THE SEAWEED RESOURCES OF EASTERN CANADA

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Canada occupies a special place among the world producers of seaweeds, mostly because it ranked first, from approximately 1950 to 1970, as a producer of the red alga *Chondrus crispus* (Irish moss), historically the first source of raw material for carrageenan extraction. However, seaweed harvesting along the coasts of the Maritimes is not a long-standing tradition, except in the case of *Palmaria palmata* (dulse), which has been harvested along the Bay of Fundy (especially on Grand Manan Island) for more than a century (even if the start of this cottage industry is difficult to date precisely).

This chapter will focus on the seaweed industry on the Atlantic (East) Coast of Canada, the Pacific (West) Coast industry being treated in a separate chapter by S. Lindstrom. Along the East Coast, the emphasis will be on the Maritimes, which include the provinces of Prince Edward Island (PEI), Nova Scotia (NS) and New Brunswick (NB) (Fig. 1). The two provinces of Québec, and Newfoundland and Labrador are omitted, even though they have been the subject of numerous surveys, exploratory missions and reports, because no significant industry is presently operating there, except the sporadic harvesting of *Laminaria* sp. (kelp) in Québec (along the St. Lawrence Estuary and the Baie des Chaleurs) which was estimated at 500 wet tons (WT) in 1994 (Bodiguel 1995), and the harvesting of *Ascophyllum nodosum* (rockweed) and *Laminaria* sp. by a few small companies in Newfoundland.

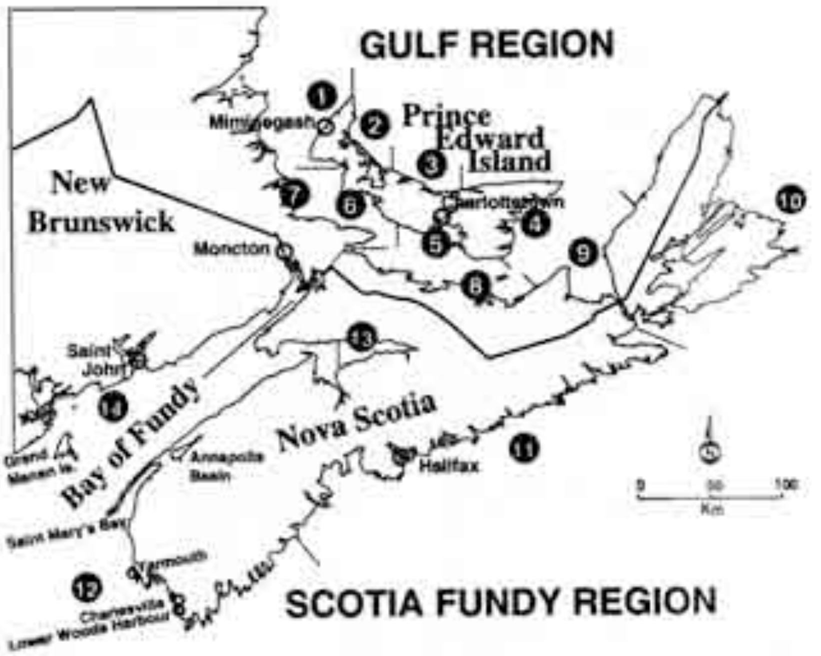

Figure 1. The Canadian south-eastern Atlantic coast (provinces of New Brunswick, Nova Scotia, and Prince Edward Island) with the boundaries of the Gulf and Scotia-Fundy Regions (now reunited in one Maritime Region) and the limits of the Marine Plant Harvesting Areas (1 - 14).

MAIN ENVIRONMENTAL FACTORS

The Maritimes are situated in the western province of the cold temperate Atlantic-boreal region (van den Hoek 1975). Seaweeds in this region have to survive drastic changes of temperature. In the summer seawater can reach 20-22°C along the shallow coast of PEI with flat sandstone bottom, while along the Bay of Fundy it rarely raises above 14-16°C, because of the significant mixing of waters due to the exceptional tidal range (the largest in the world: up to 16-19 m in certain parts of the Bay). In the winter, many coastal waters are covered with ice, with the water below in the vicinity of -1 to 0°C. The most drastic scenario can be low tide around 4:00 or 5:00 am when, in a few minutes, intertidal seaweeds experience a change of temperature from -20°C when exposed to air to around 0°C when the tide is coming in. Salinity on the Atlantic coasts of NS and NB varies between 30 and 33‰, but can be locally reduced, especially in the spring when snow and ice accumulations are melting. The north-east coast of NB and PEI, being located in the southern Gulf of St. Lawrence, can experience lower salinity (around 27-28‰). Currents, mostly associated with tides, can be extremely strong in the Bay of Fundy (2 $m.s^{-1}$ at Letite Passage between Deer Island and mainland NB).

The biodiversity richness of eastern Canada is, by no means, exceptional. South (1984) established a checklist of 354 species, subspecies, and varieties of benthic marine algae - consisting of 128 Rhodophyceae, 128 Phaeophyceae, 90 Chlorophyceae, 7 species of *Vaucheria* (Xanthophyceae) and 1 of *Phaeosaccion* (Chrysophyceae) - for the coastline from Cape Chidley, Labrador, in the North to the New Brunswick/Maine border in the South. The abundance of a few species is, however, remarkable and led to the development of three notable fisheries: Irish moss (*Chondrus crispus*), rockweed (*Ascophyllum nodosum*) and dulse (*Palmaria palmata*) harvesting.

This chapter will develop the evolution of these three fisheries/production and then analyse the emerging trends, especially in the area of cultivation.

THE IRISH MOSS (*CHONDRUS CRISPUS*) INDUSTRY

Large beds of *C. crispus* were identified in the Maritimes as early as 1830 (Bodiguel 1995). Hand-raking for commercial gain was already reported in the mid 1920's in NB (Needler 1947). However, harvesting both in PEI and NS remained minimal until World War II, mostly for the production of gels and the popular Acadian dessert “blanc mange” at the first North American seaweed extraction factory in Scituate, Massachusetts, USA. Recollections of local inhabitants date the starting of “mossing” in the region of Miminegash/Tignish (NW of PEI; Fig. 1) to 1939. In 1941, with the entrance of Japan and the USA in World War II, access to Japanese phycocolloids and *C. crispus* from France suddenly became closed to the USA and one of the less recognised “war efforts” of Canada was initiated. Very rapidly, Canada became the main supplier, the “carrageenan rakery”, of the USA for medicinal and food applications in which carrageenans were substituted for agars. From 4.5 dry tons (DT) in 1940 for PEI, the harvest jumped to 118.3 DT in 1941 and 898.2 DT in 1942 for PEI and NS combined (Needler 1942, 1947). For the period 1943-46, data are partial, but for 1946, Needler (1947) reported a harvest of 1 307.3 DT for PEI and NS combined, while MacFarlane (1964) reported 1 358.9 DT.

At the end of World War II, the market and prices stabilised again and European and Japanese competition was reactivated. Provincial and federal governments, without much concerted effort, tried to consolidate and develop the Irish moss industry. Pringle (1981, 1986) and Sharp *et al.* (1993) have divided the evolution of the Irish moss industry into four time periods (Fig. 2).

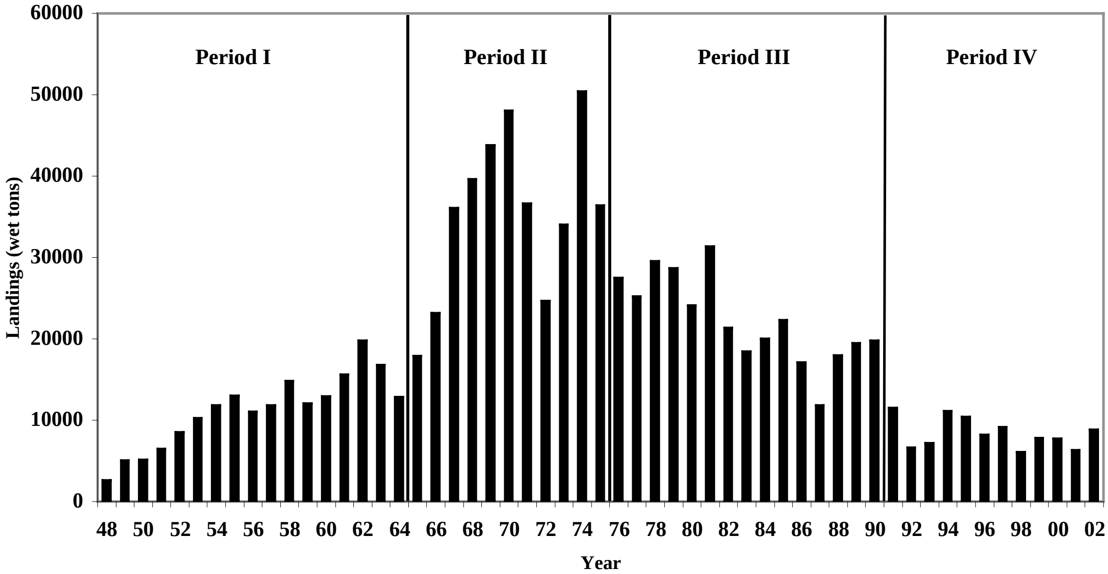

Fig. 2: Landings (wet tons) of *Chondrus crispus* in Canada from 1948 to 2002. Landings from 2003 to present are not available from the Department of Fisheries and Oceans. The characteristics of each of the four periods are explained in the text.

Period I (until 1965)

The mean annual harvest for this period was 3 800 WT with a very slow growth. Harvesting and preparing the crop for sale (sun-drying of bleached Irish moss before transport to the buying station) was labour intensive. Irish moss was mainly gathered as beach "storm toss" (Figs. 3-4), even though some hand-raking from inshore fish boats (6-9 m long) began in the late 1940's. Drag-rakes on "hauler" boats (Fig. 5), generally handled by one or two people, appeared in the early 1950's.

Several small, not always long-lived, independent companies were buying the resource for resale to major extraction companies.

Fig. 3: Harvesting of "storm toss" *Chondrus crispus* on the beach of Cape Gage, near Miminegash, PEI.

Fig. 4: Harvesting of "storm toss" *Chondrus crispus*, with a horse pulling a rake, at Cape Gage, PEI.

Fig. 5: Harvesting of *Chondrus crispus* by a single-handed “hauler” boat off Cape Gage, PEI. Three individual rakes, like the one being put back to sea, are towed on each side of the boat.

Fig. 7: Harvesting of *Chondrus crispus* by a “wincher” boat off Cape Gage, PEI. The crew is bringing three rakes, attached together, on board while three others are dragged on the other side.

Fig. 6: Sun-drying of *Chondrus crispus* at Pleasant View, near Miminegash, PEI.

Period II (1965 - 1975)

As demand for Irish moss for an ever diversifying market (Chopin 1986, Chopin *et al.* 1995) increased, harvesters decided to spend more time harvesting than preparing the crop for sale (Fig. 6). After development of an oil-fired, drum-drier at the Marine Plants Experimental Station of Miminegash from the federal Department of Fisheries and Oceans (DFO) in 1966, the technology was transferred in 1967 to private industry and company buyers purchased the bulk of the wet crop at dockside. Fishing intensity and power increased with the introduction of “wincher” boats (larger lobster boats, equipped with twin winches and booms and generally handled by 2-3 people; Fig. 7), which allowed continuous cropping (while one set of drag-rakes is manually cleaned on one side, the other is harvesting). As the lobster stocks which were showing signs of decline and rising prices (because of short supply) were not compensating for decreasing catches, it was important for fishers to diversify the use of their boats and equipment. In the early 1970's, a group of “full-time mossers” appeared, which grew between 1977 and 1980 during the federal lobster buy-back programme introduced to reduce the number of lobster fishers. During Period II, the mean annual landing increased to reach 50 000 WT in 1974 (the comparatively low landing of 1972 was due to poor weather conditions). Buyers from two Danish extraction companies (Genu Product Ltd., a subsidiary of Copenhagen Pectin Factory Ltd., and Litex

Industry) and two American extraction companies (Marine Colloids Inc. and Kraft Foods Ltd.) competed for the limited resource, while small independent buying companies gradually closed or maintained themselves with difficulty through alliances with the multi-national companies.
Already in the late 1950's, the American companies had started to import a cheaper source of carrageenans, the red algae *Kappaphycus* and *Eucheuma*, from wild harvest in Indonesia, and, in a lesser quantity, the Philippines. The political instability of Indonesia in the late 1960's, however, renewed the interest for carrageenans from *C. crispus* from the Maritimes (mostly in PEI and NS, but also in NB along the Northumberland Strait; Fig. 8).

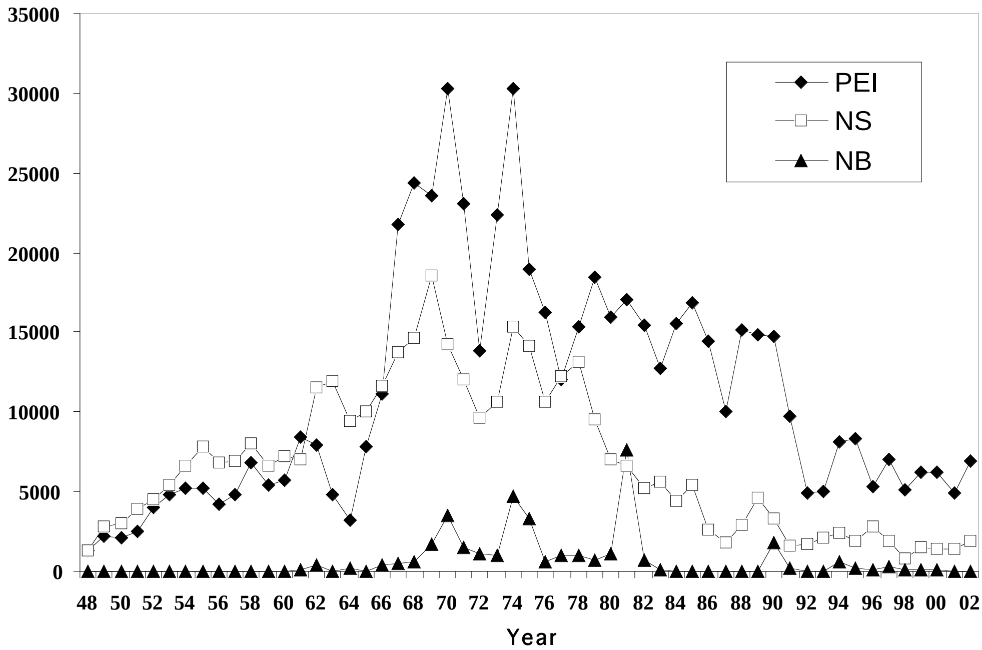

Fig. 8: Landings (wet tons) of *Chondrus crispus* from 1948 to 2002 per province (PEI: Prince Edward Island; NS: Nova Scotia; NB: New Brunswick). Landings from 2003 to present are not available from the Department of Fisheries and Oceans.

In 1969, PEI Marine Plants Co-op. built a factory in Anglo-Tingish, near Miminegash. A lack of technical expertise, lead to closure within one year of operation, using an inappropriate technology, in 1971-72. The failure of this venture had serious consequences for the Canadian seaweed industry: because of this unsuccessful story, no other attempt at developing an extraction plant was ever undertaken in Canada, which limited its role to a world supplier of raw material instead of manufactured products, where added values and profits lay.

Period III (1976 - 1990)

As written by Pringle (1986), “the bonanza of Period II was short-lived”... Period III has been characterised by wild oscillations in annual landings attributable to a combination of international competition, socio-economic and policy decisions, and biological fluctuations in the abundance of the resource, as evidence for growth and recruitment over-harvesting was presented (Pringle and Semple 1984). During that period, annual landings decreased to approximately 20 000 WT. The decline was abrupt in PEI, which had taken the national lead in terms of landings (60% in 1974 to 75% in 1985), and where approximately 100 families were depending uniquely on this activity as a source of revenue. The situation became very difficult for the full-time mossers who were no longer in a position to buy back the lobster licences they sold in the 1970's, nor to acquire one through transfer, as the lobster fishery had rebounded and unofficial licence prices had sky rocketed. The impact of the decline was not as strongly felt in NS, where “mossing” had always been considered a supplementary fishery. Stagnant demand and prices and competing fisheries gradually drew much of the labour force away. A marked decrease in landings in that province only became clearly apparent in the late 1980's and people seemed to be ready to accept it (it never created the upheavals and the social/economic context described below, which applies to the situation in PEI).

It is quite amazing to realise that a small research group (the Marine Plants Section with two scientists and three technicians at its peak) was only established in 1974 at DFO to gather stock assessment and resource science data, while the industrial/resource development of what was then an under-utilised species had been taking place for already more than 25 years! The Atlantic Coast Marine Plant Regulations, necessary to control harvesting pressure, were promulgated in 1978, only after harvesters, buyers, provincial and federal governments realised the deterioration of the resource base to the point where regulations became needed. This was also within the context of the establishment of the 200 mile economic zone, which favoured the development of management structures.

Until the early 1970's, *C. crispus* represented the main source of carrageenans and Canada provided 65-70% of the world production (Chopin 1990). In 1992, *C. crispus* represented only 3.8% of the harvested carrageenophytes (Bodiguel 1996) and Canada provided around 12% of the world-wide resource (Chopin *et al.* 1992). This complete reversal of the predominance of *C. crispus* and Canada in the carrageenan market found its origins in a major geographical shift in the production regions of raw material due to a high demand in the late 1960's related to economic development and changes in food habits throughout the world. It became obvious that *C. crispus* alone could not fulfil this increasing demand and a relative shortage of *C. crispus* forced the price of raw material up in the traditional supplying countries (Canada, France and USA). The quest for new sources of similar phycocolloids at a cheaper price was on again, with the major extracting companies in the USA, France and Denmark looking into countries in Asia, Africa and South America with fast-growing tropical algae and cheap labour costs. Max Doty, from the University of Hawaii, recommended to Marine Colloids Inc., a subsidiary of Food Machinery Corporation (FMC) that they develop the aquaculture of *Kappaphycus* and *Eucheuma* in the Philippines, a country under American influence and more stable than Indonesia at that time. After intense harvesting of natural beds between 1965 and 1970, it became evident that only aquaculture could satisfy the demand in carrageenophytes, as natural stocks were in jeopardy. The programme of Max Doty to introduce extensive low-technology *Kappaphycus* and *Eucheuma* aquaculture was extremely successful and had a major impact on the world carrageenan market: by 1992, *Kappaphycus* and *Eucheuma* represented 88% of the harvested/cultured carrageenophytes. The village of Miminegash, once the self-proclaimed “World Capital of Irish moss”, can still argue for keeping this title, but definitely not the one of “World Capital of Carrageenophytes”!

In the early 1980's, extraction companies started to worry about the near monopoly situation of the Philippines and looked again at diversifying their supplies both in terms of geographical origin and algal species. Development of *Kappaphycus* and *Eucheuma* aquaculture took place on several countries/islands of the Indian and Pacific Oceans like Indonesia, Fiji, Djibouti, Madagascar, etc. Chile became an ever-stronger partner on the world market with the harvesting and treatment of *Iridaea*/*Mazzaella*/*Gigartina* which started in 1973. Treating a single resource as an essential element is not considered cost effective (Chopin 1986), and extracting companies are more and more delivering blends of carrageenans, from several carrageenophytes, to their customers. It appears that, even if its position is much reduced, *C. crispus* retained a special status because the phycocolloids it produces (κ-, ι- and μ-carrageenans in the gametophytes, λ-carrageenans in the tetrasporophytes) have such physical and chemical properties that they remain irreplaceable in some applications. The Canadian Irish moss (35.1% of the *C. crispus* biomass harvested in the world in 1992) is consequently still exported, in reduced volume, to the USA, Denmark, Spain, and France mainly by three buying companies: Genu Product Ltd., Acadian Seaplants Limited (who bought FMC operations in Canada in 1981) and Nelson Shea (who bought the closed down PEI Marine Plants Co-op plant in 1983). Irish moss, as bleached raw material, has also retained a strong market for the clarification of beer.

Period IV (1991 - present)

Since the early 1990's, Irish moss harvesting has become more and more a complementary fishery. Some buying companies closed or dramatically reduced their purchases. Management mechanisms, at the scientific and social levels, are being challenged with often very different assessments of the situation and, consequently, very different recommendations being issued.

Not only has the competition with developing tropical countries become more pronounced, but a new competition has developed between the traditional refined carrageenans and, the less expensive to produce, semi-refined (or PNG, Philippine Natural Grade) carrageenans introduced by the Philippines (Shemberg Marketing Corp.) in the 1980's, originally for the pet food markets (Borja *et al.* 1991). In 1990, after intense lobbying, the Food and Drug Administration (FDA) of the USA allowed their uses in human food. The production of semi-refined carrageenans jumped immediately to 3 000 tons in 1991 and 18 000 tons in 1993 (Bodiguel 1995). By comparison, the production of refined carrageenans reached 24 000 tons in 1993. The world commercial carrageenophyte supply/carrageenan production picture is consequently shifting again. From a situation in which suppliers and extractors were in the developed world until the 1970's, to a situation in which suppliers were more and more located in developing countries while extractors remained concentrated in a few developed countries (mainly the USA, France, and Denmark), the present situation sees the emergence of suppliers/extractors in countries which are becoming more and more difficult to categorise as “developing” (Philippines, Indonesia, Chile, for example). If considering only the refined carrageenans, a clearly unbalanced situation existed in 1993, with 86% of the raw material suppliers in Asia and 78.2% of the extractors in North America and Europe (Bodiguel 1995). When combining both types of carrageenans, the Philippines ranked first (13 000 tons semi-refined and 2 000 tons refined carrageenans), followed by Denmark (6 300 tons refined carrageenans), the USA (4 000 tons refined carrageenans) and Indonesia (4 000 tons semi-refined carrageenans), France (3 400 tons refined carrageenans) and Chile (2 300 tons refined and 1 000 tons semi-refined carrageenans). Unfortunately, Canada cannot be listed among carrageenan producers.

Another significant impact on the Canadian Irish moss industry was a dramatic change in the algal composition of the so-called “Irish moss beds” in western PEI. Until 1986, the red alga *Furcellaria lumbricalis* was gathered as a storm-cast mixture with *C. crispus* on the north-eastern shore of PEI. Being mixed with other algae and synthesising a phycocolloid with properties in between those of carrageenans and agars [the so-called Danish agar, known presently as being a mixture of κ-, β-, and θ-carrageenans (Craigie 1990a)], this raw material had difficulties finding a market, especially after the drastic decline of natural free-floating populations of *Furcellaria* in Danish waters and, consequently, its very limited extraction by Danish firms. The provincial government of PEI was in fact buying the harvest and storing it, more as an assistance programme to harvesters than a business venture. On the western shore of PEI, where the commercial Irish moss beds are located, *F. lumbricalis* was, on the other hand, spotted infrequently (Pringle 1976). For example, in the commercial bed of Pleasant View, 4.6% of the observations reported the presence of *F. lumbricalis* in the 1978-80 surveys conducted by DFO, but this species was never reaching measurable levels of cover.

In the mid 1980's, harvesters around Miminegash observed an increasing abundance of *F. lumbricalis*. In the 1991 survey, 67.3% of the observations reported *F. lumbricalis* and 41.3% of those observations had more than 20% cover by *F. lumbricalis* (Sharp *et al.* 1993). Several hypotheses have been put forward to explain this change in species dominance from *C. crispus* to *F. lumbricalis*:

1) differential selective pressure of drag-raking between the two species with its impact revealed after several decades of intense harvesting targeted at *C. crispus*,
2) drag-raking increases the dispersal of reproductively mature *F. lumbricalis* as unattached fronds can re-attach rapidly due to their fast growing rhizoidal holdfast while *C. crispus* is not as successful because of the slow development of a discoidal holdfast,
3) assuming *F. lumbricalis* is an introduced species, the development of mixed beds with *C. crispus* could be a natural succession (Bird *et al.* 1991),
4) *F. lumbricalis* appears to colonize space not utilized by *C. crispus*, and
5) the two species appear to have different nutrient requirements (Chopin *et al.* 1995).

A ratio of *Chondrus* to *Furcellaria* exceeding 20:1 was rejected by buyers and, consequently, the harvesting effort collapsed very rapidly. Landings for PEI decreased from 16 505 WT in 1990 to 4 830 WT in 1992. Faced with this situation, harvesters created the *Furcellaria* Raking Committee whose initial mission was to find means of "eradicating" *F. lumbricalis*. With the support of the provincial government and DFO, a few management options were discussed and a four-year programme was established:

1) drag-rakes could cull the beds of *F. lumbricalis* during the harvesting season to promote purer *C. crispus* harvest and discard *F. lumbricalis* ashore (no market being available initially), and
2) start the season with an initial harvest of *F. lumbricalis* which will also delay the start of the *C. crispus* harvesting, as was recommended by Chopin *et al.* (1987) based on reproductive capacity arguments.

Management options were limited by climatic conditions [ice cover of the sea in winter, period when spores and gametes are released by *F. lumbricalis* (Bird *et al.* 1991)] and conflicting fishing activities by harvesters implicated in several fisheries.

The DFO issued special harvesting permits, set marker buoys limiting *F. lumbricalis* harvesting zones and initiated a monitoring programme. Thirty six harvesters participated; 542 WT of *F. lumbricalis* were landed in 1993 and 819 WT in 1994. Concurrently, 5 021 WT of *C. crispus* were landed in 1993 and 9 034 WT in 1994. Interestingly, *F. lumbricalis*, which was originally considered as a "pest" is finding, since 1995, a market and in the last two years a directed *F. lumbricalis* harvest was made possible through the buying company, Acadian Seaplants Limited, which is now processing and marketing this species. It is too early to identify the causes responsible for this apparent upsurge in landings of both *C. crispus* and *F. lumbricalis*. Moreover, it is well known that landings reflect cumulative effects of different factors (increased harvesting effort, extended harvesting season with an early period targeted at *F. lumbricalis*, variable strategy by the buyers with fluctuating quality standards, changes in social programmes for harvesters, natural variations in biomass of the respective species in algal communities, climatic variations, etc.) without the possibility of establishing their respective contribution. One key point, that deserves to be noted, however, is the emergence of a co-management structure/attitude of this fishery: harvesting boundaries and periods were respected and full cooperation between the different stakeholders was observed. Only the following years will confirm the sustainability of a dual season/dual species harvest.

In NS, the apparently inevitable decline continues. Deterioration of Irish moss beds had also been reported in NS, the reasons for this phenomenon never being precisely identified. It seems to be a conjunction of climatic and oceanographic changes (reduced light availability to the resource, reduced resource availability to the fishers because of decreasing frequency of low daylight tides within a 18.6 year tidal cycle (Sharp *et al.* 1986), and increased ice scouring) and increased coastal pollution (development in the 1970's and 1980's of fish-processing plants, especially for herrings, has often been blamed for the “oily effluents” directly released to the shore). It also appears that not raking beds or lower efforts, especially in sheltered areas, led to increased abundance of associated species and, consequently, less pure Irish moss beds (Sharp, pers. comm.). In 1995, only 1 992 WT were landed by 225 harvesters (they were 800 in 1980). In 1994, the buying company Genu Products Ltd. closed because of insufficient supply and Acadian Seaplants Limited remained the only buyer in the province. Mossing from two hours before to two hours after low tide, with smaller boats than in PEI (4-5 m long versus 10-20 m; Fig. 9) and long hand rakes (4-5 m long because of high tide amplitude variations and an irregular substratum preventing dragging of rakes), is a part-time activity, at low capital investment, for ageing harvesters all involved in other fisheries (no new comers and no full-time mossers). Harvesting Irish moss in the summer is not necessary to be eligible for unemployment insurance (UI, see below), like in PEI, as coastal waters are not covered with ice, hence allowing lucrative lobster fishing during the winter. Moreover, the extension of the UI period in 1983 to the summer makes mossing a less and less attractive occupation. Changes in life style are also to be considered: increasingly remote Irish moss beds meant that harvesters were away from home for several days and slept in camps on small islands; at the same time, increased demand for *Ascophyllum nodosum*, of easy shore access, meant day-time jobs and not surprisingly some harvesters switched from *C. crispus* to *A. nodosum*.

The ups and downs of the Irish moss industry, especially in PEI, can be viewed as another example of a fishery unable to successfully sustain optimal yields from a common-property marine resource. Considerable knowledge of the biology, ecology, physiology, and biochemistry of *C. crispus* has accumulated over the years (for review see, Chopin 1986). Additional resource science studies (Pringle and Sharp 1986), though not complete (Chopin *et al.* 1992), have allowed the development of biological advice for resource management through the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC). With such a science history, one would expect that by now there would be in place harvesting strategies to provide near optimal yields from identified stocks. However, it has long been known, but unfortunately too rarely recognised or remembered, that good science alone is insufficient to allow good resource management (Pringle 1986).

Fig. 9: Harvesting of *Chondrus crispus* with a long hand-rake at Pubnico, southwest NS. (photography by R. Semple).

RESOURCE MANAGEMENT JURISDICTION AND AGENCY INSTABILITY

Jurisdiction of Canadian marine resources from coastal waters seaward to the 200 mile economic zone boundary was ceded to the federal government in the British North America Act of 1867 (Pearse 1982). The DFO is currently responsible for marine resource management. A techno-centric model (Larkin 1978) was chosen in which harvest rates by species, area, season, gear type, etc. are controlled through regulations of the Fisheries Act. It is obvious that such a parcelled-out approach to marine resources impedes from an integrated ecosystem management plan. The Atlantic Coast Marine Plant Regulations, promulgated in 1978 under the Fisheries Act, were developed with input from harvesters, buyers and provincial governments, but have never been amended to reflect the ever-changing situation since then.

There has been a disagreement for many years between the federal and certain provincial governments on the interpretation of the British North America Act regarding the extent of federal jurisdiction and granting of licenses for intertidal resources (we will see that it became more of an issue for *A. nodosum* than for *C. crispus*, which is generally subtidal). For example, NS argues that the intertidal zone is provincial property (some would argue that it is at low tide, but not at high tide...!) and, consequently, promulgated in 1959 the Sea Plants Harvesting Act, which allows the granting of exclusive licenses. These licenses could be conflicting with federal licenses leading to several individuals/companies claiming rights for the same portions of coastline. This has resulted in several cases of localised over-harvesting.

In the early 1970's, the DFO's Atlantic Coast Zone consisted of three Regions - Newfoundland, Québec and the Maritime Provinces - the latter with headquarters in Halifax, NS. In 1981, a new Region, the Gulf Region, with headquarters in Moncton, NB (Fig. 1), was created, not based on biological or oceanographical arguments but rather on political reasons (the headquarters were located in the election-riding of the Minister of Fisheries of that time...!). This Region encompassed the Gulf of St. Lawrence beyond Québec waters and includes PEI. The remainder of the former Maritime Region became the Scotia-Fundy Region. The already small Marine Plants Section was broken up, but maintained in the Scotia Fundy Region, however, without direct involvement with PEI. The Gulf Region re-allocated human resources to other fisheries, leaving the seaweed fishery in this Region without a scientific programme and advice, and developing a kind of irrational aversion to marine plants (a state of mind which could be diagnosed as the “zoologist bias” or the “kingdom neutral incorrectness”!). After 8 years and a loss of data acquisition, experience and a rapport built up with the industry, an obviously much needed marine plant research programme was revived under a special agreement between the two Regions (Sharp *et al.* 1993). In 1995, the Gulf and Scotia-Fundy Regions were reunited under a resurrected, but dual, Maritime Region (the Marine Plants Section in Halifax is under the Invertebrate Fisheries Division (!) with the Manager located in Moncton...). Marine plants continue to receive little support (both financially and in human resources) compared to the other fishery sectors, emphasising the doubly profound misunderstanding of complementary fisheries, which have a significant role to play in an integrated approach to fishery management, and of seaweeds as a significant component of coastal ecosystems.

OVER-CAPITALIZATION

At the beginning, “mossing” required little sophisticated equipment and, until the early to mid 1970's, buyers provided the gear (rakes, ropes, etc.). With the development of “hauler” and “wincher” multi-purpose boats, capital investments increased and buyers stopped providing equipment or preferential loans. The majority of boat owning fishers mossed for at least a few weeks in the May-July period then became involved in other fisheries, in which prices for the resource kept increasing and remained competitive, while the price for raw materials for carrageenans stagnated or, proportionally, decreased because of competition from tropical countries with reduced labour costs and social protection.

The Atlantic Coast Marine Plant Regulations tried to introduce the concept of limited entry in 1978, but federal government policy and local social and political pressure prevented linking license number to resource abundance. All fishers producing evidence of harvest activity the previous two years were granted a license. It is not surprising that, with such a minimally regulated fishery, the harvesting pressure of approximately 100 licensed fishers over a total Irish moss bed area of approximately 875 ha in western PEI became intense rapidly. Mean annual harvest intensity (or the frequency of drag-rake coverage per hectare) for beds in Marine Plant Harvesting Area 1 (Fig. 1) was calculated as being 22.8 times. $season^{-1}$. ha^{-1} (Pringle and Semple 1984).

GOVERNMENT ECONOMIC SAFETY NET

Canada’s economy has a long tradition of being based on primary resource development (fishing, logging, mining, etc.). This type of industry is subject to sudden fluctuations, closures and insecure income for workers. To protect the latter, a government sponsored insurance plan (commonly referred to as unemployment insurance or UI) was implemented in 1941. It was modified in 1960 to include self-employed fishers, and in 1971 to include short-term seasonal workers in communities where work force unemployment exceeded 20%. Workers, with a minimum of 12 weeks employment (12 “stamps”) in the year of application, could subsequently receive benefits for 26 weeks (November-May) while minimally contributing to the fund.

Fishing communities in western PEI easily met these criteria. They were tightly knit and somewhat isolated with a social structure encouraging a community-based, economic philosophy. Seaweed harvesting represented the sole source of revenue for approximately 55 fishers and a complement for some 100 others also involved in lobster, herring and scallop fishing. Approximately 500 families, involved with beach “storm toss”, drying and selling, were also dependent on this activity. Mossing, consequently, played a key role in the local economy and the fishery was maintained not only for optimal harvest yield and economic return, but also for maximum community earnings from a combination of UI and the fishery.

“Interesting” strategies were developed, like selling a good harvest in several lots to obtain the famous 12 “stamps”, at a lower rate, but then qualifying for the UI. Fishers involved in other fisheries will moss a few weeks to secure a few “stamps” then move to more lucrative fisheries in relation with the different season opening dates for the different species; their spouse will sell the remaining of the harvest so that they can also collect “stamps” and consequently UI during the winter. When on the 1978 season’s opening day the catch rate was again low, as in the previous years, the harvesters requested an immediate meeting with DFO officials in Miminegash. Harvesters accepted the concept that the fishing-power of the fleet was too high in relation to the resource base. They seriously considered reducing rake numbers per boat, hence decreasing vessel harvest efficiency, but rejected outright the alternative of correlating the number of licenses to crop abundance. The community, it was later learned, had estimated better financial returns with 100 boats fishing uneconomically, but qualifying for UI, than 25 efficient harvesters making reasonable economic returns from the fishery!

A profound change of mentality was taking place in fishing communities: the UI was losing its role of insurance in case of hardship (loss of job) and becoming institutionalised, a right to a regular complement, built in an annual revenue based on a seasonal activity. This created a climate of dependence on government subsidies, which increased viciously as the resource and the fishing effort declined. In a few cases, it reached the paradoxical situation where government subsidies (UI) were equal if not higher than revenues from fishing, pulling away work ethic incentives. Moreover, UI (“stamps”) was calculated at the time of selling Irish moss to a buyer, which meant that in fact somebody selling a product of a fishery, without fishing it, could also be eligible for UI...! The human mind is quite imaginative when it comes to fraudulent schemes... it also means that the system has major deficiencies if it cannot, or does not want to, detect them. These profound changes in attitude are now affecting the second and third generations for whom UI is part of every-day life, along with its associated disturbing behaviours (in a nutshell, why go to school/university when 12 weeks of work provides 7 months of support?).

Provincial governments were not exempt from playing their “little game” either. By buying *F. lumbricalis* at the time when it had no market, provincial governments were supporting fishers in securing their “stamps”, therefore avoiding having them draw from the provincial income-assistance programmes (“welfare”), as they became eligible for the federal UI.

With the fishery sector coming under more and more scrutiny, especially from non-coastal parts of Canada, the federal government decided in 1996, not without creating some upheaval and harsh confrontations, to tighten access to licenses and change the criteria of eligibility to UI, now called EI (employment insurance!). From 1975 to 1995, the cost of an annual Irish moss license remained unchanged at $5, to which were added $20 for boat registration and $20 per fisher, for a total of $45. In 1996, the license was increased to $100 and the boat and fisher registrations to $50 each, for a total of $200 (in comparison, a lobster license increased from $30 to $1800). Licenses are now limited, not transferable and could be cancelled in the case of non-regular participation in the particular fishery.

There are plans to calculate the EI based no longer on the number of labour weeks but on the total annual revenue with a ceiling. It is obvious that the federal government objectives are to reduce the numbers of fishers and the entrance in the fishery sector of “part-time” fishers by the channel of auxiliary fisheries. These reforms will certainly contribute to enlarge the cleavage in fishing communities between storm toss mossers, crew members on boats and mossing captains with multiple licenses. This will also impede the transition from one category to another and the recruitment of properly trained new-comers to the profession.

To these factors can be added the weakness of the Canadian-based industrial sector. Canada has confined itself in the role of raw material supplier for the carrageenan industry. It never entered the close circle of the extractors, except, and because of, the aborted PEI Marine Plants Co-op venture at a critical time when it would have been judicious to enter the circle of the limited number of transformation companies. Small local buying companies disappeared to be replaced by a few multinational companies and one remaining Canadian company (Acadian Seaplants Limited). This lack of competition, associated with a lack of initiative and risk-taking, prevents the development of a flourishing industry and the necessary concomitant research and development. Minimal research and development, only when being supported by governmental subsidies, is not conducive to an entrepreneurial industrial sector and, consequently, reduces severely the opportunities for partnership. One of the well-known victims of this situation it contributed to create is certainly the Section working on seaweeds at the Institute for Marine Biosciences of the National Research Council of Canada (NRCC) in Halifax. This renowned group, of international reputation, in the 1970's and 1980's, always wavering between an applied and an academic mission, and limited in the industrial partnerships it could develop with a restricted undiversified industrial sector, was “sacrificed” in the mid 1990's in favour of timely funding opportunities in the aquaculture sector. The seaweed industry remains to be convinced that it is currently making profits on scientific advancements from the 1960's/1970's and that present investments in research and development would be a wise strategy for its long-term sustainability.

THE ROCKWEED (*ASCOPHYLLUM NODOSUM*) INDUSTRY

If Canada owes its reputation to the Irish moss industry, one has to recognise that presently it is in fact the brown alga *Ascophyllum nodosum*, which represents the highest biomass landings since 1987 (Fig. 10).

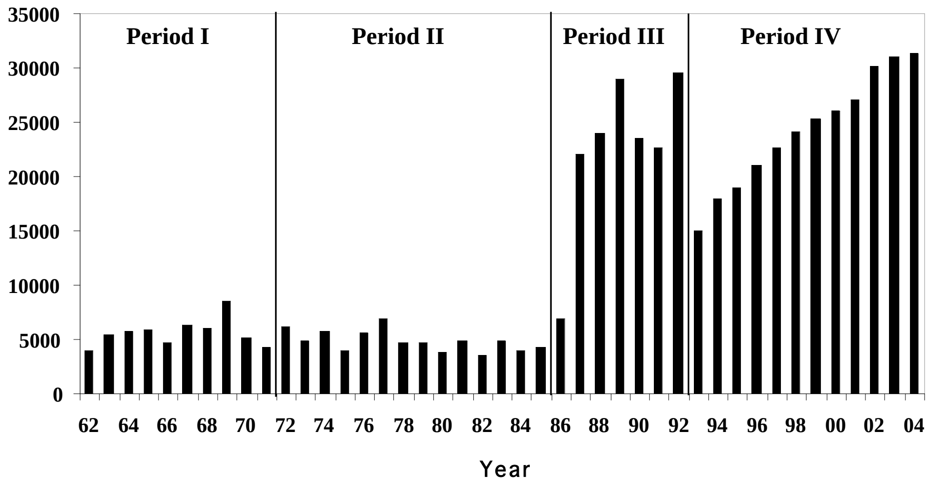

Fig. 10: Landings (wet tons) of *Ascophyllum nodosum* in Canada from 1962 to 2004. The characteristics of each of the four periods are explained in the text.

Ascophyllum nodosum is the dominant species in the sheltered to semi-exposed intertidal zone along the Atlantic coastline of the Maritimes. It forms a particularly dense cover in south-western NS and on the NS and NB sides of the Bay of Fundy. Rockweed was traditionally used as a natural fertiliser along the Maritime shores.

Harvesting for commercial purposes in south-western NS began in 1959 (Sharp 1987) when the American company Kelco constructed an alginate extraction plant in Lower Woods Harbour, Scotia Marine Products Ltd., and the company Bonda Ltd. produced seaweed meals in Yarmouth (Fig. 1). The NS government issued exclusive harvesting and buying licenses to these two companies; federal conservation regulations were only promulgated in 1978. The rockweed industry can also be divided into four periods (Sharp and Semple 1997; Fig. 10).

Period I (1959 - 1971)
Independent harvesters were hand-cutting rockweed with knives and sickles at low tides or from boats with a toothed-rake with a long wooden pole. This eventually developed into a cutter-rake with sharp blades. Harvesting was taking place in SW NS and on the NS side of the Bay of Fundy. The annual landings remained stable and low, between 4 000 and 8 000 WT, from an estimated summer standing crop of 180 000 - 240 000 WT (MacFarlane 1952, 1964, Sharp 1981).

Period II (1972 - 1985)

During this period, the mechanical Aquamarine harvesters (Fig. 11) were introduced by Scotia Marine Products Ltd. They allowed the extension of the harvesting season and a supply of raw material for a larger part of the year. This new type of harvesting tool did not change average annual landings, which remained low based on raw material demand by Scotia Marine Products Ltd. It, however, replaced hand-cutting which accounted then for less than 20% of annual landings. The Aquamarine harvesters had the disadvantage of a very limited sheltered-water operational-area and a low cutting efficiency (below 11%).

Fig. 11: Harvesting of *Ascophyllum nodosum* with mechanical Aquamarine harvesters from Scotia Marine Products Ltd. in southwest NS. (photography by J. Pringle).

Period III (1986 - 1992)

The third period started when the Norwegian company Protan bought the Kelco extraction factory and renamed it Pronova Biopolymers Ltd. The Aquamarine cutters were replaced by the highly efficient Norwegian suction cutter (Fig. 12), which could harvest 33.6 $WT.d^{-1}$, whereas a hand-harvester could gather 3.5 $WT.d^{-1}$ (Sharp *et al.* 1994). In 1992, landings of *A. nodosum* reached 20 000-30 000 WT (Fig. 11), which put Canada in second position in the world after Norway (30 000-40 000 WT) and in sixth position regarding the production of alginates (1 000 T).

Fig.12: Harvesting of *Ascophyllum nodosum* with a Norwegian suction cutter from Pronova Biopolymers Ltd. in southwest NS. (photography by J. Pringle).

The sudden increase in landings should have required a stricter management of the resource, but jurisdictional conflicts over the intertidal zone, and the disparate approaches to resource management by the provincial and federal governments since the beginning of this industry, ensured resource mismanagement. During the years of low landings (1959-85), conflicts were rare between the single provincial licensee (Scotia Marine Products Ltd.), its mechanical harvester crews, and the federally licensed individual hand-harvesters since there was only one dominant buyer and processor. However, when Pronova Biopolymers Ltd. increased its capacity threefold and introduced the Norwegian suction-cutter, and two other companies (Acadian Seaplants Limited and R.&K. Murphy, Inc.) entered the market for raw material for the production of liquid fertilisers and animal fodders, severe competitive harvesting developed, especially within the non-leased "open areas" (Sharp *et al.* 1994). The NS government, in its Provincial Seaplants Harvesting Act (1959), had not limited the number of individual licensees nor the geographical boundaries of their activities (harvesting was now also taking place along the southern and eastern shores of NS), and had partially transferred the management of the resource to the three companies, which had the responsibility of developing their harvesting plan. No accurate record of quantity and location of harvest was kept, and yield and recruitment over-harvesting became a concern (Sharp and Semple 1991), especially in two well-known "open areas", the Annapolis Basin and Saint Mary's Bay (Fig. 1). Provincial officials responded by redrawing license boundaries and by licensing previously "open areas" exclusively to companies. Anticipating these changes, harvesters with a good chance of losing access intensified harvesting. For example, the number of harvesters in the Annapolis Basin increased from 20 to over 50, landings doubled within two years, and the exploitation rate reached 95% of the available stocks (Sharp *et al.* 1994).

Meanwhile, federal resource managers continued issuing individual licenses coast wide under the Atlantic Coast Marine Plant Regulations (1978). The DFO scientist recommended the acceptance of a controlled, limited-entry management strategy, including harvest rotation or fallow period (Sharp and Tremblay 1989), but the concept of exclusive harvesting rights was continually challenged by the provincially licensed companies and the federally licensed independent harvesters. The provincial government unilaterally developed management plans, which were ignored by the federal government. Further, because jurisdiction was unclear, companies and harvesters were unsure as to whom they should lobby or appeal to resolve conflicts or have regulations enforced and fishery officers and police were not sure of their respective roles.

Not surprisingly, landings rapidly and dramatically decreased and the three companies were forced to reach "Gentlemen's agreements" to leave some of the rockweed beds to recover, as they started to realise that the sustainability of the resource, on which they had based their industry, was now in jeopardy.

Period IV (1993 - present)
The fourth period is marked by a reversion to hand-harvesting methods (Fig. 13), the reallocation of harvesting areas between harvesters/buyers and, in the case of the Annapolis Basin, a partial closure in 1993-94 and a full closure in 1995. By 1996, four beds had their biomass and plant length fully recovered and a conditional quota of 500 WT was permitted for these beds (in comparison, over 2 400 WT were harvested in this area in 1991). New harvesting strategies were enforced to allow a mean cutting height of 20 cm and a triennial, 50% (3-8 $kg.m^{-2}$) exploitation rate. This fallow period allows the canopy of *A. nodosum* to exceed 50 cm in mean height, which is a commercially sustainable harvest height (Sharp and Tremblay 1989).

Fig. 13: Hand-harvesting of *Ascophyllum nodosum* at Pubnico, southwest NS.

Pronova Biopolymers Ltd. argued that their revised allocated biomass did not permit a profitable year-long operation for alginate processing. After having invested heavily in plant expansion and modernisation, this company reduced and then ceased activity in 1995. This left only two companies active in NS in 1996. Rockweed is now used for the manufacturing of liquid fertilisers, soil conditioner and animal fodders. In 1995 (Bodiguel 1995), Canada was ranked sixth in the world, with a production of 2 500 T, behind Norway (9 000 T), Ireland (8 500 T), Iceland (4 400 T), the United Kingdom (3 500 T), China (3 000 T), and in front of France (1 700 T). By 2004, however, Canada had at least triplicated its production (Ugarte unpubl.).

By 1989, the industry had became interested in expanding to the NB side of the Bay of Fundy, where the untouched resource held the potential to exceed 140 000 WT (CAFSAC 1992). However, before the province of NB opened the harvest of *A. nodosum* for the first time in 1995, there was no legislative structure for marine plants management in that province. Following discussions on areas of responsibilities, a Memorandum of Understanding (MOU) was signed in 1991 between DFO and the Provincial Department of Agriculture, Fisheries and Aquaculture (DAFA) (Ugarte and Sharp 2001). This agreement set terms for shared management of the rockweed resource (Anon. 1994). There were five goals in this memorandum:
1) to maximize the number of continuing full-time employment opportunities for NB residents,
2) to ensure a sustainable harvest,
3) to promote the development of a commercial viable industry founded on sound business principles,
4) to integrate the rockweed industry with other users of marine resources, and
5) to ensure rockweed harvesting and processing are undertaken in an environmentally acceptable manner.

Despite the economic benefits associated with the rockweed harvest, the opening of the fishery was delayed in NB. Although seaweed harvesting was a traditional fisheries activity in PEI and NS, this activity was new to southern NB. Furthermore, the credibility of DFO was under strong criticism due to the collapse of the groundfish fisheries in Atlantic Canada. The collapse caused one of the worst social and economical disasters in Canadian history, threatening coastal communities throughout Atlantic Canada and Québec (FRCC 97). Therefore, conservation groups highlighted stakeholder concerns regarding a rockweed harvest in NB. These concerns included the long and short-term sustainability of harvesting, as well as the cumulative impact that harvesting would have on the larger Bay of Fundy ecosystem, particularly on existing fisheries. *Ascophyllum nodosum* has an important role in the Fundy ecosystem, as it provides habitat for the prey of some waterfowl (Hamilton 1997). Also, at least 22 species of fish (7 of commercial importance) are known to be associated with *A. nodosum* in parts of their life cycle (Rangeley 1994, Rangeley and Kramer 1995). Managers, cognisant of the need to have a precautionary approach, designed a five-year management strategy to develop the fishery in a sustainable way, while protecting the ecosystem. In order to achieve these goals, four phases were established in this management strategy (Fig. 14) (Ugarte and Sharp 2001).

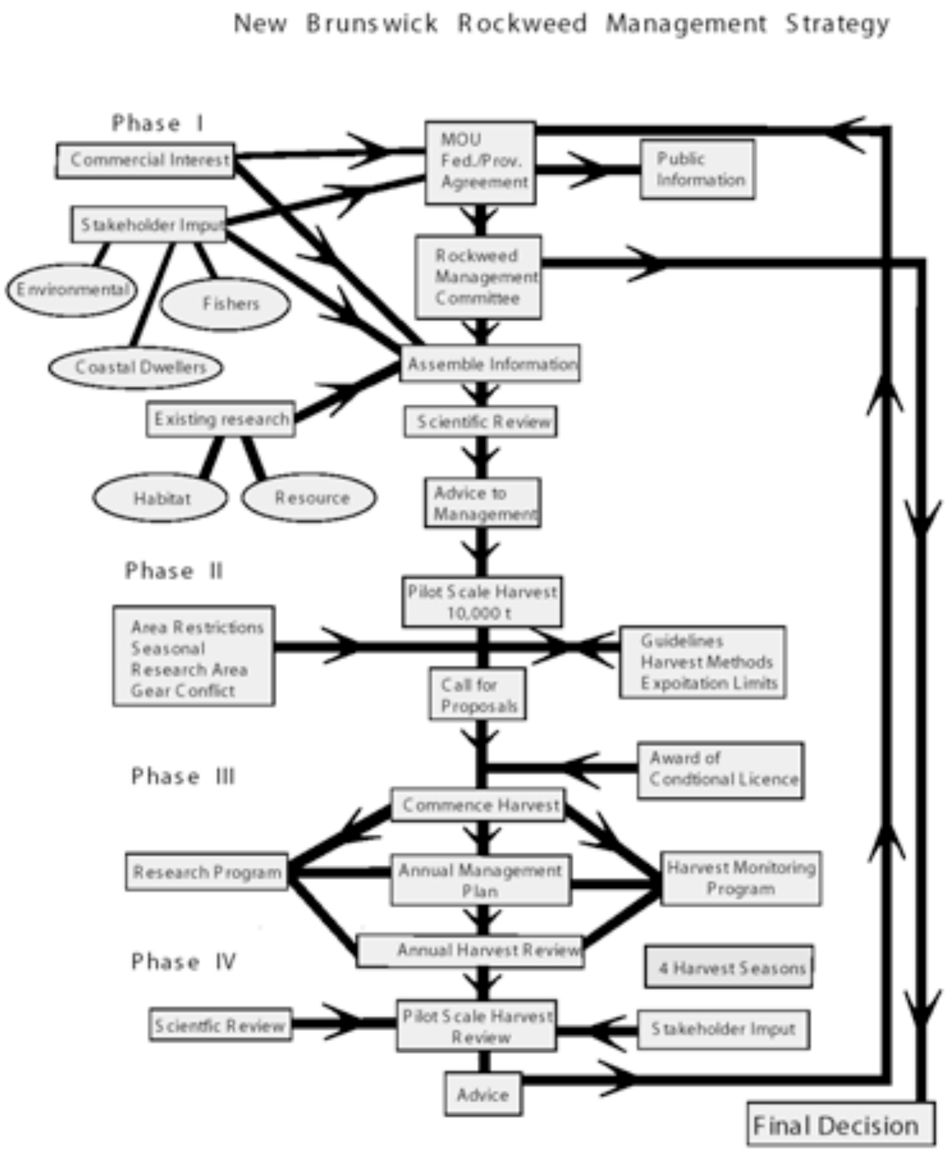

Fig. 14: Phases in the development of the management strategy for *Ascophyllum nodosum* in southern NB.

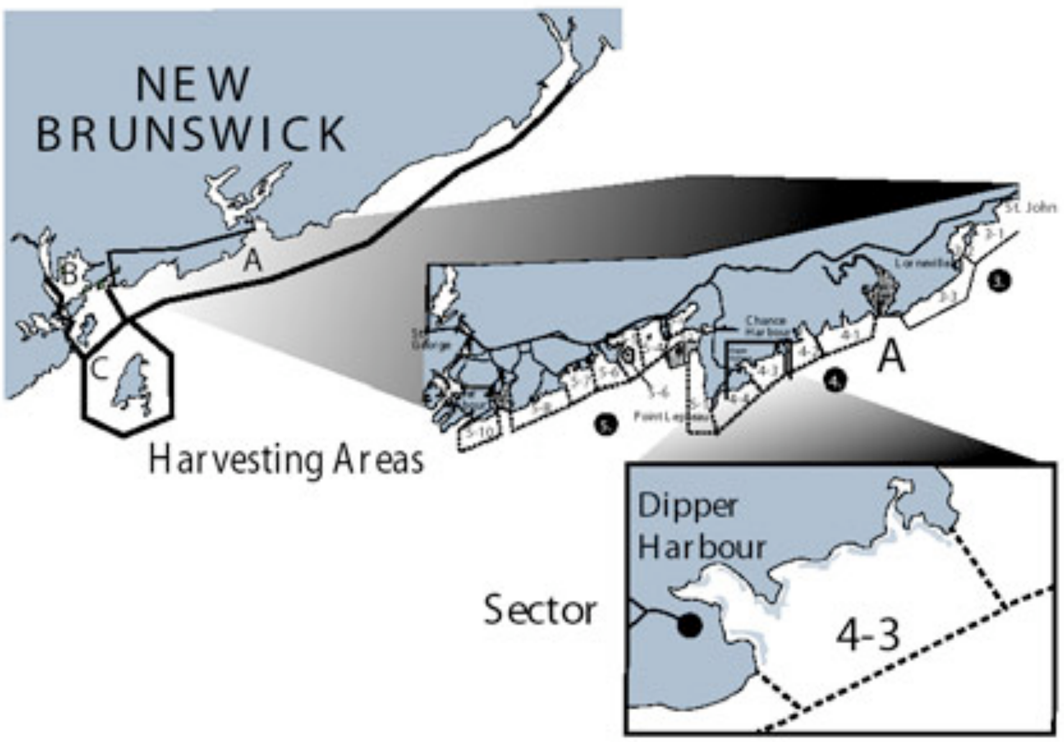

Fig. 15: *Ascophyllum nodosum* harvesting areas (A, B and C) and an example of a harvesting sector in southern NB.

Phase II

In the second phase (Fig. 14), managers set a pilot harvest quota of 10 000 WT per year (7% of the estimated standing crop) as a precautionary approach to management. Companies, individuals, or associations who were interested in harvesting rockweed were asked to submit a proposal. These proposals were to address how the stated development objectives (maximise employment, sustainable harvest, sound business principles and environmental acceptability) would be achieved. Proponents were required to include a harvest management plan outlining a three year schedule of annual raw material requirements, a map showing which sectors would be harvested, a plan detailing the projected levels of exploitation by sector, the frequency of re-harvest, mechanisms to assess the impact of harvesting on the resource, and a description of the type of controls to ensure effective management. After reviewing the proposals, the Rockweed Management Committee recommended, in 1994, that one company (Acadian Seaplants Limited) be awarded an exclusive license for all three rockweed harvesting areas. This decision was based on the conclusion that this company was the only proponent that successfully met the proposal criteria.

Phase III

The third phase of the management process began in 1995 with the commencement of the pilot scale harvest (Fig. 14). In this phase, the company was required to submit a new management plan for the harvest of rockweed at the beginning of each year. This management plan was to include the projected annual harvest by sector. At the end of each year the company was to provide the government vital statistics on the resource including records of monthly purchases from harvesters, price paid, location, and harvest dates. The Rockweed Management Committee conducted three reviews of the company's performance at pre-season, mid-season and post-season meetings. These reviews were designed to investigate problems with harvesting strategies and ensure the company was fulfilling its obligations. Finally, an independent third party was to be hired by the company to audit the recorded landings of rockweed. This review process was designed to ensure that the company complied with the yearly management strategy and the overall strategy of harvesting the resource.

Although there was an extensive detailed management plan for the pilot harvest, the provisions of this plan were not immutable. New information was anticipated annually and changes in aspects of exploitation levels, seasonal effort, distribution of the effort, and harvest technology could be integrated into the plan each year. Data inputs were derived from all sources, *i.e.* harvesters, researchers, stakeholders and the licensed company. For example, resource allocation between harvesting areas was modified in 1999 based on a re-assessment of the resource from the perspective of accessibility and economics provided by the licensed company in 1998 (Ugarte 1998). In 1995, Acadian Seaplants Limited initiated a major survey of the harvestable crop. Initially based on satellite imagery, the company is now working with 1:12 500 aerial photographs at low tide, which were digitised and analysed with NIH image analysis software. This enabled the measurement of area covered by the resource with a higher resolution than satellite resulting in an error of 2%. In addition, the company ground truthed each rockweed bed larger than 50 m along the shore of southern NB, obtaining a very accurate estimation of the total rockweed biomass for the province and within the company lease. According to this survey, rockweed covers a total surface of 1779 ha, with a total biomass of 146 697 WT in southern NB. Of this total, 129 662 WT are within the company lease.

Fig. 16: Hand-cutter rakes for harvesting *Ascophyllum nodosum* in NB. Note the three metal guards to avoid cutting plants below 25 cm from the substratum.

Fig. 17: Standard vessel, introduced in 1996 by Acadian Seaplants Limited, to harvest *Ascophyllum nodosum* in NB (Ingalls Head, Grand Manan Island, NB).

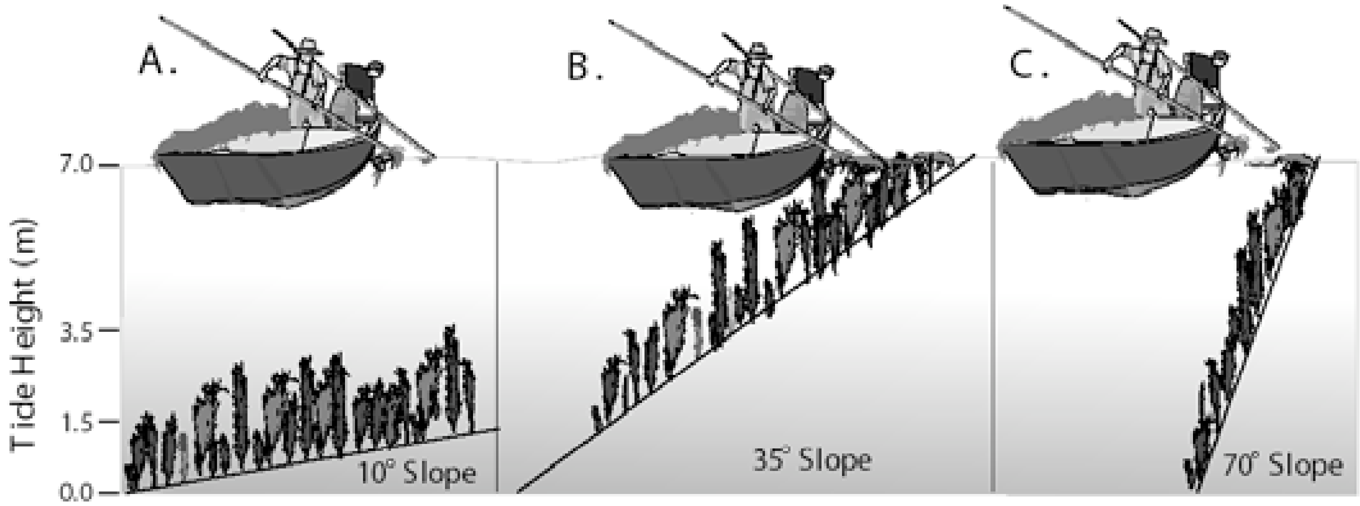

Fig. 18: Slope variations of Ascophyllum nodosum beds and their accessibility by the harvesters: (A) short accessibility due to rapid cover by tide in low slope beds; (B) ideal slope situation for harvesters with enough time to harvest and wide canopy available; (C) enough time to harvest but low catch-per-unit of effort due to narrow canopy associated with high slope.

Harvesting began in July 1995 and the season was completed by October 1995. However, landings for that year reached only 703 WT, out of the 10 000 WT allowed within the pilot plan. Logistic problems, inherent to the start of a new activity, were the main reasons (Sharp and Semple 1997). Landings sites, separate from existing wharves, had to be established and material handling procedures had to be developed. Harvesters had to become familiar with a new activity requiring new harvesting and handling techniques and skills (Fig. 16). Some vessels were inappropriate; in 1996, a standard vessel was introduced with adequate power and carrying capacity (3-5 WT, Fig. 17). The aggressive campaign carried out by conservation groups against the opening of the rockweed harvest in NB also created an initial reluctance for local people to participate in this new fishery (Ugarte and Sharp 2001, Sharp and Bodiguel 2003). Severe competition for labour with other productive sectors such as aquaculture also made the recruitment of harvesters very difficult (Sharp and Bodiguel 2003). Some individuals, evaluating their work options, did not remain with this exacting profession. Of the 32 harvesters initially recruited in early July 1995, only 5 remained until the end of the season. Another important factor that became evident after the first harvest season was that some sectors, especially in Area A (Fig. 15), were not only too remote from landing sites, but also too wave-exposed or the slope of the shoreline did not allow proper functioning of the cutter-rake; a bed with a slope between 25E to 40E is ideal as it allows the harvester to access a wider canopy of floating rockweed (Fig. 18) (Ugarte and Sharp in prep.). The exposure and steep slope reduced the total standing crop available to the company to 72 290 WT, a 44.2 % reduction.

Regarding the research and monitoring programme, a multifaceted approach was taken to carry out this component during this phase. This programme focused on the effect of the harvest on three major components: rockweed biology, the habitat and the associated fauna. The degree of shoot removal and effect of the harvest on population structure, growth and mortality were addressed by the licensee. Habitat studies conducted by DFO focused on the invertebrate fauna of the canopy and primary space. University researchers examined food linkages to wildfowl and fish use of intertidal zones, as well as nutrient variation in harvested and non-harvested plants. Personnel from DAFA monitored invertebrate by-catch and clump mortality associated with rockweed landings for sector and seasonal variability. This was a highly productive period in terms of seaweed research in NB with several graduate and undergraduate research theses completed.

Phase IV

This phase marked the end of the pilot harvest in October 1998 and the final review of the information gathered during the research and monitoring plan as well as the general performance of the company (Fig. 14). In April 1999, a formal peer review committee, the Regional Assessment Process (RAP), analysed the information gathered during the five-year pilot harvest and the research and monitoring programme. Although the harvest did not reach 10 000 WT in 1998, the 17% exploitation rate had been achieved in several sectors. The RAP committee concluded that the harvest impact on the habitat architecture was minimal and of short duration; however, it was advised to continue the harvest and maintain the precautionary approach of 17% of the standing crop, annually, in light of other knowledge gaps (Ugarte and Sharp 2001).

The research and monitoring programme provided a considerable amount of information related to the impact of the harvest on the rockweed structure, degree, extent and duration of change in the complexity of the habitat (Sharp *et al.* 1999). However, this information was felt, by some, to be insufficient to increase the exploitation rate, as some issues related to the long-term impact on the ecosystem were still unresolved. The possibility of gathering all the ecological information suggested as knowledge gaps in the CAFSAC document is very unrealistic for any marine resource in the world. In the case of rockweed, risks are minimised since structural changes in the habitat are short lived because the reduction in standing crop is compensated for by the overall production during the summer months, the time of active harvest (Ugarte *et al.* in press).

During the last few years, the Rockweed Management Committee has also reviewed the designation of several study sites and exclusion areas set aside during the establishment of the pilot harvest plan and several changes have taken place since 1999. For instance, areas that were originally set aside in order to protect the dulse (*Palmaria palmata*) resource (initially believed by some stakeholders to be conflicting with rockweed harvesting) were given to the company in exchange for sectors that were considered more sensitive to migratory birds. Also the company has yielded several additional harvesting locations at the request of some scientists carrying out long-term monitoring. The same consideration has been given to some conservation groups that have purchased land near the shore for long-term protection. To date, 17 035 WT are locked in these exclusion areas in NB.

Following the RAP review, the harvest of rockweed no longer constitutes a major issue for environmental groups and local stakeholders in NB, and the company has increased its rockweed landings from 703 WT in 1995 to 11 801 WT in 2004 in NB (Fig. 19). This increase has been possible due to a core of experienced harvesters that have been harvesting steadily since the opening of the fishery. Some of them can harvest up to 600 WT and make more than CDN$28,000 during the season. Also, a series of new portable unloading equipments have made possible the harvest in distant locations (Figs. 20-21).

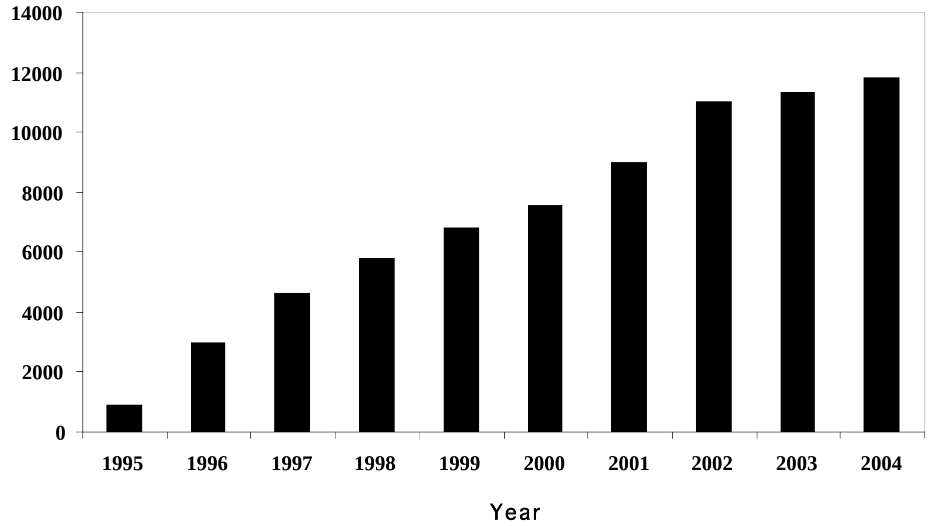

Fig. 19: Landings (wet tons) of *Ascophyllum nodosum* in southern NB since the beginning of the fishery in 1995.

Acadian Seaplants Limited has consolidated an important position world-wide with its cultivated and naturally harvested seaweed products and is currently the main seaweed processing company in Atlantic Canada. Its demand for rockweed has increased steadily since 1994, and the opening of the resource in southern NB has certainly helped to alleviate this demand. However, the 2004 landing is very close to the maximal annual harvest of 12 289 WT (17% of 72 290 WT) for that province and there seems to be little room for expansion, unless the current exploitation rate is changed or an alternative method of harvesting is allowed in those “non-accessible areas”. The exploitation rate will probably remain in place for a long period of time as conservation seems to be getting stronger in current government regulations for natural marine resources in Canada. Therefore, exploring alternative methods of harvesting appears to be an option. In NB there are more than 30 000 WT of commercial biomass (over 6 $kg.m^{-2}$) in exposed areas or areas of steep slope that could be utilised if a different method of harvesting can be adapted (Ugarte unpubl.). The province rejects any mechanical harvest method similar to those used in NS in the past, arguing that this would reduce employment and could produce a negative habitat impact. Therefore, some proposals which consider these concerns are being evaluated by the company.

This high demand for rockweed has also produced some changes in the areas that were traditionally harvested in NS. A detailed biomass survey by Acadian Seaplants Limited carried out between 1998 and 2000 in its leases located in MPHA 12 (Fig. 1) showed a total summer rockweed biomass close to 150 000 WT for this area. Contrary to NB, the harvestable biomass in MPHA 12 is close to 85%. The traditional harvesting areas along Lobster Bay near Yarmouth continue to be the most productive in terms of landing due to the concentration of resource (approx. 80 000 WT) in the Bay. However, new landing mobile technology purchased by the harvesters (Fig. 22) has also expanded the harvest along the south shore (toward Halifax) and along Saint Mary’s Bay. MPHA 11 is still an open area but its biomass is lower than that of MPHA 12 (around 30 000 WT).

Fig. 20: Alternative methods of unloading the daily *Ascophyllum nodosum* harvest in floating devices (platforms) in areas of southern NB where access to wharfs is difficult.

Fig. 21: Alternative methods of unloading the daily *Ascophyllum nodosum* harvest in floating devices (platforms), and towing behind a boat, in areas of southern NB where access to wharfs is difficult.

Fig. 22: Alternative methods of unloading the daily *Ascophyllum nodosum* harvest with mobile equipment in southwestern NS.

Fig. 23: Sun-drying of *Palmaria palmata* on a spreading ground at Roland's Sea Vegetables, Grand Manan Island, NB.

Fig. 24: Sale of sun-dried *Palmaria palmata* (dulse) at the city market in Saint John, NB.

Fig. 25: Aerial view of Acadian Seaplants Limited unique land-based cultivated seaweed operation in Charlesville, NS. (photography by Acadian Seaplants Limited).

Fig. 26: Mixed salad of Aka Hana-nori (pink), Ao Hana-nori (green) and Kiku Hana-nori (yellow), which are produced from strains of the red alga *Chondrus crispus*. (photography by Acadian Seaplants Limited).

Fig. 28: Culture of the blue mussel, *Mytilus edulis*, on a raft close to salmon cages in Charlie Cove, Bay of Fundy, NB.

Fig. 27: Culture of the kelp, *Laminaria saccharina*, in proximity to salmon cages in Bocabec Bay, Bay of Fundy, NB. (photography by S. Bastarache).

Acadian Seaplants Limited has established an exploitation rate of 25% of the harvestable resource in its leases of NS, but all the other regulations (harvesting tool, cutting height, mortality, etc.) are similar to those in NB. Harvesters are assigned a group of sectors as harvesting areas and they have the freedom to harvest the *A. nodosum* beds in a sector as they choose, keeping within the quota limits for the sectors. Harvesters keep daily harvesting logs recording the sector number and approximate harvest tonnage. These logs are compiled by individual, sector and landing site by week. At the processing plant the company produces a more accurate number by weighing each transport container from each landing site (usually the accumulated harvest from a crew or individual harvester).

THE DULSE (*PALMARIA PALMATA*) INDUSTRY

For this species it would be more appropriate to talk about a cottage-type industry as landings have always remained modest and geographically limited. In addition, this fishery has never been the subject of much attention nor of strict regulations from government agencies. Dulse harvesting and consumption in coastal communities along the Bay of Fundy (and also in New England) has a long tradition, the origin of which cannot be precisely dated (1876, according to Guptill 1992). According to Klugh (1930), 0.327 dry tons (DT) on Grand Manan Island (NB; Fig.1) and 0.078 DT around Annapolis (NS) were collected in 1921. By 1929, the harvest by 41 people had already concentrated around Grand Manan Island (0.499 DT versus 0.003 DT around Annapolis). Annual landings over the ten-year period 1982-91 averaged 38 DT in NB and 2 DT in NS (Guptill 1992). No commercial harvesting seems to have ever occurred in PEI. At the present time, most of the dulse (90%) still originates from Grand Manan Island (anyway, a fine connoisseur would tell you it is the best!), where 50-100 harvesters (and an additional 15-20 people involved in buying, packaging and shipping) harvested approximately 100 DT in 1994, between 59 and 68 DT in 1996 (R. Cronk, pers. comm.), and approximately 84 DT in 2002 (T. McEachreon, pers. comm.).

Palmaria palmata is found commonly in the intertidal and subtidal zones along the shores of the Maritimes, but is particularly abundant in the Bay of Fundy and especially around Grand Manan Island. Dulse is hand-picked off rocks at low tide in May on the East coast of the Island (Passage dulse) and from June to October on the West coast (Dark Harbour dulse). Dulse picking is also a supplementary fishery, with part-time commercial fishers eligible to collect UI (they had to buy a $5 license until a few years ago; they are not presently buying any licenses). Dulse is taken, the same day or a day after collection, to a spreading ground (usually an area of rock away from the shore, with a fish net spread over it; Fig. 23) and spread out in a thin layer to be sun-dried (6-8 hours of sunlight is sufficient to make it crispy). Sun-drying is a critical step. Improper drying because of rain, fog, overcast or sundown can ruin a crop very rapidly (discolouration or rotting). Unfavourable drying weather sometimes requires dulse to be “tied down” (held in cages under water) but for no more than a few days or deterioration occurs. Once dried, dulse is rolled up into bundles and taken to a buying station to be weighed and sold. There are 3 buyers/processors on Grand Manan Island (Atlantic Mariculture Ltd., Roland’s Sea Vegetables, and Leroy Flagg and Sons). Whole dulse is then either packaged in small bags (2 oz plastic bags or paper sacks) or into tea boxes of 45 kg to be shipped to another distributor/wholesaler or to be sold directly to grocery stores and markets in the Maritimes and New England for the traditional eaters and tourists (Fig. 24). Some Maritimers “in exile”, in other provinces or other countries, will also have dulse mail ordered to them regularly. The dulse which does not dry completely, due to inclement weather or because it is of inferior quality, is ground into dulse flakes or powder, used for flavouring in cooking as seasonings or condiments, and for manufacturing smoked/flavoured corn chips. It is also used for pills of vitamin supplements (vitamins B_1, B_{12}, C and D) and as a source of potassium, calcium, iron, sodium, magnesium and iodine, which is sold in health food, vegetarian and macrobiotic stores in the USA and Canada. Dulse is also claimed to be an anti-carcinogen and a gentle natural laxative (Guptill 1992). Some dulse is also sent to Australia, Ireland, Germany and a few other European countries. European markets are, however difficult to penetrate as harvesting of dulse is also taking place in Iceland, apparently the prime source for Europe.

It is striking to realise that the dulse industry has remained almost static in sales, production and processing methods for over 50 years. Suggestions, such as better quality grading and control, artificial drying, impoundments, and development of aquaculture, to reduce the potentially negative impact of an unstable supply have repeatedly been recommended for more than 25 years (Chenard 1971, French 1974, Neish 1976, Guptill 1992) but never fully implemented (despite a few isolated attempts). The major obstacles to innovation in this industry seem to be due more to sociological and financial rather than biological limitations (even if some buyers will argue that the market for first quality Dark Harbour dulse is supply-limited). There is resistance to change of life style by pickers, difficulty in keeping good pickers, difficulty in establishing stable quality standards and competition with other more lucrative fisheries. There has been no major investment in advertising and production technology, which would be necessary to bring about significant change.

According to Guptill (1992), sales could be increased to 200-400 DT per year with appropriate investments in marketing and promotion. The measures most likely to increase consumption in the short term would be: consumer and retailer education (cookbooks, for example, and pamphlets for tourists), advertising and in-store promotions and improved packaging and labelling. Market expansion seems to be possible by increasing consumption in existing North American markets, taking advantage of the increased popularity of low fat, healthy and exotic foods, and by penetrating Asian markets.

To increase the supply, the development of dulse aquaculture (from the simple impoundment to more sophisticated techniques) has also been recommended several times. Two trials were conducted but never reached maturity. Atlantic Mariculture Ltd. stopped its experiment in 1986, not because of biological reasons, but for simple logistic problems (loss of a free-source of circulating water which would have resulted in major investments in pumps and aeration systems). Sea King Seafoods, from Amherst, NS, had an extensive culture project, which, however, never got started because of vigorous opposition by local fishers and pickers (fear of loss of independence, employment and revenues in case an increased supply would drive prices down). The conclusion of Guptill (1992) is that any attempt at culturing dulse or radically changing the structure of the dulse industry (vertical integration) must carefully take into account the vested interests of the pickers and the other levels in the business (buyer, processor/manufacturer, distributor/wholesaler and retailer) if it is to succeed.

RECENT DEVELOPMENTS IN THE SEAWEED INDUSTRY IN THE MARITIMES

Aquaculture of *Chondrus crispus*

To resolve problems of fluctuating supply/demand ratios, risks of over-exploitation of some natural populations, fluctuating quality of raw material, prices and costs of labour and protectionism from some producers, seaweed aquaculture was advocated in the 1970's and 1980's (Edelstein *et al.* 1976, Huguenin 1976, Lapointe *et al.* 1976, Neish 1976, Waaland 1976, 1978, Neish *et al.* 1977, DeBoer 1978, Lapointe and Ryther 1978, 1979, Michanek 1978, Ryther *et al.* 1978, Fralick *et al.* 1981, Lapointe 1981, Shacklock and Doyle 1983, van der Meer 1983, Bidwell *et al.* 1985, Shacklock and Craigie 1986, Craigie and Shacklock, 1989). It is well known that it has been extremely successful in tropical environments (for example, *Kappaphycus* and *Eucheuma*).

Development of *C. crispus* cultivation in Canada was initiated in the 1970's by the late Arthur C. Neish, from the Atlantic Research Laboratory of NRCC in Halifax, who believed that the prospects were good for crops from the sea if modern agricultural principles were applied (Neish 1968). With his team, tank systems were built and numerous parameters were tested: forms and sizes of tanks; agitation of water and seaweeds; strain selection; inoculum density; water exchange rates and timing; quality, quantity and frequency of nutrient additions; impact of nutrients on carrageenan production (the famous Neish effect); carbon dioxide enrichment; temperature; salinity; light intensity; photoperiod; epiphytism; etc. (Craigie 1990b).

After 15 years of research, some believed that seaweed aquaculture in temperate regions could not yet compete with the harvest of natural populations, mostly because of the high operation and labour costs and inadequate solar and thermal conditions (Bidwell *et al.* 1985). Some others, however, did believe in it and when Acadian Seaplants Limited was formed in 1981 (www.acadianseaplants.com), one of its objectives was to complete the commercialisation of *C. crispus* cultivation with the support of scientists of the Atlantic Research Laboratory, especially of Dr. J. Craigie, first at the Sandy Cove Aquaculture Research Station and then at the Acadian Seaplants Limited facility in Charlesville, south-west NS (Figs. 1 and 24) (Isaacs 1990).

The reason for the development of the aquaculture of *C. crispus* is the fact that extraction of raw material harvested in natural beds yields a variable mixture of carrageenans of the κ- and λ-families. This is directly linked to the ratio of indistinguishable vegetative gametophytes and sporophytes in the harvest, as gametophytes produce carrageenans of the κ-family and sporophytes carrageenans of the λ-family (Chen *et al.* 1973, McCandless *et al.* 1973, Witt 1985). If there are ample sources of κ-/ι-carrageenans, mostly from *Kappaphycus* and *Eucheuma* in tropical regions, sources of λ-carrageenans are much more limited and unstable. Carrageenans of the λ-family are highly viscous, non-gelling phycocolloids well suited to applications in cold, dry-packaged, instant-mix food products (Witt 1985). However, a low world supply of poor quality λ-carrageenan (approximately 200 T in 1987) did not justify the development of such a market (P.S. Laite, pers. comm. to Craigie 1990b). In the hope of alleviating the problem of supply and consequently develop a market (it could, however, be argued that an abundance of supply is not a guarantee of market...), two approaches were considered. The first one was to design a system, based on the different chemical and mechanical properties of the different carrageenans, which would separate gametophytes from sporophytes in harvested raw material. This was developed by the company Carratech Inc. in Charlottetown, PEI (Fig. 1). It led to two patents (Whitaker 1988, 1989) but never found any commercialisation partners. The other approach was to develop the culture of λ-carrageenan producing plants by inoculating tanks specifically with sporophytes (Chen *et al.* 1975).

During the 1980's, the long development process permitted the evolution from small-scale research tanks to the pilot-stage (six 2 000 m^2 tanks) to the full-production stage in late spring of 1987 (17 tanks of 2 000 m^2 and 9 tanks of various smaller sizes over 3.4 ha); in 2004 the commercial operation covered 8 ha (Fig. 25). By October 1987, the selected sporophytic isolate BH-D (originally from Basin Head, PEI) had produced approximately 300 WT (Craigie 1990b). During the pilot-operation process, new techniques in dealing with large-scale tanks were developed, such as the design of tanks and aeration systems to keep seaweeds moving and refinement of the harvesting strategy (initially thinning excess growth to harvesting entire tanks followed by re-inoculation). The over-wintering of a large quantity of plants under the cold winter conditions of the Maritimes was solved with a simple and inexpensive approach: as the water temperature reached 0°C, both agitation and seawater exchange are interrupted and up to half of the water in the tanks is allowed to freeze (Shacklock and Craigie 1986, Craigie 1990b). As long as stocking densities were not exceeding ca. 10 $kg.m^{-3}$ and nutrient status of the plant was sufficient to avoid bleaching in case of growth under mild winter conditions, inocula at the bottom of the tanks could be routinely carried into the next growing season. Problems of weed control (mostly epiphytic *Enteromorpha* and *Ulva*) appeared to be satisfactorily addressed by keeping a "manageable" population of grazers (*Gammarus*, *Idotea*) in tanks. This solution appeared superior to other techniques, such as increased loading densities, pulse feeding of fertilisers, and application of algicides (Craigie 1990b). The culture facility was not exempt of outbreaks of diseases of fungal or bacterial origins, typical of any high-density culture system, and control strategies were developed.

The net production over a year was 6.27 kg $DW.m^{-2}$ (Craigie and Shacklock 1989) and the overall annual conversion of solar irradiance was, therefore, ca. 1.76%, which compared favourably with photosynthetic efficiencies between 0.5% and 1.3% for terrestrial plants of temperate regions (after all, it can be argued that a potato field, covered with snow in winter in PEI, is not producing more than a *Chondrus* tank covered with ice during the same period!). However, comparison with subtropical efficiencies of terrestrial plants, ranging from 0.5% to 2.5% (Hall 1980), was less flattering. Even if domestication of *C. crispus* had been successfully achieved by optimising physical, chemical and biological parameters through long-term committed research and development (mostly supported by government agencies), and the system had demonstrated sustained high levels of productivity on an annual basis, one was forced to accept that production costs of such Irish moss were higher than those obtained from the harvest of natural beds and that the gain in carrageenan purity could not offset these costs. When supply of λ-carrageenan was finally available on the market, the main client, Marine Colloids, shied away.

Since then, Acadian Seaplants Limited has reconverted its facility to the culture of a unique strain of edible *C. crispus*, Hana-nori™, for the Asian (mostly Japanese) human food market (kaiso salads, sashimi garnishes and soups) by manipulating the colour and the texture of selected isolates (Fig. 26). The transformation of the Charlesville operation from an Irish moss cultivation facility for carrageenans into one for edible seaweeds, with much higher added value, was a remarkable conversion and a brilliant niche market strategy for the company, which plans to cultivate other species. Acadian Seaplants Limited invests approximately 10% of its revenue in resource and product R&D and manufacturing technology annually.

Aquaculture of Nova Scotia Sea Parsley™ and opika-1™

Ocean Produce International (OPI; www.oceanproduce.com), from Dartmouth, NS, was founded in 1995 by a group of investors to bring new and unique sea vegetables to market. OPI entered into an agreement with NRCC to commercialise two "strains" of dwarf male mutants of *Palmaria palmata* isolated in 1978 by the then Atlantic Research Laboratory, in Halifax. The name of these sea vegetables has been trade marked by OPI as Nova Scotia Sea Parsley™ (because this short (4-6 cm), highly branched morph can remind someone of the shape of parsley) and opika-1™, respectively. Initially, it was grown in seawater tanks (sorry... "mariponically"!) in the greenhouses of the Aquaculture Research Station at Sandy Cove, NS. OPI can now operate a greenhouse with tanks using a saltwater well system in Shelbourne, NS. The production capacity is reported to be 20-36 tonnes per year. The company is now looking for licensed growers, partnerships and joint ventures, while ensuring the quality standards are met and kept by providing technology transfer and technical assistance. The main applications of Nova Scotia Sea Parsley™ and Sea Parsley Florets™ seem to be as garnishes and flakes in salads, seasonings, sauces, soups, pasta, pies, cheese spreads, hence targeting the expanding health food sector. In 2005, the price of 1 kg of Nova Scotia Sea Parsley™ is US$320. Green Sea Parsley™ is used in nutraceuticals, functional foods and drinks as an ingredient in "green drink" powders, and as a source of omega-3 compounds. Sea Parsley Antisensitivity Compound™ is used in cosmetics and skin care products. The excitatory amino acid products opika-1™ kainic and dihydrokainic acids are fine chemicals used in neurological research (sold for US$4,400 and US$6,160 per gram, respectively).

It is presently unclear if the OPI venture will be successful or not. It is also not clear if the company has license agreements or not with individuals, groups or institutions, which would operate like franchises. OPI affirms that its long-term plans are to adapt culture techniques, developed by the now Institute for Marine Biosciences, to bring additional sea vegetables to discerning customers around the world.

Aquaculture of nori (*Porphyra*) and kelp (*Laminaria*) as the inorganic extractive components of integrated multi-trophic aquaculture systems

After a rapid expansion throughout the world, and particularly in the Bay of Fundy, the salmon aquaculture industry is starting to realize that each habitat can carry only a certain level of mono-activity, and that exceeding the carrying capacity can generate severe disturbances, (including diseases, eutrophication, toxic blooms and “green tides”) in the receiving waters (Phillips *et al.* 1985, Gowen and Bradbury 1987, Folke and Kautsky 1989).

One emerging consequence of fish aquaculture activities is a significant loading of nutrients (especially dissolved nitrogen (N) and phosphorus (P), and particulate material) in coastal waters (Beveridge 1987). Several countries, where intensive aquaculture is already an established industry, are in the process of implementing restrictions on the amount of nutrients allowed to be discharged to fish farms, as excessive fertilisation can alter significantly the quality of the benthos and waters, generally sought after by multi-users (Håkanson *et al.* 1988). Nutrient rich waters, in the vicinity of fish farms, also favour the growth of opportunistic annual filamentous algae, such as *Ulva*, *Enteromorpha*, *Cladophora*, and *Pilayella*, which are causing severe biofouling of cages, and restricting water and nutrient circulation patterns (Indergaard and Jensen 1983, Rönnberg *et al.* 1992). At the same time, the decline of economically valuable perennial algae (*Ascophyllum*, *Fucus*, and *Laminaria*) has been recorded due to increased competition, decreased light penetration and increased sedimentation of organic matter (Wallentinus 1981).

Different methods have been used to try to minimize the effect of nutrient loading, such as reducing nutrients and their leaching from diets and trapping or stabilising of the faecal matter (Phillips *et al.* 1993). However, 20-30% of N and 60-70% of P are still not consumed or released as faeces (Soto 1996). The other approach is to develop polyculture systems by integrating the culture of macroalgae and suspension-feeders to fish culture (Ryther *et al.* 1978, Indergaard and Jensen 1983, Folke and Kautsky 1989, 1991, 1992, Petrell and Mazahari 1992, Petrell *et al.* 1993, Subandar *et al.* 1993, Folke *et al.* 1994, Bodvin *et al.* 1996, Kautsky *et al.* 1996a, Chopin *et al.* 2001, Troell *et al.* 2003, Neori *et al.* 2004). Seaweeds can use the excess nutrient supply and other animal metabolic by-products, for growth (Chopin *et al.* 1990a, b, Fujita *et al.* 1989), while providing a significant amount of needed oxygen for fish farms through photosynthetic activity (Wildish *et al.* 1993). Moreover, by selecting seaweeds of commercial value (for the food, textile, pharmaceutical, biotechnological, cosmetics and other enterprises), additional profits can be realised by industry (Petrell *et al.* 1993). Kautsky *et al.* (1996b) have developed the interesting concept of an “ecological footprint”, which is the life support area needed per square meter of aquaculture activity. For 1 m^2 of salmon aquaculture, the N production requires 340 m^2 of pelagic production to be assimilated, and the P production requires 400 m^2 of pelagic production. By integrating the culture of *Gracilaria* to salmon aquaculture in Chile, these authors were able to reduce these ecological footprints to 150 m^2 for N and 25 m^2 for P.

The first author has been developing, with colleagues in New England, a similar programme of integrated aquaculture in NB and Maine by replacing *Gracilaria* (for the agar market) by *Porphyra* (direct human consumption and biotechnology markets). The salmon/nori integrated aquaculture project was based on the premises that it should offer several advantages at different levels:

1) The seaweed farming component represents an additional income for the salmon farmer. Moreover, by diversifying the sources of income and the labour training, the farmer protects himself/herself from a dangerously fluctuating salmon market at the national and international level, of which he/she has very little control. *Porphyra*, either as a source of food for direct human consumption or for developing biotechnological applications, is a crop with a very high added value.
2) There should be substantial savings as there should be no fertilisation costs. Nutrients produced by the salmon farm will fertilise, at no cost, the seaweeds. Consequently, a higher nori production can be anticipated in an integrated system compared to a uniquely nori farm.
3) Integrated aquaculture improves water and habitat quality of coastal waters by increasing nutrient removal by seaweeds naturally and, hence, at a net profit.
4) If *Porphyra* reveals itself as an efficient biological nutrient removal system, one can even contemplate the possibility of increasing the number of salmon cages at a particular site, hence, creating even more revenue.
5) Integration of economically important marine plants in an aquaculture system allows the management of eutrophication problems associated with present fish mono-aquaculture and coastal agriculture/urban/industrial practices. Any amount of nutrients that can be utilised by marine harvested crops will reduce that available for the growth of opportunistic and undesirable algae such as *Ulva*, *Enteromorpha*, and *Cladophora* - which are responsible for low-value "green tide" biomass, the disposal cost of which becomes rapidly prohibitive (Fletcher 1990) - or toxic phytoplanktonic species. Moreover, the periodic short-time harvest of *Porphyra* assures a constantly renewed removal of nutrients from the coastal ecosystem. This is not the case with bloom-forming macro- and microalgae, which recycle their nutrients back to the water column when they die and decay, and consequently perpetuate conditions favourable for future blooms. Even if the complete replacement of problem species by introducing this competition for nutrients is not achieved, partial replacement may be sufficient to reduce the biomass of problem species below the threshold of hypertrophic events (Merrill 1996).

Preliminary results in Cobscook Bay, north-eastern Maine, USA, where the nori company Coastal Plantations International Inc. was located, demonstrated that *Porphyra yezoensis* is able to detect high nutrient loading in coastal waters resulting from anthropogenic activities (*e.g.* fish aquaculture and intense scallop dragging putting back into suspension nutrients trapped in sediments). Tissue N levels were between 6.64 and 7.27% DW in Cobscook Bay on November 1, 1996, while the highest contents recorded by Chopin *et al.* (1996) in *A. nodosum* were 2.68% DW, between 4 and 4.5% DW in *Polysiphonia lanosa* and *Pilayella littoralis*, and 4.38% DW in *C. crispus* (Chopin unpubl.). Tissue P levels were between 7.06 and 8.47 mg P. g DW^{-1}, whereas the P content of *Porphyra purpurea* in Dipper Harbour, NB (a location remote from the two above anthropogenic activities) was 3.24 mg P. g DW^{-1}. *Chondrus crispus* is known to have tissues saturated at around 4-4.5 mg P. g DW^{-1} (Chopin *et al.* 1995). Consequently, *Porphyra* could be used as a bio-indicator for nutrient loading and as a biological nutrient removal system to sustain and improve the productivity and carrying capacity of coastal waters, especially in regions of intensive fish aquaculture activities, to contribute to the development of a responsible management of nearshore coastal waters. *Porphyra* can be considered as an extremely efficient nutrient pump, certainly associated with its morphology (thin blade with 1 or 2 layers of cells, all involved in absorption). It could be argued that this morphology, while creating an efficient pump, does not allow storage in reserve tissues as in the case of the large brown algae (Laminariales, Fucales). However, the advantage of *Porphyra* is its rapid growth, which allows the harvest of a crop every 9-15 days (I. Levine, pers. comm.). Consequently, frequent harvesting amounts to significant quantities of nutrients being constantly removed from coastal waters, hence the concept of using *Porphyra* as a biological nutrient removal system integrated with salmon aquaculture.

Unfortunately, Coastal Plantations International Inc. ceased operations and the lack of a reliable source of nori-seeded nets stopped further development of this project. Part of it is continuing as a land-based experimental summer flounder/nori tank cultivation system in New Hampshire, USA, with the company Great Bay Aquafarms Inc.

Since 2001, the first author is the principal investigator of an interdisciplinary research project, with a team of scientists from the University of New Brunswick and the DFO Biological Station in Saint Andrews, NB, that is developing the concept of integrated multi-trophic aquaculture (IMTA). Current marine monoculture production models are premised on the assumption of continual expansion. This fuels the development of commodity-based systems and the eventual erosion of environmental quality, as lower profit margins are compensated for by increased volumes within geographical expansion and carrying capacity constraints (Chopin and Bastarache 2004). The project, supported by AquaNet, the Canadian Network of Centres of Excellence for Aquaculture, focuses on a new paradigm: how to optimise aquaculture lease space and biomass production through biomitigation to reduce environmental impacts, diversification for sustainable economic viability, and social acceptance of the improved practices (Chopin *et al.* 1999, 2001, Troell *et al.* 2003, Neori *et al.* 2004). It is time to realise that monoculture practices do not offer the best use of cultivation units. When one considers the seawater volume available at a leased site and the volume of water column actually occupied by a series of salmon cages, it is obvious that a cultivation unit (*i.e.* a site) is not optimised. Developing IMTA systems will not only bring increased profitability per cultivation unit through economic diversification by co-cultivating several value-added marine crops, it will also bring environmental and social sustainability and acceptability.

Phase I tested the feasibility of the IMTA concept by combining inorganic extractive aquaculture of the kelp, *Laminaria saccharina*, and organic extractive aquaculture of the blue mussel, *Mytilus edulis*, with the fed aquaculture of salmon, *Salmo salar*, to provide a balanced ecosystem approach to aquaculture practices (Figs. 27-28). Phase II increased the production of kelps and mussels towards an industrial, pilot-scale level. Food safety tracking was a significant component of the second phase. Physical/chemical modelling (especially of the oxygen budget) and the socio-economic component were initiated. The main results from Phases I and II are:

- Culture techniques, both in the laboratory and a three aquaculture sites with different exposure characteristics, of the kelp, *L. saccharina*, have been improved (the lab phase has been reduced from 113 to 35 days, and the biomass production has been increased from 8.0 to 20.7 kg. m^{-1} of rope). Kelps grown in the vicinity of salmon farms increased their growth rates by 46 % in comparison to kelps grown at reference sites.
- An innovative *in situ* method (time-lapse underwater video of siphons) to determine the quantitative feeding rate of the blue mussel, *M. edulis*, was developed to show that mussels are not only capable of capturing excess food particles from the fish farm but also increase their

feeding rates in response to the presence of these particles. Seston levels at salmon farms are elevated by a factor of 2 to 4 over ambient levels and are of very high quality (up to 90 % organic). Enhanced growth rates at farm sites (50 % more than that of mussels at reference sites) and accelerated production times to commercial size (approximately 18 months from socking) reflect this increase in food energy, as mussels ingest fish food particles with approximately the same efficiency as phytoplankton species.
- None of the therapeutants used in salmon aquaculture have been detected in kelps or mussels collected from the integrated sites (Chopin *et al.* 2002, Sephton *et al.* 2003b, Martin *et al.* 2004).
- Blooms of the phytoplanktonic species, *Alexandrium fundyense*, occur during the summer months and PSP toxins are accumulated by mussels; however, mussels can be safely harvested with proper management (Sephton *et al.* 2002, 2003a,b,c). Marketing of the product will have to occur outside of the toxic algal season, which will modify the final size of the marketed product. This is a common practice in many shellfish producing countries and implementation of such a management technique for Canada will need to be investigated.
- The logistics of the kelp and mussel culture portion of an integrated operation appear to fit well with the day-to-day operations of a regular salmon farm. Mussel seed acquisition was not an issue as the cleaning of the nets provides an abundant source of juvenile mussels.
- A survey of aquaculture attitudes found that the general public is more negative towards current monoculture practices and, although relatively unfamiliar with the concept, feels positive that integration would be successful.
- A study of the seaweed products and markets was conducted and recommended the relatively small volume/high value-added niche market approach as the most appropriate strategy at this stage.
- Following a successful workshop in March 2004 in Saint John, NB, the network investigators are working with the Canadian Shellfish Sanitation Program (CSSP) partners [*i.e.* DFO, Environment Canada and the Canadian Food Inspection Agency (CFIA)] to define the appropriate food safety and the Hazard Analysis and Critical Control Point (HACCP) -based policies and procedures, on a pilot basis, for an integrated site. Based on further industry/government consultation and development, this should allow for the development of commercial scale integrated operations under an amended/revised CSSP policy framework.
- The interdisciplinary team has been able to deliver a varied set of documents (peer reviewed papers, book chapters, proceedings of international conferences, non-refereed technical papers, magazine and newspaper articles, and an English/French bilingual DVD) to disseminate the knowledge it has gained since 2001 to the different targeted audiences: researchers, federal and provincial agencies, industry, professional associations, environmental NGOs, and the general and school public. The bilingual DVD, entitled “Integrated Aquaculture - An Old Recycling Concept for Renewed Sustainability” can be accessed through the following links:
http://www.aquanet.ca/English/media/video/int_aqua_e.wmv
http://www.aquanet.ca/French/media/video/int_aqua_f.wmv

As current findings support the establishment of IMTA systems in the Bay of Fundy, the team now plans to proceed with phase III: scaling-up of the experimental systems to commercial level, extend its application to the West coast of Canada, and increase its trophic components and links even more by testing and developing the combined aquaculture of other species with similar or complementary functions in an integrated system.

Recent experimental developments
Recent developments of sea urchin cultures have increased the demand for *Laminaria* for these organisms which are also fed with different artificial diets. There are presently 10 experimental projects of sea urchin farming (Y. Chiasson, pers. comm.) along the Bay of Fundy, the Northumberland Strait (between NB and PEI) and the Baie des Chaleurs (NE of NB). There are also 20 applications for licenses in NS (Sharp, pers. comm.). Further development should certainly contemplate the parallel development of *Laminaria* culture.

Two companies are also investigating (semi-industrial stage) the feasibility of the production of herring-roe-on-kelp in the Northumberland Strait by using *L. digitata* and *L. saccharina*.

Recent developments in the use of seaweeds in crafts should also be noted. Several people in the Maritimes are now producing wreaths, baskets, frames, etc. with seaweeds, either simply dried or preserved through a non-toxic process (M. Henry, pers. comm.).

CONCLUSION

Writing of this chapter was an opportunity to describe frankly, without compliance, the evolution of the seaweed industry in Canada. The difficulty in clearly understanding a fishery is that Science, or the consideration of the biology of one species at a time, will only give one a partial explanation of its evolution. For a global understanding of a fishery, it is imperative to integrate scientific data to social, economic and political information within an ecosystem and over a long period of time. It is very revealing that the present paper would have extreme difficulty in being published in a biological science journal, being considered not Ahard science@ enough, or a social/economic/political science journal, being then considered Atoo scientific@! The present book, hence, appeared the appropriate venue.

The seaweed industry in Canada, when described without circumlocutions, is in fact not that different from other fisheries (of seaweeds or other species) in other countries. It has its deepest roots in the concept of the sea as part of the Commons with unlimited resources, gifts to the Humanity but exploited by a few. When the State, originally with good intentions, starts to subsidise relatively less developed coastal regions without a long-term strategy, over-capitalisation, over-attraction for a certain labour force and increased fishing efficiency and effort appear rapidly and jeopardise the sustainability of the resource. When the situation becomes too compromised, the industrialisation effort is generally shifted toward the management effort of a resource then recognised as limited but renewable. Neo-classic economic theories emerge: the number of fishers and the fishing capacity have to be reduced to face a declining resource. Fishery strategies are dictated by the economic and biological variations of the resource. Others argue that the notion of Commons, and the system of monospecific licenses, should be rejected to swing to the concept of multi-species, individual and transferable quotas, leading to a kind of privatisation of the sea, which will force fishers to manage the resource in a responsible, sustainable and profit-earning manner (suppression of UI assistance). Assigning to individuals or companies exclusive rights to an area can lead to effective management. Guidelines would have, however, to be developed to ensure acquisition, recording and analysis of fishery management data. Individual/company management of a common property resource is fraught with risks (fear of short-term profits prevailing over long-term, optimal-yield objectives) and still requires some control mechanisms (annual review, renewal subject to proactive observance of a management plan, etc.), which ultimately come under a governmental agency of one sort or another.

Different models have been constructed over the years. The key problem for all of them is the apprehension and quantification of the fluctuations, natural or not, of the resource, climatic and oceanographic conditions, fishing effort and markets. Factors other than Science limit attainment of optimal yields and, hence, good resource management (Pringle 1985, 1986). One key parameter, which is surprisingly constantly missing, is the realisation and consideration that to manage a fishery, one needs not only to have an in-depth knowledge of what is fished but also of who is fishing. An integrated management, hence, also requires an in-depth sociological and anthropological knowledge of human societies, and their own fluctuations, to properly manage one species common to all fisheries: the human species.

Licensing systems are one of the measures often used to reduce over-harvesting. However, their monospecificity prevents the mobility of fishers from one fishery to another, as a reaction to fluctuations of the resource or of the markets. Complementary fisheries, like Irish moss, would then have a useful role of buffer against those fluctuations. The rigidity of licensing systems can, hence, be viewed in the long term as aggravating over-harvesting by trapping fishers in fisheries that become less and less viable (Bodiguel 1996). In addition, the rigidity of the season opening dates does not allow taking into consideration the fluctuations of the resource. A variable season opening date, based on an evaluation of the resource during the pre-season, was suggested (Chopin *et al.* 1987) but never officially implemented because of the nightmare it will create for its implementation and enforcement, as all the season opening dates of the different fisheries are tightly linked.

At the present time, fishery resource management in Canada is under severe criticism from all sides. The federal government, through DFO, is accused of neither providing employment nor conserving the resource. Critics should, however, remember that fishery resource management is a relatively young discipline (Pringle 1986), far from an exact science, which requires the integration of biological, economical, sociological, and political sciences... a difficult task in a world of over-specialisation. Until now, the emphasis has been put on biological sciences; it is important to realise that fishery resource management is, in a large part, human resource management (Pringle and Sharp 1986). All components (fishers, scientists, regulators, politicians, etc.) should be represented, listened to and active stakeholders in the elaboration and implementation of an integrated, long-term resource management plan reached by consensus. This pre-supposes a redistribution of power and responsibilities. The regulation enacting system must also be flexible enough to allow for swift updating in concert with new socio-economic and biological information/situations.

Development of a renewable resource should at least be coincidental with stable programmes of resource science and resource management. Community economic assistance should complement, not detract from, management of the community=s renewable natural resources. Politicians and government officials, prior to modifying a system, should use an experimental approach to determine the long-term consequences of policy changes (for example, a pilot investigation with a component of the population) and win the confidence of the affected communities. This requires years of work within a stable, but not unalterable, enforceable framework.

Although resource management, with total jurisdiction awarded to a single government, is not above criticism, Pringle (1986) found it superior to jurisdiction split between governments. The quibbling over jurisdiction of the intertidal zone between NS and federal governments, while the management of a resource and the local economy were at stake, is irresponsible and immature (after all, the history of the Canadian Federation could be considered quite recent in comparison to the history of some other countries in the world!). Fortunately, the two governments realised the negative impact of their conflict and developed a MOU in 1991, which permits joint management until jurisdiction is decided by the courts. A more rational and co-ordinated management of the rockweed resource in NB is still in its infancy and, thus, it is too early to evaluate the success of this multi-lateral approach; early indicators suggest, however, that it has been a step in the right direction.

The development of seaweed aquaculture in the Maritimes is encouraging. If, in the case of *C. crispus* and *P. palmata*, it is a matter of aquaculture systems for the production of one crop (edible Irish moss or Nova Scotia Sea Parsley™), what is proposed with *Porphyra* and *Laminaria* is integrated multi-trophic aquaculture, with certainly the production of a valuable algal crop, but also the use of seaweeds for biomitigation.

Integrated aquaculture is not a new concept! Asian countries have been practising it for centuries (Chan 1993). Interestingly, civilisations that have been most successful at developing integrated aquaculture systems are the ones that treat wastes as valuable resources and know the whole meaning of the word Arecycling@ because they have been living in closed systems, where everything has to be reusable, for centuries. Western countries are regularly Areinventing the wheel@ (Ryther *et al.* 1978, Indergaard and Jensen 1983, Kautsky *et al.* 1996a, Chopin *et al.* 2001), culminating now in the use of such buzz-phrases as: Aecological engineering for environmentally improved and sustainable aquaculture operations@! The determination to develop IMTA systems, however, will only come about if there is a major change in the consumer=s attitude related to eating products cultured on Awastes@ and in political and economical reasoning by seeking sustainability, long-term profitability and responsible management of coastal waters.

In his effort to promote IMTA in NB the first author realised that a concept, even if it is based on common sense, will not always necessarily rapidly penetrate minds! To successfully develop an IMTA industry, a clear commitment from the different players (the aquaculturists, the scientists, the governmental departments and the funding agencies) is needed, associated with a clear respect and appreciation of their respective contributions, while recognising their specificities. The role and mission of research and development should be clearly understood. Presently, everybody wants to be involved in the famous R&D, but some would like to forget the AR@ as rapidly as possible or to do it at no cost (or only if it is at the cost of a subsidising agency!). One has to realise that the order of the letters has its significance: it is R&D, not D&R (the horses before the carriage!). One should not forget that the prosperous development of nori aquaculture in Asia is due to the scientific discovery of the life cycle of *Porphyra* by Drew (1949), not the reverse. Research and development/monitoring should be conducted in a scientific manner to obtain and keep credibility and validity. If not properly carried out, it could lead to questionable data, unfounded speculations and biased conclusions which could jeopardise further developments for an entire region. Consequently, one has to recognise that R&D/monitoring is a full component of any economic development plan and associated with a cost. Temptations of shortcuts and rash handling of the R&D/monitoring component are just a sign of lack of understanding of the coastal environment and lack of vision for a long-term sustainable development of integrated aquaculture. One should also not forget that R&D is only justified if a AC@ (commercialisation) comes next; unfortunately there is frequently a major gap between R&D and C, often because the appropriate funding structures and incentives are not in place to take a R&D project to a C reality.

One must also understand that the performance evaluation of integrated systems requires a different approach from the typical linear growth models used for mono-aquaculture over the last decades, without consideration of the environmental and social costs. Five-year profitability models, with the goal of reaching 100% performance for each cultured species in isolation, should be replaced by total, long-term and sustainable economic models in which the yield per unit resource input is evaluated (Kautsky *et al.* 1996a).

Let us not forget that we are still in the infancy of aquaculture and that some agricultural practices have taken centuries to develop fully.

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