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A decade of change in the seaweed hydrocolloids industry

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Abstract Seaweed hydrocolloid markets continue to grow, but instead of the 3–5% achieved in the 1980s and 1990s, the growth rate has fallen to 1–3% per year. This growth has been largely driven by emerging markets in China, Eastern Europe, Brazil, etc. Sales of agar, alginates and carrageenans in the US and Europe are holding up reasonably well in spite of the recession. However, price increases to offset costs in 2008 and 2009 have begun to have a dampening effect on sales, especially in markets where substitution or extension with less expensive ingredients is possible. These higher prices have been driven by higher energy, chemicals and seaweed costs. The higher seaweed costs reflect seaweed shortages, particularly for carrageenan-bearing seaweeds. The Philippines and Indonesia are the dominant producers of the farmed *Kappaphycus* and *Eucheuma* species upon which the carrageenan industry depends and both countries are experiencing factors limiting seaweed production. Similar tightening of seaweed supplies are beginning to show up in brown seaweeds used for extracting alginates, and in the red seaweeds for extracting agar. The structure of the industry is also undergoing change. Producers in China are getting stronger, and while they have not yet developed the marketing skills to compete effectively in the developed world markets, they have captured much of their home market. China does not produce the red and brown seaweeds needed for higher end food hydrocolloid production. Stocking their factories with raw material has led to the supply problems. Sales growth continues to suffer from few new product development successes in recent years; although some health care applications are showing some promise, i.e., carrageenan gel capsules and alginate micro-beads.

Keywords Hydrocolloids · Agar · Alginate · Carrageenan

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List of country abbreviations

AR	Argentina
AU	Australia
CA	Canada
CL	Chile
CN	China
ES	Spain
FR	France
ID	Indonesia
IE	Ireland
IS	Iceland
JP	Japan
KR	Korea
MA	Morocco
MX	Mexico
MY	Malaysia
NA	Namibia
NO	Norway
PE	Peru
PH	Philippines
PT	Portugal
TZ	Tanzania (Zanzibar)
UK	United Kingdom
US	United States
VN	Vietnam
ZA	South Africa

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Introduction

The principal commercial seaweed extracts continue to be the three hydrocolloids: agar, alginates, and carrageenans. However, biologically active compounds such as plant and animal nutritional supplements are growing in importance, and seaweeds as food and seaweed-derived food flavors, colors and nutrients are attracting considerable commercial attention.

The processed food industry is still the primary market for the seaweed hydrocolloids where they serve as texturing agents and stabilizers; although agar and its derivative products agarose and bacteriological agar have long enjoyed attractive markets as microbiological and electrophoresis media, respectively. Alginates continue to be used in textile printing, paper coating and other relatively low margin industrial applications, but their use in restructured meat products for pet and human foods offer better profit margins. Interest is growing in the use of alginate beads for controlled drug release, and this could develop into a profitable niche market. Carrageenan has long enjoyed a small share of the personal care toothpaste binder market and has started to make inroads into cosmetics and pharmaceuticals e.g. drug capsules and excipient formulations.

The last decade has not been an easy one for this industry. Seaweed costs have escalated, particularly in the last year or so as demand has outstripped supply. Chemical and energy costs are second only to seaweed in determining overall production cost, and they too have escalated. At the same time, numerous low cost producers in Asia, particularly China, have introduced a competitive environment that has made it difficult or impossible to pass all of these cost increases along to customers. Our prediction is that there will be a further shake out of the industry, and only those companies with control of their raw material supplies, efficient manufacturing and strong sales and marketing will survive.

Those of you who have been around since the early days of International Seaweed Symposia will recall that the chemistry of seaweed hydrocolloids attracted numerous Proceedings papers of significant importance to the industry. The same can be said for papers on the phycology, taxonomy, and vegetative cultivation of the commercially important genera and species. Today, only a smattering of papers of direct relevance to solving the technical problems of the seaweed hydrocolloids industry can be found on ISS programs. We do not mean to imply that the industry has lost its need for knowledge from the scientific community; it is just that the needs are now more in the realms of new applications development, industrial engineering, and enterprise management of the commercial seaweed supply chain, problems not particularly amenable to solutions by the ISA membership.

One aquaculture technology receiving attention at this symposium that is beginning to impact on the phycocolloid industry is Integrated Multi-Trophic Aquaculture or IMTA which is showing promise of producing commercial quantities of seaweed for hydrocolloid extraction as well as growing fish for human consumption in ponds, net enclosures, and the like. This is taking place in various parts of the world, but seems to be most advanced in Indonesia where *Gracilaria* for agar production is being grown in ponds along with milk fish to take advantage of nutrient synergies.

Sales volume and value or revenue growth

Turning now to some historical sales data, Table 1 shows the estimated volume of sales in metric tons of these hydrocolloids over a 10-year time period. Let us pause for a moment to introduce two unit definitions. Volume refers to production or sales in metric tons (t). The unit for value or revenue will be currency or, in this paper, US dollars.

The overall compound annual volume growth rate for these hydrocolloids over the decade under consideration has been less than 2%. This relatively low growth rate has been the result of some ups and downs in specific markets. The sales estimates for carrageenan include refined carrageenan, PES, for human food and a lesser processed SRC for pet food for the carrageenan sales. SRC for pet food has shown a decline from 1999 to 2009 and if it is removed from the carrageenan totals, the compound growth rate for carrageenan would be slightly more than 4% The alginate and PGA sales include industrial grades for textile printing, paper coating, and welding rod flux in addition to grades for food, beverage, personal care, and pharmaceutical uses and show a compound annual growth rate of only about 1%, but this growth has been brought down by the decline in sales of pet and commercial fish foods. Considering just the more attractive food and pharma markets, the compound annual growth rate is 3.7%. Agar sales include microbiological grades in addition to food grades. The compound annual growth rate of 2.5% has not been affected by the distortion observed for carrageenan and alginates.

Table 1 Seaweed hydrocolloid sales volume: last decade growth

Seaweed hydrocolloid	1999 sales (t)	2009 sales (t)
Agar	7,500	9,600
Alginates	23,000	26,500
Carrageenans	42,000	50,000
Total	72,500	86,100

The authors are not confident that all of the Asian sales of seaweed hydrocolloids by Asian producers have been accounted for, especially those with facilities in China. Many small factories have opened in recent years, and it is hard to keep track of those that are succeeding in home markets and those falling by the wayside. Certainly, there was a rapid growth in alginates for textile printing in China in the early part of this decade, but there has been a slowing of growth in these markets attributed to the recession.

As noted earlier, these volume growth rates in foods have not come so much from new applications as from emerging markets such as China, Eastern Europe, and Brazil where processed foods are being adapted and adopted from the Western diet. Relatively little in the way of new product development will be needed to encourage consumers in these nations to adopt some Western food habits. To our great relief, the seaweed hydrocolloids mostly end up in nutritious processed foods such as yogurt and other dairy products, soy milk as well as in deli meats such as ham and turkey breast. Very little goes into the ubiquitous and low nutrition snack foods.

Sales of agar, alginates and carrageenans for food use in the US and Europe, are currently holding up reasonably well in spite of the recession. There are a number of reasons relating to the allocation of family income that account for this result. In a recession with high unemployment rates, the food buyer is looking for bargains in the way of lowest cost per kilogram of nutrition. The family budget does not allow for as much eating out as when economic times are good. Both of these conditions drive up the market for processed foods, and thereby for food additives. For the housewife who will be preparing more meals at home, the convenience of processed foods will be an added impetus for higher sales of processed foods and additives.

There will continue to be attractive volume growth for seaweed hydrocolloids as economic advancement spreads through developing nations and recovery from the recession at last lessens unemployment in more advanced nations. However, for mature markets like the US and Europe, new products are needed to sustain any significant per capita growth. In the past, new products came about through cooperative R&D between food additive producers and food companies. However, the R&D staffs of both have been cut to the bare bone, and until they are built back up, there is little hope for any product breakthroughs.

Over-building of production capacity, particularly in carrageenan, have helped lower prices through heavy competition even in the face of higher seaweed, energy, and chemicals costs. However, hydrocolloid prices finally began to rise in late 2008 and early 2009 when producers could no longer absorb the higher costs without some price increases. Even the Chinese producers by mid-2009 realized their low margins were not sustainable, and their government would not support their losses. Higher hydrocolloid prices have led to some substitution or extension of seaweed hydrocolloids with less expensive ingredients; although this route to lower cost has little potential left in it after years of being exploited.

Table 2 provides an estimate of current average prices of seaweed hydrocolloids and the prices a decade ago. There are several commercial grades of each hydrocolloid, so the prices in the table are blends of grades. The data in Tables 1 and 2 can be combined to obtain the annual revenue of seaweed hydrocolloids in international trade. The revenue estimates for 1999 and 2009 are shown in Table 3.

Sales have roughly doubled in 10 years for a compound annual growth rate of about 6%. This breaks down into about 4% compound annual price increases and about 2% volume growth rate. As noted earlier, none of these growth rates was uniform over the decade being considered, and the price growth in particular has been concentrated in the last 2 or 3 years when cost inflation of energy, chemicals, seaweeds, and transportation were most severe. Price fluctuations over the last decade have been particularly pronounced for agar even though the Table 3 shows virtually the same price today as a decade ago. This occurred for reasons of price competition as much as it did for cost increases.

A decade of change in industry structure and production

Overview

In one respect, this is a mature industry tracing its roots to the 1930s, but it has undergone considerable change in past and continues changing to this day. Until the 1960s and 1970s, the producers of seaweed hydrocolloids were privately owned, entrepreneurial enterprises. Consolidation began with horizontal integration, e.g., Hercules marrying its cellulosic gums with Copenhagen Pectin/CPKelco's carrageenan and pectin. Even before that, vertical integration took place in the carrageenan industry when the strong production capability of Algin Corp. was merged with the strong technical and sales capabilities of Seaplant Corp to form Marine Colloids/FMC. More recently, horizontal integration has been achieved without interference from

Table 2 Average prices of seaweed hydrocolloids

Seaweed hydrocolloid	1999 (US$ kg^{-1})	2009 (US$ kg^{-1})
Agar	17	18
Alginates	9	12
Carrageenans	7	10.5

Table 3 Seaweed hydrocolloid sales value: last decade growth

Seaweed hydrocolloid	1999 sales (million US$)	2009 sales (million US$)
Agar	128	173
Alginates	225	318
Carrageenans	291	527
Total	644	1,018

anti-trust authorities, e.g., FMC already owned alginate producer Pronova in Norway, but was able to acquire ISP's alginate business to now have 35% to 45% of the western world market.

Consolidation has been mostly limited to Western hemisphere companies while small to medium size producers keep popping up in Asia, particularly in Indonesia and China and, except for alginates, in Indonesia, consolidation is probably inevitable in Asia. However, any move in that direction has been slowed by the current recession.

One lesson these newer Asian players have yet to learn is the importance of marketing skills including strong technical service. No amount of process control can avoid natural product variability out the end of a primary process line. Nor can many applications be satisfied with primary generic products. Being able to blend the primary products to meet customer performance needs is a mixture of science and long, hands-on experience. Even learning how to measure a customer's performance needs in the laboratory is no easy task. The common wisdom holds that the seaweed hydrocolloids have become commodity products with the lowest price provider getting the business. While this may be true in some markets, there are numerous specialty applications where the companies with the technical marketing skills can reap respectable profits. Some of these companies do not produce hydrocolloids but buy them from the producers who can meet their demanding needs. These companies act more like secondary producers than they do like the conventional agent or distributor. Ingredients Solutions, a company in which one of the authors was a founder (HB), is one such secondary producer and Eurogum, based in Denmark is another example of this.

In the Philippines, producers have experienced another type of expansion. The farming of carrageenan seaweeds was first established commercially there, and numerous small companies were set up. Today there are four or five fairly strong Filipino-owned companies, in particular, Shemberg Corp, PCI Worldwide, TBK and Marcel Trading Corp. However, major Western producers (CPKelco, FMC, and Cargill) have established primary production facilities in the Philippines to take advantage of the cost savings resulting from being close to the source of their major raw material. These facilities are wholly owned by the foreign company except for Philippines Bio Industries which was established as a joint venture between Cargill (really its predecessor) and PCI Worldwide (and its predecessor as well).

We do not mean to ignore South American production of hydrocolloids, particularly Chile and to a much lesser degree in Brazil and Argentina. However production, except for agar and carrageenan, is still relatively small in these countries; e.g., the privately owned firms of Soriano SA in Argentina and Gelymar in Chile. Foreign producers have built plants in Chile to be closer to their seaweed raw material (Danisco, Ina) or have formed supply agreements (FMC with Gelymar). In addition to producing seaweed hydrocolloids, Chile is an important exporters of red and brown seaweeds to producers in Europe, the US, China, and Japan. Some Chilean weeds have unique hydrocolloid properties that are needed by the industry to meet specific applications requirements, i.e., *Gigartina* for carrageenan dairy and personal care applications, and *Lessonia* species for various alginate food and pharma applications.

China does not produce the red and brown seaweeds needed to produce higher performance hydrocolloids. Stocking their factories with seaweeds from Philippines, Indonesia and Chile has led to the supply problems that will be more thoroughly discussed below.

Turning now to the individual hydrocolloids, the structure of each will be considered.

Agar

Agar is a relatively mature industry in terms of manufacturing methods and applications. Today most processors are using press/syneresis technology; although some still favor freeze/thaw technology or a mixture of these technologies. While the basic processes may not have changed, improvements in presses and freezing equipment must be noted. High-pressure membrane presses have greatly improved dewatering of agar and thereby reducing energy requirements for final drying before powder milling.

Gracilaria and *Gelidium* are the principal seaweeds for commercially producing agar. *Gracilaria* has become the preferred seaweed for making food grade agar; because it has been successfully cultivated in Chile and Indonesia. *Gelidium* continues to be the preferred seaweed for making bacteriological and pharmaceutical grade agars and agarose. Strong-gelling agar is extracted directly from *Gelidium* with a dilute acid solution to break down cell walls in a pressure cooker; whereas extracting strong-gelling agar from *Gracilaria* requires the use of a boiling alkali solution. The alkali treatment converts the galactose 6-SO_4 to 3, 6 anhydrogalactose, well-known chemistry that "de-kinks" the polygalactose molecules and enhances the gelling process. These process differences explain why it is difficult to optimize the production of agar from both seaweeds in the same process line. Obviously, there is an advantage to being able to produce more than one seaweed hydrocolloid in the same process line. MSC in Korea and Hispanagar in Spain are two companies that have produced gel-press carrageenan and gel-press agar in essentially the same process lines; although Hispanagar has recently exited carrageenan production because of low profit margins.

At one time there were hundreds of small processors of agar primarily in the Asia-Pacific area. Most were primitive cottage industries and others were only producing for local or regional use. In the last 10 years, a number of these small agar processors have closed down or reduced out puts at their plants in Spain, Portugal, Italy, France, Morocco, Japan, and Korea. Old, inefficient processes were behind most of these closures. At the same time new, more modern factories have been constructed or existing capacities expanded, particularly in Indonesia, Chile, and China.

Japan historically has been a major producer and domestic user of agar. However, due to rising production and environmental costs in Japan, agar producers there have invested in external production or have started outsourcing their agar needs. A good example of these practices would be Ina Food Industry Co. Ltd.

Currently, two companies have emerged as undisputed leaders within the industry: Algas Marinas in Chile and Agarindo Bogatama in Indonesia; between them, they are producing about 3,600 t y^{-1} or about 38% of current production. Other strong producers are Setexam in Morocco, MSC Co. in Korea, Hispanagar in Spain and Huey Shyang Seaweed Industrial Company in China. These six companies account for about 5,500 t y^{-1} of production/sales or 57% of current total market.

Some European producers have also chosen to expand production outside their home country. B & V from Italy has production interests in Indonesia and Morocco (although production there has been recently curtailed). Hispanagar, with some existing overseas operations, has started up activities in China as well.

The geographic distribution of agar production at the beginning and at the end of the last decade breaks down as shown in Table 4.

The compound annual volume growth rate in agar production over the last 10 years has been 2.5% per year as noted earlier. Based on the data in Table 3, the compound annual value growth rate over the same period has been 3.1% per year. This annual value increase is less than we will see for alginate and carrageenan. Competition both among processors and other gums has held down price increases. Current world extraction capacity is estimated to be 12,500 t y^{-1} versus 9,600 t y^{-1} being utilized. This translates to 77% plant utilization which is at the lower end of the utilization range for efficient operation.

Table 4 Geographic distribution of agar production

Region	1999 volume (t)	2009 volume (t)
Europe	1,000	700
Africa	900	800
Americas	2,600	2,800
Asia-Pacific	3,000	5,300
Total production	7,500	9,600
Total capacity	9,000	12,500
% Utilization	83%	77%

Agar products continue to be unique when compared with alginate and carrageenan products. The latter are almost exclusively sold as coarse to fine powders; whereas agar is still sold in the other forms shown in Table 5. The non-powder forms arise primarily from the older processes used to make the agar.

The most significant changes reflected in Table 5 have been the increase in *Gracilaria* agar powder production and decrease in *Gelidium* powder. This primarily reflects the increased availability of competitively priced cultivated *Gracilaria*.

Alginates

Alginates of commerce are primarily the alkali or alkaline earth salts of alginic acid; the sodium salt being the most widely used in foods. The only other derivative of alginic acid that is used in the food industry is propylene glycol alginate or PGA.

Twenty-five to 30 years ago almost all extraction of alginates took place in Europe, USA, and Japan. The major change in the alginates industry over the last decade has been the emergence of producers in China in the 1980s. Initially, production was limited to low cost, low quality alginate for the local industrial markets produced from locally cultivated *Laminaria (Saccharina) japonica*. By the 1990s, China producers were competing in western

Table 5 Product forms of agar

Product form	1999 Volume (t)	1999 Share (%)	2009 Volume (t)	2009 Share (%)
Powder, *Gracilaria*	4,100	55	7,650	80
Powder, *Gelidium*	2,800	37	1,550	16
Square, *Gelidium*	300	4	200	2
Strip, *Gelidium*	300	4	200	2
Total	7,500	100	9,600	100

industrial markets for alginates, primarily based on low cost. Even though *L. japonica* is abundant in China, the low guluronic to mannuronic acid ratio (G/M) of the alginate extracted from it yields weakly gelling alginates. Their performance is acceptable only for industrial products such as textile printing and paper coating. To compete in the food ingredients market in the US and EU, alginate producers in China have had to import Chilean and Peruvian medium G seaweeds such as *Lessonia nigrescens* that has increased their costs.

As noted above, considerable consolidation has taken place in western alginate producers. During the decade being considered here, Kelco exited the production of alginates and sold their San Diego, California and Girvan, Scotland plants to ISP. FMC entered the business through acquisition of the Pronova facility in Haugesund, Norway and later acquired the ISP alginate facilities. ISP had already closed the San Diego factory, and FMC stopped production in Scotland combining that production with its facility in Norway where they are concentrating on manufacturing high quality food and pharma grades. Danisco and Cargill are smaller producers in France, and Kimica continues to be a major producer headquartered in Japan, but with a substantial part of its production in Chile. Kibun, today called Food Chemifa Co, is a smaller Japanese alginates producer. Both Kimica and Food Chemifa are producing PGA with Kimica being by far the larger.

The geographic distribution of alginate production at the beginning and at the end of the last decade breaks down as shown in Table 6. Alginates are frequently sold as blends that greatly increase the volume of product in commerce. Table 6 attempts to remove non-alginate blending components of products in the marketplace and report only the pure alginates.

It should be noted that reliable figures from China are difficult to obtain. Perhaps China in 2009 produced an additional 5,000 t of mainly industrial grade material. This would mean total world production reached in excess 30,000 t of alginates and required an additional 50,000 t of dry *L. japonica* seaweed as raw material. In addition, Table 6 shows 89% plant utilization in 1999 that suggests a potential squeeze on production was looming, but the relatively slow growth and some plant improvements reduced plant utilization to a comfortable and efficient level of 76% by 2009.

From Table 6, we also learn that total world production capacity over the last 10 years has expanded by 25%, mainly in China. During the same period production/sales have increased by only 6% or hardly 1% per year, the lowest of the hydrocolloids being studied. The main reason for this slow growth has been a leveling off of growth in the large industrial grade markets. The slow to no growth in these markets has been offset by increased sales for food and pharma uses.

Also worth mentioning is that alginate manufacturing in USA has ceased to exist; whereas Europe is still able to maintain a fairly substantial part of their alginate industry even though Europe is a high-cost production region. This is primarily due to FMC's ability to increase their market share of high quality, specialty grades of alginates being sold in developed countries. Of the 8,900 t y^{-1} of alginates still being produced in Europe, two-thirds is being produced by FMC in its Norway facility. Asia-Pacific, on the other hand, is where the real capacity growth has taken place, but at the same time markets for this capacity is mostly in the Asia-Pacific region.

Table 6 Geographic distribution of alginate production

Region	1999 alginate volume (t)	1999 PGA volume (t)	2009 alginate volume (t)	2009 PGA volume (t)
Europe	12,000	0	10,000	0
Americas	4,000	1,000	1000	100
Asia-Pacific	9,000	1,000	15,500	1,900
Sub-total	25,000	2,000	26,500	2,000
Total capacity	28,000	2,300	35,000	
% Utilization	89%		76%	

Carrageenan

Of the three categories of hydrocolloids under consideration, carrageenan is the most difficult to characterize. First of all is the chemical nomenclature: the brittle gel-forming kappa, the elastic gel-forming iota, and the non-gelling, but commercially unavailable, lambda. To replace lambda in cold soluble applications the mu/nu hybrids obtained from Chilean *Gigartina* and *Sarcothalia* species are used. Alkali treating of these extracts yields kappa/iota hybrids that find use in dairy and toothpaste products. Kappa carrageenan today is almost exclusively obtained from farmed *Kappaphycus alvarezii* and iota from farmed *Eucheuma denticulatum.*

The chemical complexity of carrageenan is surpassed only by the regulatory complexity. In the 1970s, an energy efficient process was developed in the Philippines to make a lower cost, strong-gelling kappa carrageenan and a weakly gelling iota. These semi-refined products gradually replaced the use of refined carrageenan as the gelling agent in canned meat pet foods. The process required lower capital investment than standard carrageenan refineries and the semi-refined extracts could be profitably sold for about two-thirds the price of conventionally refined carrageenan.

At the beginning, this product was not controlled for microbiological contamination; because the pet food meat products containing the gelling agent were sterilized in the process of being retorted. Eventually, this semi-refined product was sufficiently purified in the manufacturing process to yield a carrageenan suitable for human consumption.

On the regulatory front, the US FDA considered the refined and semi-refined carrageenan sufficiently similar not to require differentiation on ingredients labels. However, the European Commission and the FAO/WHO Codex Alimentarius required ingredient labels to differentiate the two products as carrageenan or E-407 and as PES or E-407a.

The lower purity product used in pet foods has never had a uniformly regulated label name in any jurisdiction and has been called variously seaweed flour, alkali-modified flour (AMF) or semi-refined carrageenan (SRC).

Twenty-five years ago, almost all carrageenan extraction took place in Western Europe and USA with the remainder taking place in Asia-Pacific and Latin America. Since then, the situation has changed considerably and in particular with the introduction of human food-grade semi-refined carrageenan (PES). From its start in the mid 1970s, PES has progressively reconfigured the geographic distribution of production facilities as well as increasing the percent of PES being produced.

Table 7 displays the significant changes in production of different carrageenan types and in geographic regions of production that have taken place over the last decade.

One interesting change that has taken place is that gel-press refined carrageenan has surged ahead of alcohol-refined carrageenan. The lower cost of gel-press in relation to the cost of alcohol refined accounts for this. The gel-press process produces only kappa carrageenan; whereas the more versatile alcohol process can produce all carrageenan types (except PES). As a result, most gel-press kappa goes either to the lower margin Asian water jelly market or to meat applications where it must compete with even lower cost PES kappa. In contrast, most of the alcohol product goes to higher margin applications such as toothpaste, cold soluble dairy products, and some pharma applications.

Figure 1 shows the percent of production for each carrageenan type in 1999 and in 2009. The overall result has been that alcohol carrageenan has declined in market share during the last decade (32% to 23%) and gel-press carrageenan has increased in market share (20% to 26%) The real winner of the market share race has been PES which has grown in market share from 22% to 41% during the decade. For reasons to be discussed below, the production of pet-food-grade carrageenan fell from 26% to 10% during the same period.

It was noted earlier that the average volume growth rate for the decade under consideration was only 2 to 3% per year. Table 7 clearly shows that this low rate of growth was heavily influenced by the decline of SRC for pet food. As noted earlier, if this product is taken out of consideration the growth rates of the remaining carrageenans are 4% to 5% per year, a growth rate that has prevailed since the 1970s.

To fully understand the implications of Table 7, we need to look at current average producer selling prices of the four product types in 1999 and today. Table 8 is an estimate of these selling prices.

Food processors have realized substantial savings by using this lower cost form of carrageenan. This has been possible since many applications properties of PES are almost equivalent to refined counterparts. This is particularly true in processed meats and in the less sophisticated dairy products.

At 76% capacity utilization for PES there is adequate unused capacity for growth over the next few years. Furthermore, adding capacity to this process is relatively inexpensive with a fast turnaround time. Before adding any new capacity, however, producers should increase utilization to improve operating efficiencies. Overcapacity in the long run leads to excessive price competition and hurts everyone in the value chain.

The situation for SRC Pet Food is clearly already one of overcapacity. This does not reflect new capacity being introduced in recent years, but the decline in the market. This decline is in part due to dry kibble replacing a portion of the canned meat products' market and in part due to reformulation to lower-cost gelling agents.

There has been a fairly significant increase in production capacity for gel-press-refined carrageenan in recent years, particularly in Asia-Pacific. Only kappa carrageenan is regularly made by this process, so it competes head on with the principal PES product in meat applications. While capacity utilization is currently satisfactory for gel press there are indications a decline in utilization may be in store. On the other hand, there has been negligible increase in alcohol-precipitated carrageenan in recent years. In fact, some capacity has been taken off stream at CPKelco and at Shemberg Biotech. Capital expenditure on these plants has for the most part been limited to cost-reduction and quality improvements.

Major market segments

Agar

Agar, alginate, and carrageenan each have unique properties when it comes to finding their market niches. Agar and carrageenan form thermally reversible gels; whereas alginate gels do not melt on heating since they have been cross-linked by divalent cations. It is not the aim of this paper to cover the

Table 7 Geographic distribution of carrageenan production

Region (t)	RC alcohol (t)	RC gel press (t)	PES (t)	SRC pet (t)	Total (t)
1999					
Europe	7,700	2,500	200		10,400
Americas	4,800	2,000			6,800
Asia-Pacific	1,000	3,000	8,000	11,000	23,000
China		1,000	1,000		2,000
Total production	13,500	8,500	9,200	11,000	42,200
Total capacity	15,200	11,000	12,000	13,000	55,200
Percent utilization	88%	77%	77%	85%	76%
2009					
Europe	6,000	1,000	100		7,100
Americas	4,500	3,500	1,400		9,400
Asia-Pacific	1,000	4,000	16,000	5,000	26,000
China		4,500	3,000		7,500
Total production	11,500	13,000	20,500	5,000	50,000
Total capacity	13,500	16,500	27,000	8,000	65,000
Percent utilization	85%	78%	76%	65%	76%

technology of applications for seaweed hydrocolloids in any depth, but instead display the growth of major use categories over the past decade.

Table 9 shows the major market segments for agar by volume. Food applications continue to grow, and have been driven by the growth of processed foods in developing countries.

Agar melts and gels at higher temperatures than carrageenan so it finds uses in pastry fillings and glazes that can be applied before the pastry is baked without melting in the pastry oven. In processed meats, carrageenan is the favored water binder or texturing agent, but agar hold on to the gelatine replacement market in canned meats and aspics. The texture of agar in fruit jellies also compete with kappa carrageenan jellies, but the agar texture is preferred in parts of Asia, particularly in Japan.

Although significantly smaller, the markets for the specialty grades shown in Table 9 are quite attractive because of better profit margins. This large melt/gel hysteresis loop for agar makes it uniquely suited for bacteriological use. For instance its gels can be sterilized without melting. Agarose, a sulfate-free very pure form of agar finds widespread use today in gel electrophoretic analysis of the molecules of biotechnology.

Figure 2 graphically displays the percent of the total for each market segment shown in Table 9. There has been little change in the distribution over the last decade which is not so surprising for this mature product. The retail market is interesting. This is for the agar powder sold in grocery stores and used by housewives to make water gel desserts in the home. This market has declined in Western countries, but is still growing in Asia.

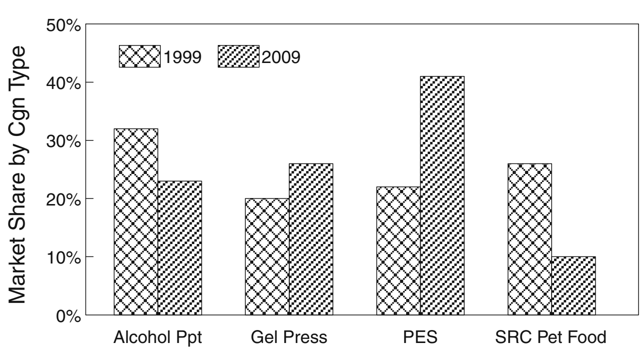

Fig. 1 Carrageenan market share by production method

Alginates

The breakdown of alginate market segments by volume is shown in Table 10. Growth of alginate markets is a mix of geographic re-distribution of established markets, e.g., textile growth (and then decline in the recession) in China, and a few new developments in the food and pharma area.

This is probably as good a place as any to point out that the numbers presented in this paper are based on the authors' personal experience and discussions with

Table 8 Average 2009 prices of carrageenan types

Seaweed hydrocolloid	1999 Price (US$ kg^{-1})	2009 Price (US$ kg^{-1})
Alcohol ppt.	11	15
Gel press	9	12
PES	5.50	8
SRC pet	3.50	6

Table 9 Agar market segmentation over last decade

Market segment	1999 volume (t)	2009 volume (t)
Confections/water gels	2,800	3,250
Baking	2,300	2,800
Retail (gel powder)	1,200	2,000
Meat	200	150
Other (dairy etc)	300	500
Bacto/pharma/agarose	700	900
Total	7,500	9,600

Table 10 Alginate market segmentation over the last decade

Market segment	1999 volume (t)	2009 volume (t)
Technical grades	11,000	11,000
Food/pharma	8,000	13,000
Animal feed	4,000	1,000
PGA	2,000	1,500
Total	25,000	26,500

colleagues as well as studying published market studies. However, there is no assurance of accuracy. China has become a major market and producer of alginates, but both production and sales estimates are at best a guess.

Since the cross-linked alginate gels do not melt they find use in restructured meats that when cooked are subjected to even higher cooking temperatures than the baked goods for which agar is satisfactory. Restructured vegetables such as onion rings and pimento for olive stuffing take advantage of the high strength of these calcium cross-linked alginate gels. Industrial applications require similar properties except for the high gel strength required in most food applications.

Figure 3 shows each market segment as a percent of the total. Food and pharma has increased its share of the toal considerably over the last decade while the percentage for the technical grade has leveled off. Animal feed use has nearly been wiped out also because the pet food portion of this segment is increasingly switching to dry pet food types instead. Likewise, the use of alginate in fish foods seems to be on the decline. As for PGA, foam stabilization in beer has been the major historical market and this seems to be declining as the trend for "natural" beer continues.

Carrageenan

The breakdown of major carrageenan markets and how volumes have changed over the last decade are shown in Table 11. One of carrageenan's major attributes is its reactivity with proteins, particularly those in milk. Concentrations as low as 0.01% carrageenan can form a network with milk proteins to suspend cocoa particles in chocolate milk; whereas ten times this concentration of carrageenan alone would be needed to form such a network.

Therefore, it is not surprising that dairy applications are still growing in use. However, the dairy market has not grown as rapidly as the processed meat market, particularly ham and other deli meats such as turkey breast. In processed meats, carrageenan serves as a water binding agent that prevents loss of moisture during cooking that improves cooked yields and prevents an undesirable dry texture or bite. Figure 4 shows the distribution of market segments as a percent of the total and emphasizes these comments on relative market share. The market share for dairy uses has declined from 40% to 31% of the total over the last decade while the market share for meat uses has increased from 33% to 41%.

Carrageenan water gel desserts are not particularly popular in the US or the Europe where gelatine is preferred to give a soft texture gel that melts in the mouth. However, kappa carrageenan water gel desserts are popular in Asia.

Carrageenan has long had attributes as a toothpaste binder (texture, cellulase resistance, etc.), but it is losing ground to cheaper CMC as the need for cellulase resistance in has declined with improved household hygiene around the world.

The fall off in use of carrageenan in pet food is largely due to the shift away from canned meat products to dry dog and cat food as noted earlier.

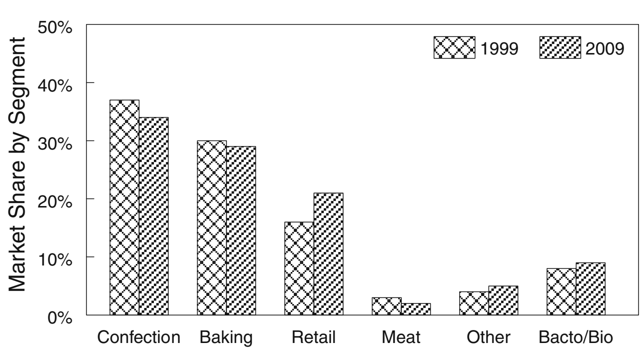

Fig. 2 Agar market share by application

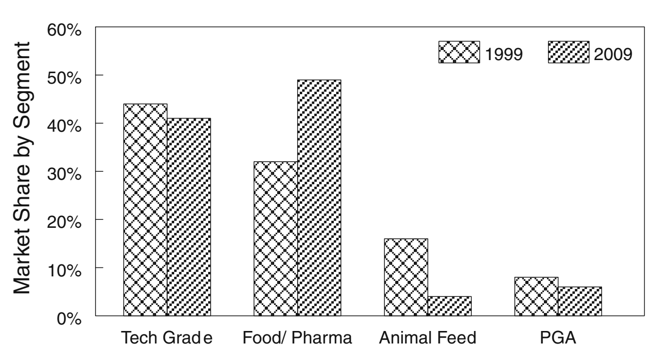

Fig. 3 Alginates market share by application

Table 11 Carrageenan market segmentation over the last decade

Market segment	1999 volume (t)	2009 volume (t)
Meat	10,000	18,500
Dairy	12,000	14,000
Water gels	4,500	8,500
Toothpaste	1,500	2,000
Others	2,000	2,000
Total food grade	30,000	45,000
Pet food	12,000	5,000
Grand total	42,000	50,000

Seaweeds, the limiting resource in the value chain

The seaweed hydrocolloids industry has been hit by a number of shocks in recent years including high and erratic energy and chemical costs, but none has been more unpredictable and disruptive than availability and costs of seaweeds, particularly for carrageenan producers and those marketing this hydrocolloid.

Anyone in the carrageenan business these days is constantly being reminded of how important seaweed availability, cost, and quality are to a profitable enterprise, and none is in a very favorable range at this writing (December 2009). Availability and cost of alginate seaweeds is also beginning to be a concern of alginate producers. As best as the authors can determine, agar-bearing weeds are still in good supply at reasonable cost.

Agar seaweeds

As mentioned earlier agar is extracted from *Gracilaria* and *Gelidium*, but *Pterocladia* and *Ahnfeltia* have also been used. In practice, *Gracilaria* and *Gelidium* are the dominant industrial species, and there is hardly any production based on *Ahnfeltia* or *Pterocladia* material.

Gracilaria is the only species that is commercially cultivated at present, and this is taking place mostly in Indonesia and Chile. Cultivation of this seaweed also takes place to a much lesser degree in Malaysia, Thailand, and China. Small quantities are also being cultivated in South Africa and Namibia.

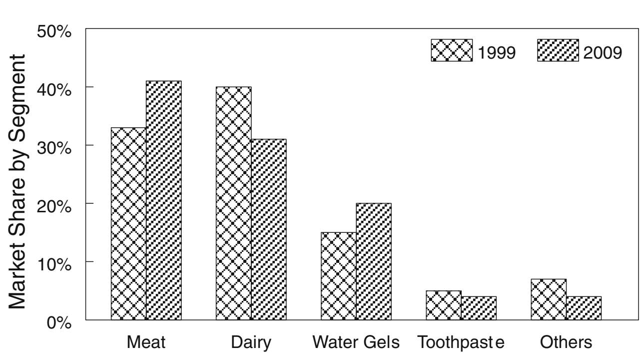

Fig. 4 Carrageenan market share by application (without pet food)

Gelidium has so far has not been commercially cultivated, but it is still the preferred weed for producing quick soluble and bacteriological agar which in turn is the starting material for agarose. Harvesting *Gelidium* mainly takes place in Spain, Portugal and Morocco with lesser amounts coming from South Korea, Japan, and Mexico.

As was seen in Table 5, *Gracilaria* has grown in importance for extracting agar over the last ten years in contrast with *Gelidium* that is declining in importance. There seems to be an adequate supply of *Gelidium* to supply its current markets, but growth will have to come from cultivated *Gracilaria*.

Table 12 shows the harvest growth or decline by location for the period of 1999 to 2009 for *Gracilaria* and *Gelidium.*

In 2009, 80% of agar raw material was *Gracilaria* up from 63% in 1999. As will be shown below, this situation is not unlike that for carrageenan where 79% of the raw material is cultivated *K. alvarezii* ("cottonii").

Unlike the export price of seaweeds for alginates and carrageenan, the export price for *Gracilaria* has remained fairly stable over the last decade. For instance, the price for *Gracilaria* from Chile has been about US$ 1,200/t over this period.

Alginate seaweeds

Within the last 10 years, a marked shift has taken place in the seaweed species being used for extracting alginates. In 1999, *Ascophyllum nodosum* and *Macrocystis pyrifera* accounted for 58% of the harvest as shown in Table 13, but that mix

Table 12 Geographic harvest history for agar seaweeds 1999 to 2009

Type/location[a]	1999 (dry t)	2009 (dry t)
Gracilaria		
ES-PT	300	200
NA	450	300
CL–PE-AR	22,350	30,000
ID-CN-VN	10,900	27,000
Sub Total	34,000	57,500
Gelidium		
MX	800	800
ES-PT-FR	7,400	4,000
MA	7,000	6,000
JP-KR-ID	5,000	4,000
Sub Total	20,200	14,800
Grand Total	54,200	72,300

[a] See list of country abbreviations

Table 13 Geographic harvest alginate seaweeds 1999 and 2009

Type	Harvest location[a]	Extract type	1999 Harvest (dry t)	%	2009 Harvest (dry t)	%
Laminaria spp.	FR, IE, UK, NO	Med/High G	5,000	6	30,500	32
Lessonia spp.	CL, PE	Med/High G	7,000	8	27,000	28
Laminaria spp.	CN, JP	Med G	13,000	16	20,000	21
Macrocystis	US, MX, CL	Low G	35,000	42	5,000	6
Durvillaea	AU	Low G	4,500	6	4,500	5
Flavicans	CL, PE	High G	3,000	4	4,000	4
Ecklonia	ZA	Med G	3,000	2	2,000	2
Ascophyllum	FR, IS, I E, UK	Low G	13,500	16	2,000	2
		Total	84.000	100	95,000	100

[a] See list of country abbreviations

has gradually changed. Today *Laminaria* and *Lessonia* species are dominant, accounting for 81% of the harvest. Table 13 illustrates this trend as well as the trend in shifting procurement locations. Variation in extract properties are expressed as guluronic (G) acid content where “High G” extracts yield the strongest and most rigid gel

The dramatic decrease in usage of *Ascophyllum* and *Macrocystis*, both yielding Low G extracts reflects a shift in market demand as well as seaweed availability. Today’s most important and profitable applications require High G extracts such as can be obtained from *Laminaria hyperborea*, particularly the weed from Norway. Its use has increased considerably in the last decade, and today, it along with *Lessonia* from Chile are perceived as the most attractive and versatile species available when selling to the high end of the alginate market.

China has been cultivating *L. japonica* on floating rafts since 1952 and high production figures of 250,000 dry t y^{-1} or higher have been reported. Today *L. japonica* production has decreased due to decreased demand for its extract and more economically attractive cultivation alternatives. Current annual production is probably well below 200,000 dry t and aside from being used for low-grade industrial alginates some is also being used for production of iodine and mannitol. Chinese alginate producers are importing increasing amounts of *Lessonia nigrescens* from Chile and Peru in order for their alginate quality to compete in international food and pharma markets.

Ireland, Scotland, Iceland, France, and Canada possess substantial resources of *Ascophyllum nodosum* seaweed and Table 13 shows that this seaweed provided 16% of the 1999 harvest of alginate raw material. However, this species is now relatively costly to harvest and the extract quality is not competitive with other species, so hardly any is being used today. In addition, special *A. nodosum* extracts are finding new, more profitable markets as a source of animal and plant nutrients and growth promoters. Acadian Seaplants Ltd of Maritime Canada is one example. Not too many years ago Acadian Seaplants was primarily a supplier of seaweeds as raw material to hydrocolloid producers. Since then, they have converted from this relatively low margin business to the much more attractive making and marketing *Ascophyllum* extracts of plant and animal growth promoters

Macrocystis pyrifera typically grows from central California to Baja California and was in the past an important raw material for the alginate industry, particularly Kelco in San Diego. However, for ecological and cost reasons, the formerly advantageous mechanical harvesting of this weed became obsolete. Furthermore, consolidation within the industry, i.e., ISP’s purchase of Kelco led to the San Diego plant being closed. Today, only small quantities of this species are being harvested. It is ironic that harvesting was curtailed in part for ecological reasons (disturbing the otter population living among the seaweed), and now the accumulating un-harvested weed being cast ashore after storms is causing an environmental problem.

In summary, suitable seaweeds for alginate production over the past decade have become more difficult and

Table 14 Geographic harvest carrageenan seaweeds 1999 vs 2009

Type	Major locations[a]	Extract type	1999 harvest (dry t)	2009 harvest (dry t)
‘Cottonii’	PH-ID-MY-TZ	Kappa	131,000	160,000
‘Spinosum’	PH-ID-TZ	Iota	20,000	23,000
Gigartina	CL-MA-PE-MX	Kappa-2	13,000	15,000
Chondrus	CA-US-FR-ES-PT-KR	Kappa-2[b]	4,000	4,500
Total			168,000	202,500

[a] See list of country abbreviations

[b] Higher kappa/iota ratio than in *Gigartina*

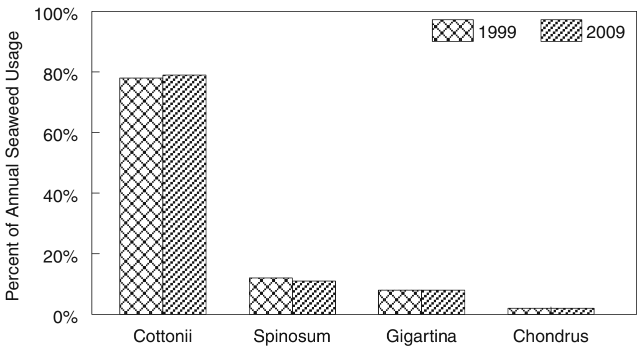

Fig. 5 Distribution of major seaweeds used for carrageenan production

expensive to obtain, and this trend is likely to continue unless cultivation of a medium to high G weed could be developed.

The main issues alginate producers must face are:

- Changing locations for alginate production
- Rising non-alginate uses for the same types of seaweed
- Increasing government controls on the harvesting of natural seaweeds
- All easily accessible large natural seaweed resources already being harvested

There are large unused quantities of suitable alginate seaweeds in the world, but little of this is currently accessible at reasonable cost. In many places, the cost of access is so prohibitive that it is likely to remain so.

Overall, the world supply/demand balance for alginate seaweeds is more fragile today than a decade ago and therefore more vulnerable to potential disruption by events such as El Nino, rising seawater temperatures in general, and pollution. To illustrate the impact of these factors, the average export price for dry *Lessonia* spp. out of Chile was in year 2000 US\$ 350 t^{-1} whereas in year 2009 price had gone up to US\$ 950 t^{-1}.

Carrageenan seaweeds

The seaweeds for production of carrageenan are dominated by the warm water species *K. alvarezii* ("cottonii") and *Eucheuma denticulatum* ("spinosum"). Both are being cultivated by vegetative growth primarily in the Philippines and Indonesia with smaller amounts from Tanzania. The other seaweeds being used are cold water species: *Sarcothalia crispata*, *Gigartina skottsbergii* ("Gigartina radula" of commerce) coming mainly from Chile with smaller amounts from Mexico. *Chondrus crispus*, another cold water carrageenophyte comes predominantly from Maritimes Canada with smaller amounts from France but is declining in availability and use. None of these cold water weeds is cultivated, so supply depends entirely on the natural harvest. These cold water weeds are needed to supply specific types of carrageenan that cannot be obtained from the cultivated, warm water weeds.

Table 14 shows seaweed types, extract types, and tonnage harvested amongst the seaweeds being utilized. Figure 5 shows the distribution of usage by seaweed type at the beginning and end of the decade under consideration. As can be seen from the figure, there has been little change in this distribution. A weight of 160.000 t of 'cottonii' were harvested in 2009 of which no less than 150.000 t or 94% originated in the Philippines and Indonesia alone. Other countries cultivating 'cottonii' do not seem to be able to expand production to any sizeable extend. Therefore, future additional supplies will most likely come from Indonesia.

Table 15 shows the annual production and average annual price of cottonii in Indonesia and in the Philippines since 2000. The time trends are displayed in Figs. 6, 7, and 8.

The most striking observation from Fig. 6 is the decline in cottonii production in the Philippines and the corresponding increase in production in Indonesia. The combined production from these two regions has increased only slightly the last decade. The Philippines is currently

Table 15 A decade of production and prices of "cottonii" in the Philippines and Indonesia

Year	Philippines Production (dry t)	Indonesia Production (dry t)	Total cottonii Production (dry t)	Philippines Price (US\$ t^{-1}dry)	Indonesia Price (US\$ t^{-1}dry)
2000	113,000	27,000	140,000	\$710	\$650
2001	97,000	28,000	125,000	\$575	\$525
2002	91,000	30,000	121,000	\$420	\$535
2003	90,000	44,000	134,000	\$770	\$615
2004	97,000	49,000	146,000	\$850	\$750
2005	89,000	56,000	145,000	\$774	\$650
2006	84,000	68,000	142,000	\$748	\$617
2007	81,000	74,000	155,000	\$947	\$811
2008	73,000	79,000	152,000	\$2,342	\$2,166
2009	61,000	85,000	146,000	\$1,280	\$1,208

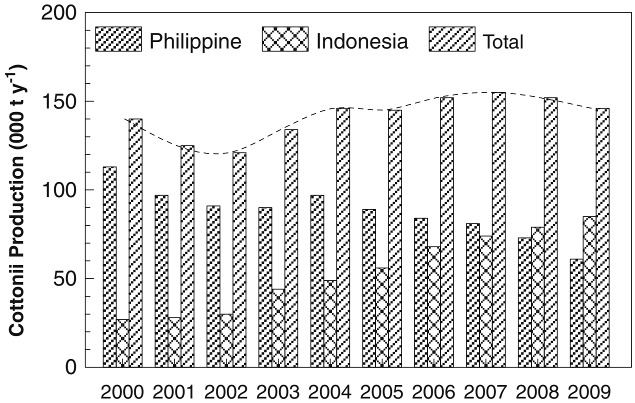

Fig. 6 Production of 'cottonii' in the Philippines and Indonesia

experiencing declining production of cottonii due to unfavorable weather conditions and political unrest in farming areas. Filipino farmers have also cut back on the average farm size in part to drive up the price but also enjoy the lifestyle higher income per hectare has brought them. Only time will tell if the downward trend can be reversed. The increase in Indonesian production stems primarily from a greater number of farmers opening up new areas for cottonii mariculture.

Figure 7 shows average cottonii price changes by quarter from 2005 through 2009. This presentation of price trends is more informative than the annual average prices shown in Table 14. Prices began their substantial rise in late 2007 peaking in late 2008. During this period demand, principally from new plants in China, severely outstripped cottonii supplies causing the exorbitant price increases. Keep in mind that there are hardly any quantities of carrageenan seaweeds growing in China. The Chinese buyers exacerbated the problem by what is known in the trade as "campaign buying", i.e., buying aggressively for a short period of the year and then discontinue buying all together. In this way, they were able to get their raw material supplies for the year before the price rise was fully in effect. Fortunately, the benefits to the Chinese has washed through the system and more uniform buying timed with the growing seasons is again being practiced by most major buyers.

At the time Fig. 7 was prepared (December 2009), the price was leveling off at about US$1,400/dry t, but whether the price will go up, down or remain the same is impossible to predict at this juncture. There is no question, however, that this volatility in cottonii price (the most used seaweed by the carrageenan industry) is causing strains between producers and customers for carrageenan. Figure 8 shows the impact of cottonii seaweed price on carrageenan selling prices. Profit margins in the food processing industry were already low due to higher energy costs and higher costs of other commodities, so they were very reluctant to accept higher prices from food additive producers. As a consequence, profit margins for carrageenan producers have been battered.

Other factors to consider in analyzing these price and supply problems are:

- Poor weather conditions have led to increased water temperatures and heavier than usual rains. These in turn have led to "ice-ice" (a debilitating tropical seaweed disease) outbreaks, depletion of nutrients at farm sites, exhausted seed stock material being planted. The high demand for 'cottonii' has led to harvesting immature weeds that in turn leads to poorer quality carrageenan being extracted from these weeds
- Misinformation is constantly circulating among suppliers and buyers, and price stability will not be returned until reliable production statistics and other relevant market intelligence become available to farmers, traders and processors in real time

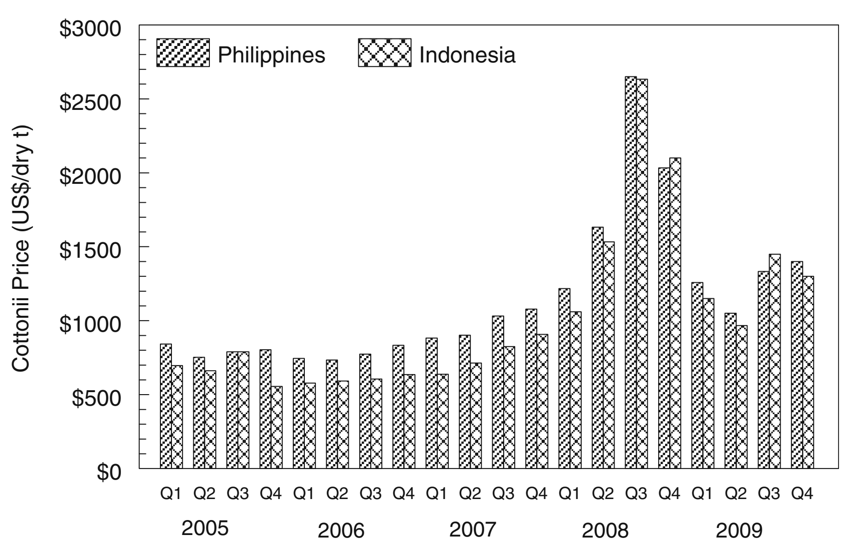

Fig. 7 Quarterly 'cottonii' prices between 2005 and 2009

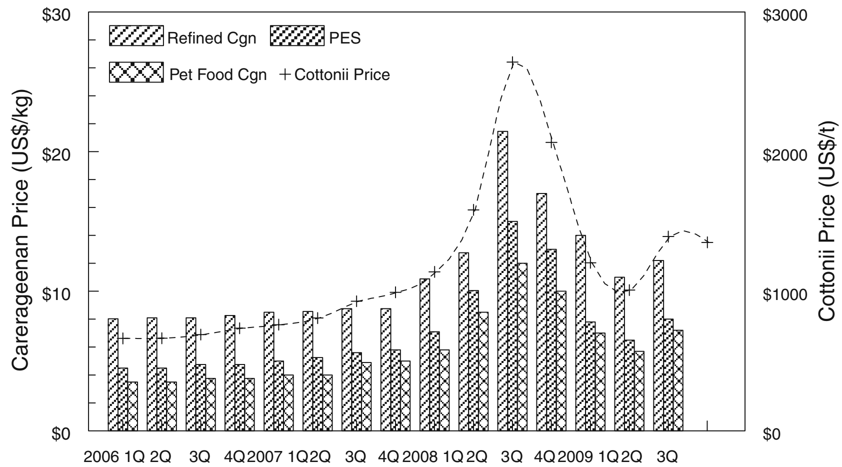

Fig. 8 Effect of 'cottonii' prices on carrageenan selling prices between 2005 and 2009

Figure 9 is the authors attempt to depict what has happened to the organization and management of the chain of value in moving from tech service to seaweed farmers to the sales and marketing of carrageenan to end-use customers. Since the 1970s, there has been a gradual erosion of cohesion in this value chain which had been held together by major players such as Genu (CPKelco), MCI (FMC), and Satia (Cargill). The first break came when Mars, the major pet food user of SRC, provided incentives to Filipino entrepreneurs such as Shemberg and Marcel to expand. The most recent break occurred when China producers aggressively entered the carrageenan market without an established source of seaweeds. Whether this broken value chain can or should be put back together is anybody's guess.

The discussion on seaweeds for producing agar, alginates and carrageenan will end with a summary of price movements for the major seaweed together in Table 16. The prices in this table clearly emphasize where demand is outstripping supply thus driving price increases. In some cases, supply is controlled by the natural harvest supply (*Chondrus*; *S. crispata*). In others, it is controlled by a mixture of the availability of fishermen and accessibility of the natural crop (*Lessonia*, *G. skottsbergii*). While cultivation has stabilized the price of *Gracilaria*, it has not done so for cottonii. In this case, the reasons are a complex mixture of resource management, socio-economic conditions, and cultural factors, all of which have been discussed earlier.

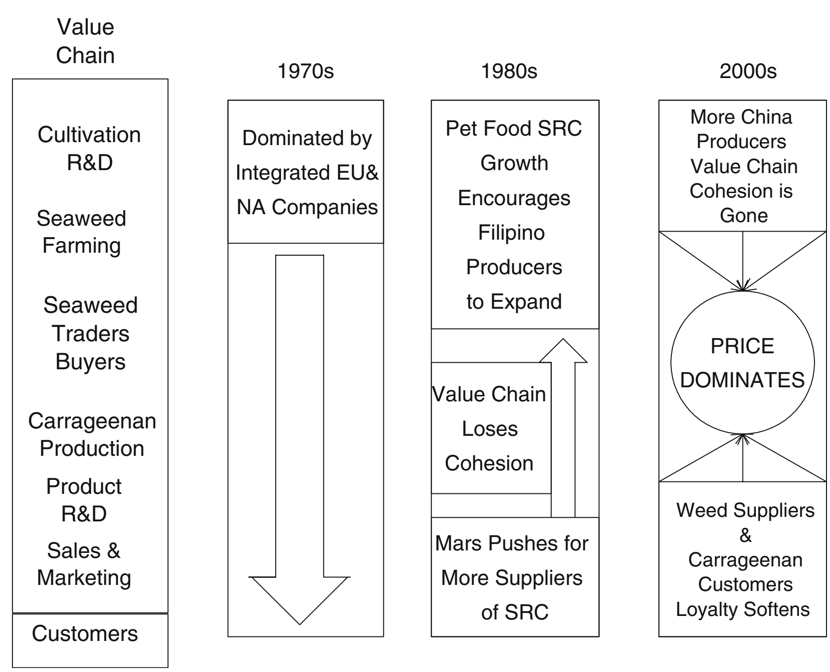

Fig. 9 Changes in organization of the carrageenan value chain since the early 1970 s

Table 16 Summary of price movements for major seaweeds in last decade

Seaweed	US$ t^{-1} 1999	US$ t^{-1} 2009	% increase
Gracilaria	1,260	1,300	3
Lessonia	350	950	171
Cottonii	600	1,400	133
Spinosum	350	350	0
Chondrus (NS)	1,800	3,400	89
Chondrus (PEI)	1,000	1,875	88
G. skottsbergii	1,400	3,000	114
S. crispata	1,000	2,300	130

Conclusions and recommendations

Agar and alginates continue to be the most attractive and generally profitable businesses. Growth, while modest, has been enough to generate the cash flows necessary to support the overheads needed for regulatory reform and capital investment needed to improve plants and equipment. Selling price increases have generally been adequate to offset seaweed, energy, and chemicals costs. The agar and alginate industries have also benefited by recent consolidation of alginate producers, and the fact there are few players in the international markets for agar. Availability of seaweeds have not been a problem for alginates during the last decade, but can be expected to present supply and cost problems, particularly for high gel strength types, in the future. The cultivation of *Gracilaria* has insulated the agar producers from raw material problems, and adequate supplies of *Gelidium* for its special uses will probably continue

Carrageenan has not fared so well. With regulatory approval of semi-refined carrageenan as a food additive, a number of producers in the Philippines, Indonesia, and China began competing in the world markets. This put pressure on producers of refined carrageenan to be able to compete. Offering blends of semi-refined and refined carrageenan has been a successful strategy for a better cost structure. Producers of alcohol-precipitated refined carrageenan, the most expensive to produce have found niche markets willing to pay the higher price for these products. Gel-press-refined carrageenan is approaching commodity status, but one or two producers have been able to keep their costs down to maintain profitability.

Somewhat surprisingly, semi-refined carrageenan has done reasonably well for the lowest-cost producers. Those that have tied up with experienced marketing companies that are well positioned geographically are enjoying good prices for their products. Semi-refined carrageenan offers considerable flexibility in formulating the lowest cost product for a specific application with the best performance characteristics.

The biggest problem facing carrageenan producers today relates to seaweed availability and cost as noted above. Until supply and demand can be better balanced, this will continue to be a somewhat chaotic market.

Some recommendations to come out of this study are better raw material management led by hydrocolloid producers and the need for more industry/government sponsored research into strain improvements that are more tolerant of environmental changes. This industry will continue to experience modest profit improvement unless R&D into new applications is renewed and better product differentiation is achieved. Without new applications, more and more existing products will turn into commodities. More industry consolidation is also called for to form the critical masses needed to support new seaweed farming initiatives, R&D, process improvement and the like. Factories will continue to move closer to raw material sources. Since factories will, in general, be far away from major markets for seaweed hydrocolloids, joint ventures with strong marketing firms is called for. Southeast Asia seems to be an area ripe for joint ventures. Otherwise, the multinationals will continue to lose market share. Short of joint ventures, outsourcing manufacturing is an alternative.

And last but not least, China has to stop importing commodities and exporting inflation.

Acknowledgments This paper has been prepared by the authors primarily from their own knowledge of the seaweed hydrocolloid industry, and we take full responsibilities for its contents. We also confess to having much more hands-on experience with the carrageenan industry than with the agar and alginates industries. Much of the quantitative data presented here is not available in the published literature. To verify our estimates of this information, we asked some of our colleagues to review our numbers. We are particularly indebted to Neil Lawson and Richard Searle, retired from Kelco/ISP and Monica Alquati of Alimex, for their assistance with the alginates sections and to Miquel Depolo and Rachid Lebbar, principals of Algas Marinas and Setexam, respectively, for their assistance with the agar sections. Marcial "Jun" Solante of Shemberg was most helpful with the history of cottonii pricing. The comprehensive work of Dennis McHugh reported in "A guide to the seaweed industry" *FAO Fisheries Technical Paper* No. 441 (2003) was invaluable to us in maintaining our perspective.