability and complicated logistics for maintaining optimal conditions (temperature, light, pH, nutrients and CO2) for photosynthetic efficiency at large scales is where the current commercial viability of algal culture for biofuels seems to fail. Further to this are costs associated with harvesting and processing microalgae (see below).

Biofuels

The conference provided a venue to vent diverse opinions on the viability of algal culture for biofuel applications. There was no shortage of controversy surrounding this issue and some of the claims being made by organisations seeking government and venture capital funding. With the aim of attracting investor or government funding, the production capacity of algae has often been grossly overstated (Walker 2008). A summary of research findings of productivity are provided in Table 2-1. Microalgae are the dominant alga being researched for biodiesel production, but this is regarded as second generation biofuels with further research and development required, while macroalgae have the potential as a first generation biofuel for ethanol production, particularly in the event of carbon taxes, trading schemes and government directives.

Overall however, there was a feeling that algae do represent a real potential source of biofuels (both biodiesel and ethanol) (Borowitzka (in press) 2008, Grobbelaar 2008, Rodolfi et al. 2008, Vonshak 2008), but that either the technology is not yet optimal, microalgae will become competitive only when oil prices increase further, or that the culture scale or conditions required is prohibitive for certain technologies (Fig. 2-1). There is a strong indication that limitations to production, cost and scale may be overcome in the right situation with the right species, demonstrated by the investment, research and development in this field.


Commercial Viability of Large Scale Algal Biofuel Production

- Increasing the yield and productivity of key species of algae
- How best to achieve target production costs

Figure 4 Extract of key topics from the announcement of the 4th annual event of the "Next Generation Biofuels Market" to be held in Amsterdam, October 2008.

Microalgae and biodiesel

There was a strong focus on the culture of microalgae for production of biodiesel, as oil based biofuels have higher energy content than bio-ethanol (Fouchard et al. 2008). However with the lowest current production costs at >US$5/litre (Borowitzka (in press) 2008), the energy and cost required to make the algal biodiesel implies it is not yet competitive with petroleum or other biodiesel products. The production costs of biodiesel from microalgae are high, not only due to the cost of culture technology at large scales as described above, but also due to the cost of harvesting the microalgae and the downstream processing of oil extraction from microalgal cells (Rodolfi et al. 2008). A large number of presentations addressed the issues around achieving high and consistent productivity of pure microalgal cultures with a high oil content (Griffiths et al. 2008), and oil contents of up to 80% were reported (Fouchard et al. 2008); while others focused on the technology for harvesting the algae and/or extracting the oils (Lee et al. 2008, Lewis and Schaum 2008, Rahbari et al. 2008).

Macroalgae and ethanol

Production of ethanol from macroalgae was regarded as a most promising alternative to food crops for biofuel production. Various species of macroalgae were proposed as candidates for bio-ethanol crops, including *Gracilaria* sp. and *Ulva* sp. (Hanisak 2008), as well as ocean based culture of larger kelp species (Adams et al. 2008, Kraan 2008). The processing technology to provide ethanol from macroalgae exists and the substitution from current food crops to macroalgae should not be difficult (Adams et al. 2008). The culture of macroalgal species for biofuels would be strongly related to the production of macroalgae in integrated aquaculture systems (see below).

Table 1 Summary of some of the reported algal productivity (growth) rates using diverse species in different culture technology systems.

Reference (abstract) #	Species	System	Productivity (dry wt) (g/m-2xd-1)
Borowitszka (2)	microalgae	ponds	20
		panels	100
		tubular biocoils	29
Weisman (15)	microalgae	ponds 70% shade	10
		" 75% int. shade	10
		ponds uncovered	20
Tredici (14)	Seapalm	intertidal	38
Neori (29)	macroalgae	IMTA tank	30-110
Hanisak (94)	Gracilaria	IMTA field	35
Mata (53)	Bonnemaisoniaceae	IMTA tank	50-120
Robertson-Anderson (57)	Ulva	IMTA tank	40

* IMTA = Integrated Multi-Trophic Aquaculture

Algae and Health

Algae and health was also a strong theme covering aspects of health and well being applications in skin care and spa treatments (see section 2 and below), but primarily with a focus on nutrition. A workshop was held one evening to discuss the promotion of seaweed products as healthy. One issue is that although there is strong evidence for many nutritional benefits from seaweeds, there are still a lot of overambitious or unsubstantiated claims being made about seaweed products in general that haven't been well researched, thus potentially affecting the value of real health benefits from seaweed (Belay 2008). For example, one company that presented at the workshop, SeaVegg, produces powdered seaweed capsules with a very strong "infomercial" approach, and with limited clinical research. In contrast, there were many nutrition and biotechnology delegates with presentations about specific scientific evidence for the health benefits of seaweed.

Health

Jane Teas, a key speaker at the Algae and Health workshop, did research using powdered *Undaria* to demonstrate clear health benefits from ingesting fucanoids, fucixanthins and alginic acids. These benefits included reduced rates of breast cancer and increased numbers of CD4 helper cells in HIV patients, however the effect of the seaweed compounds varied for the same species sourced between different countries (Australia vs. South America), and what growth period the plant was harvested (the sporophyll stage was most effective), as well as which part of the plant (the reproductive parts were most productive).

Further, a range of macroalgae had been screened for various bioactive compounds, for example, *Fuscus* sp. were found to have very high anti-oxidant properties, and further brown and red macroalgal species were found to have cytotoxic activities (Zubia et al. 2008), a common *Ecklonia* kelp showed strong anti-inflammatory properties (Ahn et al. 2008).

Similarly microalgae compounds also exhibited comparable health benefits including antioxidant (Jaime et al. 2008), anti-fungal, anti cancer (Garcia-Chacon et al. 2008), anti-viral, antibiotic (Gupta and Irfan 2008) and cholesterol reducing activities (Dvir and Arad (Malis) 2008). Methods for extraction were also covered (Jaime et al. 2008, Santoyo et al. 2008).

Nutrition

Inclusion of whole seaweed as a function food ingredient was also a key health topic, and the Irish Sea Fisheries Board and the Irish Food Agency are currently supporting the development of a seaweed cookbook with a nutritional focus. Prannie Rhatigan, a medical doctor, is the author of the book and she is a keen advocate of nutrition, and in particular the health benefits of seaweed in the diet (Rhatigan 2008). Prannie grew up in Ireland as a child eating seaweed from the shores and has a good understanding of the uses for different seaweeds and how to prepare them (Fig 2-2). Her recipe book includes chocolates, pates, guiness and seaweed bread and smoothies. Similar diverse food application for algae were reported from Thailand (Peerapornpisal 2008).

Prannie and Teas also highlighted the need for awareness of the risk of a high iodine intake from kelp products (large brown seaweeds) for people with thyroid problems. However the cause of thyroid problems in the western world is generally due to a lack of iodine in the diet. Further issues related to health and safety, as well as the need for better regulation and accreditation for algal products in the western world were also presented (Belay 2008, Sassi et al. 2008).

Figure 5 Seaweed use in traditional and modern adaptations of Irish cuisine. (clock wise from top left) wild harvested seaweed drying on racks, dried "sea spaghetti", green smoothie with seaweed, diverse dried and powdered seaweed species used as condiments with meals, sea spaghetti and carrot salad. Photos at the house of Dr. Prannie Rhatigan, Sligo.

Aquaculture

Integrated Multi-trophic Aquaculture

Integrated multi-trophic aquaculture systems were also a key topic at the conference, and well cited researchers in this field provided further insights into an increased variety of algal species for IMTA systems both on land and in the water. One keynote speaker from Australia, Rocky de Nys, highlighted the considerable differences between environmental conditions in the tropics of northern Australia, versus the temperate regions, that consequently the issues and questions for the industries in the geographically separate areas are quite different. Primarily, the high rainfall and monsoonal season limits tropical aquaculture to fresh and brackish water species. However the environmental concerns remain and the discharge requirements for aquaculture systems are becoming more stringent; currently 3mg N/L or 1kg N/ha/day, and 0.4mg P/L or 0.15 kg/ha/day, and 30% of the culture pond area is required for bioremediation. Consequently, farms aren’t operating at their maximum capacity due to these regulations, providing an opportunity for application of algal culture in Australia.

A range of species with potential for integrated aquaculture were presented, and included *Caulerpa* species in Australia (Paul and de Nys 2008), polyculture of *Cladophora*, *Chaetomorpha* and *Ulva* species (de Paula Silva et al. 2008, Robertson-Anderson et al. 2008), kelps (Chopin et al. 2008), *Gracilaria* (Abreu et al. 2008), *Porphyra* (Edwards et al. 2008, Levy et al. 2008, Neefus et al. 2008) and Bonnemaisoniacea family (Mata and Santos 2008) species. The various systems included sea-based cages, to extensive ponds and recirculation tanks. Reported benefits included nutrient removal and reduction in bacterial counts; *Ulva* sp. for example produce H_2O_2 and other antibacterial compounds (Robertson-Anderson et al. 2008). Some of the culture technology or species cultivars have been patented (Cruz-Suarez et al. 2008, Levy et al. 2008).

Seaweed in aquaculture diets

In addition to IMTA systems, there were calls for an innovative way to reduce carbon outputs by taking a greater systems perspective. Ellem and Herbertson (Ellem and Herbertson 2008) and integrating algal production with the aquaculture of fish to replace the high carbon producing ruminant industry. There was also a range of seaweed applications in aquaculture diets (Soler Vila et al. 2008), and although it cannot replace fish oil and protein totally, it improves the fish feed quality and is preferable to vegetable protein. Cruz-Suarez (Cruz-Suarez et al. 2008) confirmed previous findings that up to 10% algal content in commercial feeds improved the protein, carotenoid (pigmentation) content of prawn meat, and significantly improved growth performance.

Itinerary

20-22/06/2008	**Travel to Ireland**
22-27/06/2008	**11th International Conference on Applied Phycology**
	Attended 47 oral presentations, 2 workshops on topics:
	Culture Technology
	Algal Products
	Biofuels
	Algae and Health
	Aquaculture
	Science and Industry
30/06-2/07/2008	**Field visits**
	Dr. Prannie Rhatigan - conference presenter and seaweed nutritionist
	Voya Seaweed Baths, Sligo (modern baths)
	Kilcullen's Seaweed Baths, Enniscrone (historical baths)
	Lissadel Shellfish Company, Grange (microalgae and shellfish hatchery)
	Iarla Connellan (seaweed, microalgae and shellfish hatchery and farm)
3/06 - 5/06/2008	**Return travel**

References

Abreu, M. H., D. A. Varela, D. A. Henriquez, C. Yarish, I. Sousa-Pinto, and A. H. Buschmann. 2008. Traditional vs. integrated aquaculture of *Gracilaria chilensis* C.J. Bird, McLachlan and E.C. Oliveira: productivity and physiological performance. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Acien, F. G., C. V. Gonzalez, J. M. Fernandez, M. Garcia-Gonzalez, J. Moreno, E. Sierra, M. G. Guerrero, and E. Molina. 2008. Removal of CO2 from flue gases coupled to the photosynthetic generation of biomass and exoploysaccharides by cyanobacteria. *11th International Conference on Applied Phycology*, Galway, Ireland.

Adams, J., J. Gallagher, and I. Donnison. 2008. Fermentation studies on selected macroalgal species for bioethanol production. *11th International Conference on Applied Phycology*, Galway, Ireland.

Ahn, G., E. Park, K. W. Lee, Y.-J. Jeon, and Y. Jee. 2008. Enzymatic extract from Ecklonia cava inhibits topical inflammatory response in the TPA model of model of mouse ear inflammation. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Beardall, J. 2008. Physical and physiological constrainsts on the efficacy of microalgae for CO2 bioremediation. *11th International Conference on Applied Phycology*, Galway, Ireland.

Belay, A. 2008. Quality, safety and regulatory aspexcts of microalgal foods and supplements. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Ben-Amotz, A. 2008. Production of marine unicellular algae on wastes of coal burning electric power plant for cost-effective biofuels. *11th International Conference on Applied Phycology*, Galway, Ireland.

Borowitzka, M. A. (in press) 2008. Algae and Biofuels: Quo vadis? *11th International Conference on Applied Phycology*. Journal of Applied Phycology, Galway, Ireland.

Chopin, T., R. Shea, M. Sawhney, E. Campell, E. Belyea, S. Bastarache, W. Armstrong, J. Sewuster, R. Ugarte, P. Watson, T. Wilcox, M. Szemerda, R. Marvin, F. Powell, M. Holland, G. K. Reid, S. M. C. Robinson, N. Ridler, F. Page, K. Haya, L. Burridge, and S. Boyne-Travis. 2008. The Integrated multi-trophic aquaculture (IMTA) conceptand its development in the Bay of Fundy, Canada. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Cordover, R. 2007. Seaweed Agronomy: Cropping in inland saline groundwater evaporation basins. *RIRDC research paper 07/033*. Rural Industries Research and Development Corporation, Canberra.

Cruz-Suarez, L. E., A. A. Leon, A. Pena-Rodriguez, G. Rodriguez-Pena, B. Moll, and D. Ricque-Marie. 2008. Co-cultured shrimp with *Ulva clathrata* to optimize shrimp commercial feed utilization. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

CSIRO. 2007. Biofuels in Australia - Issues and Prospects. *RIRDC research report 07/070*. Rural Industries Research and Development Corporation, Canberra.

de Paula Silva, P. H., R. de Nys, and N. A. Paul. 2008. Application of "green tide" filamentous algae to bioremediation of aquaculture effluent. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Dvir, I., and S. Arad (Malis). 2008. Therapeutic effects of nutraceuticals from the red microalga *Porphyridium* sp. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Edwards, M., A. Werner, A. Dring, and S. Kraan. 2008. Further advances in the cultivation techniques of *Palmaria palmata*, *Laminaria digitata* and *Porphyra* species in Ireland. *11th International Conference on Applied Phycology*, Galway, Ireland.

Ellem, G. K., and J. G. Herbertson. 2008. Unlocking the potential of microalgae for bioenergy and materials. *11th International Conference on Applied Phycology*, Galway, Ireland.

Fouchard, S., J. Pruvost, G. Van Vooren, and J. Legrang. 2008. Evaluation of *Neochloris oleoabundans* lipids (TAGS) productivities in photobioreactor for biodiesel application. *11th Internation Conference on Applied Phycology*. Journal of Applied Phycology, Galway, Ireland.

Garcia-Chacon, R., E. Ramon-Gallegos, A. Reyes-Arellano, F. Arenas-Huertero, A. Cruz-Orea, and R. Olvera-Ramirez. 2008. Use of phycoerythrin isolated from cyanobacteria in photodynamic therapy for cancer treatment. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Griffiths, M. J., R. P. Van Hille, and S. T. L. Harrison. 2008. Optimising algal growth and lipid productivity for biodiesel production. *11th International Conference on Applied Phycology*, Galway, Ireland.

Grobbelaar, J. U. 2008. Upper limits of photosynthetic productivity and problems of scaling. *11th International Conference on Applied Phycology*, Galway, Ireland.

Gupta, R. K., and M. Irfan. 2008. Algae: a source of nutraceuticals. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Hanisak, M. D. 2008. A green look at red alge: cultivating *Gracilaria* for biofuel production and bioremediation. *11th International Conference on Applied Phycology*. Journal of Applied Phycology, Galway, Ireland.

Jaime, L., I. Rodriguez-Meizoso, S. Santoyo, A. Cifuented, S. Suarez, E. Ibanez, and F. J. Senorans. 2008. Extraction of anti-oxidant compounds from haematococcus pluvialis using pressurized liquids. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Kraan, S. 2008. Macroalgae for biofuels: myth or reality? *11th International Conference on Applied Phycology*, Galway, Ireland.

Lee, A., D. Lewis, and P. Ashman. 2008. Microbial bioflocculation of Pleurochrysis cartera, the primary stage for commercial harvesting. *11th International Conference on Applied Phycology*, Galway, Ireland.

Lee, B. W. 2007. An Assessment of Research Opportunities for Fresh and Saltwater Marine Vegetables Stage 1. *RIRDC research paper 97/49*. Rural Industries Research and Development Corporation, Canberra.

Lee, B. W., and K. Momdjian. 1997. The Australian Seaweed Industry - A Baseline Review of Research and Development. *A report for the Rural Industries Research and Development Corporation PRJ CON-9A*, Canberra.

Levy, I., A. Israel, and M. Friedlander. 2008. Noritech's porphyra cultivation technology. *11th International Conference on Appled Phycology*, Galway, Ireland.

Lewis, D. M., and M. T. Schaum. 2008. Investigation of lipd and fatty acid extraction techniques from *Pleurochrysis carterae* and *Botryococcus braunii* for microalgal biodiesel production. *11th International Conference on Applied Phycology*, Galway, Ireland.

Lundquist, T. J., and J. R. Benemann. 2008. Algal wastewater treatment with biofuel feedstock production. *11th International Conference on Applied Phycology*, Galway, Ireland.

Mata, L., and R. Santos. 2008. Bonnemaisoniacea species as valuable candidates for fish/seaweed integrated aquaculture. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Neefus, C. D., J. P. Day, A. B. Walker, D. L. Berlinsky, and C. Yarish. 2008. Optimization of anintegrated cod/nori recirculating aquaculture system. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Paul, N. A., and R. de Nys. 2008. Promise and pitfalls of locally abundant seaweeds as biofilters for integrated aquaculture. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Peerapornpisal, P. 2008. Edible freshwater macroalgae in northern Thailand. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Qin, J. 2005. Bio-Hydrocarbons from Algae. *RIRDC research report SQC-1A*. Rural Industries Research and Development Corporation, Canberra.

Rahbari, M., D. M. Lewis, and P. Ashman. 2008. Dewatering *Pleurochrysis carterae* for large scale production of biofuel. *11th International Conference on Applied Phycology*, Galway, Ireland.

Rhatigan, P. 2008. Cooking upa storm with seaweeds.... from Irish shores; Extracts froma forthecoming seaweed cookbook. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

RIRDC. 2002. Integrated biosystems for sustainable development. Rural Industries Research and Development Corporation.

Robertson-Anderson, D., M. Potgieter, M. Hansen, J. J. Bolton, M. Troell, R. J. Anderson, C. Halling, and T. Probyn. 2008. A pilot scale integrated seaweed (*Ulva lactuca*) and abalone (*Haliotis midae*) recirculation system. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Rodolfi, L., N. Bassi, G. Padovani, G. Bonini, G. Zittelli, L. Del Bimbo, N. Biondi, and M. R. Tredici. 2008. Oil from Microalgae. *11th International Conference on Applied Phycology*, Galway, Ireland.

Santoyo, S., L. Jaime, I. Rodriguez-Meizoso, G. Garcia-Blairsy Reina, A. Cifuentes, F. J. Senorans, and E. Ibanez. 2008. Extraction of functional compunds from Phormidium sp. using pressurized liquids. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Sassi, J. F., A. Menguy, P. Dion, and Y. Lerat. 2008. Algae applications: benefits, quality and safety. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Soler Vila, A., M. D. Guiry, and S. Kraan. 2008. Applications of algae as feed ingredient in aquaculture diets: an overview. *11th Internation Confernce on Applied Phycology*, Galway, Ireland.

Tredici. 2008. Maximum and actual productivities of outdoor algae cultures. Pages 52. *11th International Conference on Applied Phycology*, Galway, Ireland.

Vonshak, A. 2008. Photosynthetic efficiency: the holy grail. *11th International Conference on Applied Phycology*.

Walker, D. A. 2008. What limits photosynthesis? - A reappraisal. *11th International Conference on Applied Phycology*, Galway, Ireland.

Weissman, J. C. 2008. Factors limiting photosynthetic efficiency in outdoor mass culture of microalgae. Pages 52. *11th International Conference on Applied Phycology*, Galway, Ireland.

Winberg, P. C., D. Ghosh, and L. Tapsell. 2008. Seaweed culture in integrated multi-trophic aquaculture: nutritional benefits and systems for Australia. *RIRDC project PRJ-000162*. Rural Industries Research and Development Corporation, Canberra.

Zubia, M., V. Kerjean, M. S. Fabe, Berthou, C., and E. Deslandes. 2008. Antioxidant and tumoral activites of 31 marine algae from Brittany coasts (France). *11th International Conference on Applied Phycology*, Galway, Ireland.

Using Algae in the 21st Century

—Novel Opportunities in a Changing World—

A report from the 11th International Conference on Applied Phycology

RIRDC Publication No. 08/159

This report summarizes the latest research and industry trends through conference sessions from the 11th International Conference on Applied Phycology, that were of relevance to the potential seaweed industries in Australia. These sessions included algal culture, algal products (especially biofuels), health and nutrition and integrated multi-trophic aquaculture systems.

Applied phycology generally implies that there are industry applications related to the culture of seaweeds; although seaweed industries in Ireland, Asia and Africa still rely on wild harvest of seaweeds. The various culture technologies of seaweed in both macro and microalgal forms was therefore a key theme at the conference. A variety of culture methods exist, and research efforts focused on optimising yields using different lighting, nutrient, water supply and flow regimes.

A most dominant and controversial topic was that of algae and biofuels, the viability of which is strongly linked to costs of production, harvest and oil extraction (microalgae) or fermentation to ethanol (macroalgae).

The Rural Industries Research and Development Corporation (RIRDC) manages and funds priority research and translates results into practical outcomes for industry.

Our business is about developing a more profitable, dynamic and sustainable rural sector. Most of the information we produce can be purchased or downoaded for free from our website <www.rirdc.gov.au>.

Cover photo: A collection of algal (seaweed) species washed up along the west coast of Ireland at Coral Beach, County Connemara.

Contact RIRDC:
Level 2
15 National Circuit
Barton ACT 2600

PO Box 4776
Kingston ACT 2604

Ph: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au
web: www.rirdc.gov.au

This publication can be viewed at our website—www.rirdc.gov.au. RIRDC books can be purchased from:.

www.rirdc.gov.au

RIRDC Innovation for rural Australia