Hydrobiologia **398/399:** 7–14, 1999.
J.M. Kain (Jones), M.T. Brown & M. Lahaye (eds), Sixteenth International Seaweed Symposium,

Red algal polysaccharide industry: economics and research status at the turn of the century*

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Key words: co-production, cyclic production, mariculture, sustainable development

Abstract

Commercial research priorities target production cost reduction and expansion of new applications for established products to increase profitability. Cost effective seaweed production for phycocolloids relies on: (1) species and strain selection, (2) vegetative reproduction, (3) improvements in cultivation, harvesting and drying and storage. Increasingly, present linear technologies based on consumption of raw materials and production of product, and waste, will be replaced by cyclic technologies which maximize utilization of waste as raw material resources. Co-production and synergistic product development are not only green, but cost effective. Transportation of resources and products is energy expensive, but regional production promises to reduce transportation costs. Marine phycologists have important roles to play in the phycocolloid industry, especially in the development of co-generation and co-production technologies, in the domestication of seaweed cultivars to remove harvest pressure on target species and sensitive ecosystems, and in the development of regional low technology production.

Introduction

It is axiomatic that basic research really is basic, and provides the essential foundation for application and technology (Magne, 1993). It is also true that when headlines pronounce 'currency crisis deepens' and 'monetary austerity promoted' that even less support can be expected for basic research. I don't make policy, so don't blame me. I merely report the obvious, and make suggestions for surviving with some grace and dignity. Since interactions between marine phycologists and the phycocolloid industry are based on the premise that co-operation can increase their net profit, we need to consider how best we can enhance their profitability, while directing their efforts toward sustainable development. The following is intended as a brief status report, followed by predictions of motivating forces and directions for development in the 21st century.

* This paper is dedicated to my friend and colleague Dr Kimon T. Bird, 30 October 1951–29 October 1996.

Linear production versus sustainable development

Traditionally, production has been seen as a linear process, with raw materials entering at one end and then being transformed into products which are distributed and sold at the other end (Figure 1). Increasingly, the 'green' or environmental movement has helped us recognize that (1) all processes on earth are cyclical, not linear and (2) there is no 'away' where anything can be disposed of or dumped. The concept of sustainable development (Hawken, 1993) has profound implications for both marine phycologists and for ecologically balanced production in the phycocolloid industry (Bodvin et al., 1996) as we begin the 21st century.

Let's now address the questions of how marine phycologists can interact with the phycocolloid industry to enhance sustainable development by replacing linear processes with cyclic production? And how we can turn 'black' (the accountant's profit line) into 'green' (ecologically sound practice)? And what's in it for me? My specific comments are based on my experience with red algal phycolloids, both agars and carrageenans. However, many of these remarks will

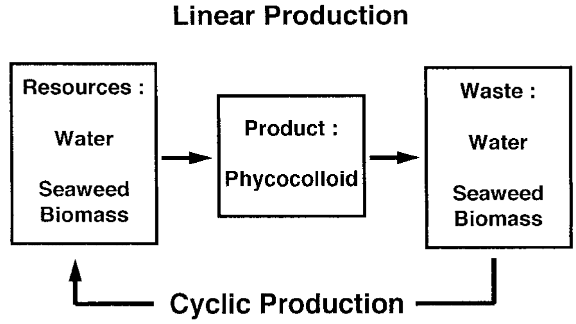

Figure 1. Linear production results in waste while cyclic production utilizes waste as resource for new products.

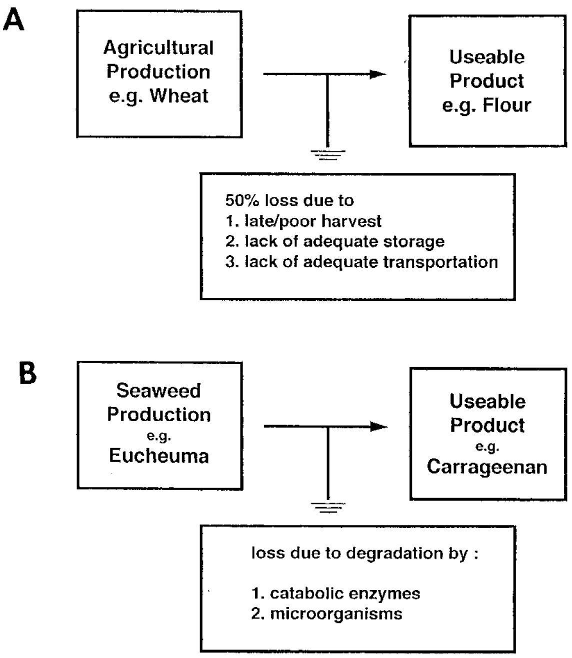

Figure 2. Increased production does not necessarily result in increased product when there is significant loss due to poor harvest and storage techniques, and lack of transportation. (A) Agricultural model, (B) Seaweed model.

have application to the brown algal (alginate) industry as well.

With the deconstruction of the USSR (CCCP) we learn that it was not uncommon for 50% of agricultural production in any given year to be lost due to poor harvesting, primitive storage and inadequate transportation (Figure 2A). So wheat and potatoes would rot in the field or in open air storage on the ground for lack of transport to processing facilities. Conventional wisdom makes all of us economic advisors in this simplistic scenario. Both distance and hindsight give us 20/20 vision. We realize that in this specific case increased agricultural production would not appreciably increase amounts of food. We understand that excellent solutions are worthless unless they match specific, immediate problems. In the former USSR, attempts to improve harvest efficiency, crop storage without loss, and transportation of crops for processing should have been priorities, while any attempt to increase agricultural production would have been an excercise in futility. When we superimpose this schematic of poor agricultural practices on phycocolloid production, we note an uncomfortable fit (Figure 2B). Many of us pursue research programs aimed at a marginal increase in phycocolloid production even though adequate biomass exists to produce most carrageenan and agar products. Profitability for many industries is constrained by variables other than biomass production, including (Figure 3):

(1) Poor quality control due to variability in harvest and storage of dried biomass

Unless seaweed is quickly and thoroughly dried, and kept dry, phycocolloids are irreversibly degraded both by catabolic enzymes and microorganisms. Bacteria (Jaffray et al., 1997) as well as fungi (Melo et al., 1997) have been implicated in the degradation of phycocolloid polysaccharides during storage. Under tropical field conditions, rain and humidity are inextricably connected to mariculture sites. We wonder if the effective drying and storage technologies associated with the leaf tobacco industry cannot be modified for the phycocolloid industry?

It is possible that good things come to those who wait. But for those of us who are less patient, I recommend a meeting of field agents representing the phycocolloid and tobacco industries with microbiologists to discuss microbial degradation problems associated with long-term storage and shipment of seaweed biomass.

(2) Long distance transportation of biomass for phycocolloid extraction.

When coal was discovered in Australia, entrepreneurs envisioned huge ships exporting coal to Europe. This business venture was quickly derailed by reality when an engineer calculated that a coal freighter would burn more coal for its own fuel than could be carried on such a long trip around South America. In general, for any bulky (low density) commodity, it is cost effective to pre-process prior to shipping. This gen-

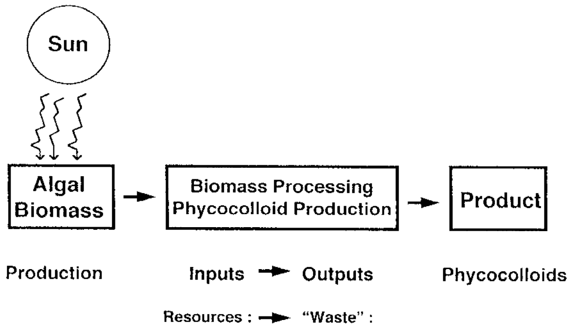

Figure 3. In the phycocolloid industry, profitability is constrained by variables in addition to biomass production.

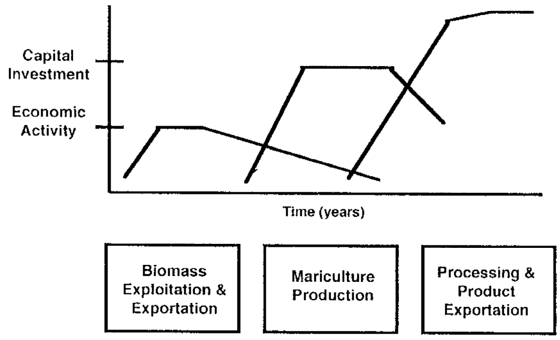

Figure 4. Relationship of capital investment and economic activity increase to the sequence of phycocolloid exploitation.

eralization will become dramatically more significant in economic equations as:

(a) the artificially low price of fuel is adjusted upward; and

(b) producing countries insist on a greater profit share which always comes from value added products rather than from commodities.

Only government beaurocracy would consider it rational and cost effective to grow biomass in southeast Asia, ship the biomass to America or Europe for processing, and then ship the value-added product back to southeast Asia for distribution and sales. In Indonesia, local processing of *Kappaphycus* began in 1988. Now alkali-treated cottonii (ATC), Philippine natural grade (PNG), semi-refined carrageenan (SRC), seaweed flour (SF) and natural washed carrageenan (NWC) are among the products developed for export and further refinement (Luxton, 1993).

(3) A conspicuous corollary to the economic liability of long distance transport of biomass is the problem of long distance transport of product.

In the 21st century, long distance separation of production and markets will be an unsustainable luxury. The phycocolloid industry must work with producers to develop semi-refined products for low cost transportation to refinement sites in Europe and America. Eventually, production and consumption must be localized, if not nationally, then at least regionally. Generalizations always lack impact and tend to be less than memorable. We identify with the specific and personal. Therefore, I will cite a specific example by way of illustration. Since commercial cultivation of *Gracilaria* began in Chile in 1982, production, freed of reliance on diminishing wild populations, has expanded dramatically (Zertuche Gonzales, 1993). Now Chile processes high-grade agar sufficient for the domestic market and for export (Oliveira & Alveal, 1990; Avila & Sequel, 1993; Alveal et al., 1997), with more than 70% of the *Gracilaria* harvest supporting local refinement (Norambuena, 1996). The present status and evolution of phycocolloid production in Chile have been summarized by Santelices (1996). It seems significant that the initial stage characterized by collection of wild populations potentially results in both the greatest environmental degradation, food web disruption and the least economic activity (Figure 4).

(4) Water, biomass and wastes management

The phycocolloid industry requires huge inputs of water and biomass, and produces huge outputs of waste water and biomass residue. There are several solutions to the associated problems: first, large amounts (as opposed to small amounts) of waste are a much bigger problem than simple mathematical increase. That is, disposing of 100 000 metric tons of biomass residue is not just l000 times more difficult than disposing of l000 metric tons. The relationship is probably more geometric than mathematical. Second, waste water and biomass residue are much greater problems in industrialized, urban settings than in rural, agricultural environments. I will remind you that animal manure is fertilizer on the farm, but waste and pollution in the city.

The solution suggested by both of the above problems is the same: decentralized, small scale processing in rural, agricultural areas where both waste water and biomass residue can be incorporated into agricultural production (Figure 5). My example here is Thailand. In order to reduce its dependency on imported agar, which is vital to sustaining a micropropagation industry of orchids and other horticultural plants,

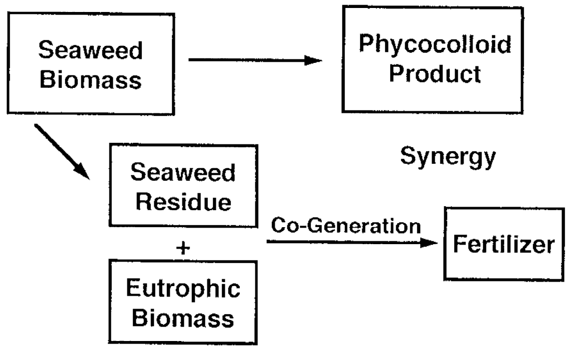

Figure 5. Co-production and synergy increase profitability and transform waste into renewable resources.

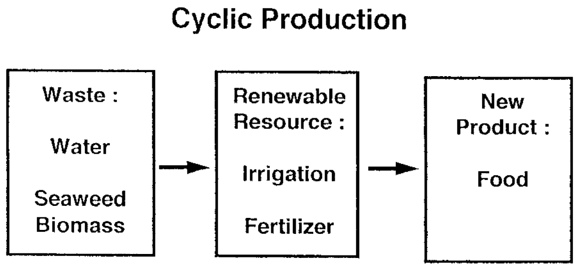

Figure 6. In cyclic processes, production design transforms waste into renewable resources.

Thailand initiated a program to produce and process seaweed locally (Chardrkrachang & Chinadit, 1988; Chinadit & Chandrkrachang, 1986). This system is elegant for its simplicity and reliance on low technology as opposed to high-tech processes. It is based on small-scale co-operatives processing *Gracilaria* for agar using materials at hand such as coconut presses. Semi-refined agar can be used locally, or sold to national processors for the manufacture of high-grade agar. The seaweed residue can be composted for fertilizer, and the processing water routed to the village irrigation system.

(5) Co-production and synergy

The solution to the above problems leads logically to the concept of co-production and synergy — the process by which the interaction of two or more components results in an effect of which each is individually incapable and/or which is greater than the sum of the individual components (Figure 5).

As an example of co-production, organic wastes from salmon farming can be used as resources for new products. Specifically, production of both shellfish and seaweeds is enhanced when they are placed ‘downstream’ in an aquaculture system (Bodvin et al., 1996). Bioconversion of biomass by fermentation to useful products is not generally cost effective. However, transformation of algal biomass with other organic waste (wood and manure) results in a competitive fertilizer (Morand et al., 1990). In many areas of the world with polluted coastal ecosystems, eutrophication results in significant production of biomass (Rosenberg, 1985) and resultant ecological impact (Chassany de Casabianca, 1984). A bioconversion facility established to process phycocolloid biomass residue into fertilizer (co-production) could synergize by accepting eutrophication biomass, with twin positive environmental results: increased production of fertilizer and removal of nutrients which typically recycle to support rounds of biomass production (Morand et al., 1990).

Value of biosphere components

Once we accept that all processes are cyclic and not linear, production design will seek to transform waste into renewable, recycled resources (Figure 6). The next logical step is to understand the hidden value of biosphere components in maintaining a liveable environment. Presently, more than 40% of the Earth’s primary productivity is redirected to human consumption (Hawken, 1993). We cannot save endangered species, protect habitat and redirect the bulk of solar-based production to our own selfish ends (Figure 6).

We can’t have our cake and eat it too. As biologists and scientists, we should be concerned about the potential our research has to encourage and aid environmental degradation. Therefore, as we identify new target species for the phycocolloid industry, every effort should be made to shorten the transition time during which the species is collected from naturally occurring stocks and all biomass comes from mariculture. *Gelidiella* is representative of the agarophytes that many of us have helped develop as an attractive resource for the phycocolloid industry (Kapraun et al., 1994; Roleda et al. 1997a, b). More than a decade ago, it was proposed that a management scheme be developed prior to commercial harvest of *Gelidiella* natural stocks (Trono & Ganzon-Fortes, 1985), or at a minimum, that pruning/cutting harvest replace whole plant collection. Not surprisingly, over-exploitation and over-harvesting of natural beds and collection of whole plants of this slow growing species remain the norm. World-wide, most biomass continues to come from wild populations (Ganzon-Fortes, 1994) even though we know that this alga plays a significant role in coral reef ecology.

Resource utilization

At this point in any discussion of resource utilization, a distinction should be made between pragmatism and idealism. Many would agree that habitat destruction is bad, but what realistic alternative exists to foster economic development? We can just as easily ask if it is pragmatic to over-harvest and destroy a resource in a few years, or if it is idealistic to impose a management program with restraints for collecting procedure and harvest season to prolong the economic viability of a resource? It is no accident that countries with the strongest environmental laws also have the strongest economies! It has always been this way. Our English words for economy and ecology are both derived from the Greek *oikos* (household), and reflect the intimate relationship between sustainable development and husbandry of resources.

No resource exists solely and exclusively for the pleasure and benefit of man. All resources serve important functions as food, habitat, nursery and substrate stabilizers (Santelices, 1996). All of these functions have value and must be included in all cost–benefit calculations. There ain't no free lunch. Now we return to our rhetorical questions: How can we turn 'black' into 'green'? What's in it for me? We collectively have tremendous resources of information, knowledge and experience which can help the phycocolloid industry.

(1) We can help reduce production variability and degradation of stored biomass by creative use of technology for drying and storage of seaweed. Better quality seaweed translates into less biomass required for extraction, and reduced demands on water and energy resources.

(2) We can help develop co-generation and synergistic technologies. Together is better, not just more fun!

(3) We can encourage and support co-operatives based on small scale, local production–extraction of semi-refined product. This move should not be viewed as a source of competition to the big producers. They can guarantee supplies of semi-refined product by contracting with co-operatives.

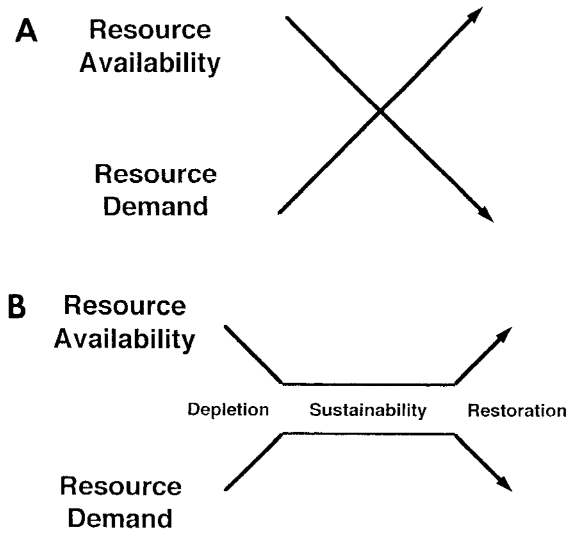

Figure 7. Non-sustainable and sustainable development compared. (A) Exploitation of natural populations results in decreased resource in response to increased demand. (B) Reliance on mariculture permits sustainability and an opportunity to restore previously damaged habitat.

(4) We can renew our efforts to turn from reliance on harvest of wild populations, which leads to destruction of ecosystems, by developing resources which are amenable to mariculture (Figure 7A). Resource sustainability, and ecosystem restoration both rely on successful mariculture (Figure 7B). The literature is replete with the consistent, predictable sequence of events that can be associated with attempts to utilize natural seaweed populations as sustainable, renewable resources for the phycocolloid industry (Norambuena, 1996). Although careful management is possible, especially with brown algae utilized for alginates (Avila & Seguel, 1993; Barilotti & Zertuche-Gonzales, 1990), typically natural wild populations are severely reduced in a region, and the harvest moves on, leaving the coastal subsistence inhabitants in predictable poverty (Fortes, 1993; Oliveira, 1990; Oliveira & Berchez, 1993). The human and ecological losses are seldom calculated in economic equations as long as new biomass sources are available to the industry. This waste of resources is unnecessary and, therefore, largely inexcusable as long-term profitability is highly correlated with sustainable development (Figure 4).

In contrast, the Philippine mariculture experience for *Eucheuma* remains a realistic model for seaweed farming in developing countries (Doty & Alvarez, 1975; Ricohermoso & Deveau, 1978; Trono, 1992;

Yarish & Wamukoya, 1990). For those of you who may have been on another planet for the last 25 years, I will summarize as follows:

(a) The Philippines carrageenan industry is based on the mariculture of *Eucheuma* and *Kappaphycus* cultivars, not wild populations (Trono, 1992).
(b) Mariculture results in less environmental impact and degradation than occurs with harvest of wild populations.
(c) Specific cultivars are grown vegetatively, making the system responsive to quality control and cultivar improvement (Dawes & Koch, 199l; Dawes et al., 1993, 1994).

My recommendation is this: if it can't be grown in a low-impact mariculture system, it should be used with great caution. As long as marine resources are viewed as common property, they will typically become part of the tragedy of the commons, over-exploited with no one taking responsibility (Hardin, l968). For coastal regions determined to develop a phycocolloid industry, we marine biologists and scientists can help in several ways. We can encourage the development and implementation of cultivation technologies for *Mazzaella (Iridaea)*, *Gigartina*, and *Gelidium*, *Pterocladia* and *Gelidiella*, all of which are desperately needed (Akatsuka, 1986; Avila & Seguel, 1993; Barilotti & Zertuche-González, 1990; Gallardo et al., 1990; Macler & Zupan, 1991; Oliveira, 1981; Oliveira & Berchez, 1993; Rueness & Fredriksen, 1990). More of us need to approach this seemingly hopeless task although, like marriage, it could be viewed by the pessimistic as a triumph of hope over reason. There is reason for cautious optimism. *Hypnea* in many respects is typical of these commercially exploited seaweeds in that its natural populations are generally insufficient to sustain economic harvest pressure (Mshigeni & Chapman, 1994; Schenkman, 1989). Fortunately, determined attempts to domesticate this seaweed and make it amenable to mariculture are starting to produce encouraging results (Berchez et al., 1993; Camaro Neto, 1987). Efforts to propagate *Gelidium* spp., which are characterized by relatively fragile natural populations and strong cyclic crop fluctuations, are showing promise (Rojas et al., 1996).

Surely someone among us can develop a system for growing other seaweeds commercially. In the mean time, we should consider phycocolloid production based on introduction of cultivars as an alternative to depletion of natural populations of target species. Problems associated with *Codium fragile* in the north Atlantic (Fralick & Mathieson, 1972; Kapraun et al., 1988) and *Caulerpa taxifolia* in the Mediterranean (Meinez et al., 1993) should not reflexively prompt us to equate introduction of seaweed cultivars with spread of the Ebola virus. "Although there are sound ecological arguments to avoid cultivar introduction, some are more passionate than scientific. The potential in many cases has been exaggerated and careful introduction can be successful provided it occurs under a set of reasonable criteria" (Oliveira, 1990). *Eucheuma* and *Kappaphycus* cultivars have been widely transported and introduced throughout the Indo-Pacific. *Gracilaria chilensis* has been safely introduced in Brazil (Plastino & Oliveira, 1988) and *Porphyra* from Japan is now grown in New England and Puget Sound (Mumford 1990, Bergdahl, 1990).

(5) We can help to develop new, high value products including agarose which has proven indispensable to biotechnology (Renn, 1990), agars with medical and dental applications (Kasloff, 1990) and alginates for high-performance bio-paper (Kobayashi, 1990). These products promote a healthy bottom line (black) with high per unit values, rather than profit by shear volume, and so qualify as 'green'. One approach to the development of new phycocolloid resources is based on genetic transformation and the creation of novel genome combinations (Cheney *in litt.*; Huang et al., 1996; Sivan et al., 1995). This basic research deserves our support and encouragement. Recent comprehensive reviews of contributions from biotechnology are available both with an industry perspective (Renn, 1990, 1997) and with a view from the field (Bird, 1995). There is little I can say in a brief time that could add to their insights, comments and recommendations.

In summary, I remind you that the marine phycocolloid industry has come a long way since Doty pioneered *Eucheuma* farming (Doty & Alvarez, 1975). Now a world-wide industry can impact on major ecosystems and affect emerging economies. I don't think that it is reasonable to blame coastal subsistence fishermen who are uneducated, or industry representatives who may be uninformed or ill-advised for environmental and economic problems which are emerging, when we marine biologists and scientists do not take the lead in doing the right thing. Sustainable development: it's good for the industry, and it's good for me!

Acknowledgements

The author gratefully acknowledges financial support from the United States Agency for International Development (HRN-5600-G-2023-0). Gratitude and appreciation for logistical support, research collaboration and friendship are expressed to Drs A. Hurtado-Ponce, L. Liao and G. Trono and to numerous other colleagues at the UP Institute of Marine Science and the University of San Carlos Marine Botany Program. Dr Don Renn is acknowledged for critical comments on the manuscript and for useful insights into the phycocolloid industry. This paper represents contribution number 182 from the Center for Marine Science Research, UNC-Wilmington.

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