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Information to Support Assessment of Stock Status of Commercially Harvested Species of Marine Plants in Nova Scotia: Irish Moss, Rockweed and Kelp

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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This paper is dedicated to the memory of Constance MacFarlane, whom recognized the need for conservation principles in the harvest of marine plants long before it became fashionable in intellectual or management dogma. Her observations and insight – obtained with primitive equipment and hard work – are as relevant today as they were over 70 years ago. She remains an inspiration to all Canadian phycologists.

- H. Vandermeulen

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ABSTRACT

A literature review was performed which included examining over 200 publications relevant to the harvest of marine plants in Nova Scotia. The seaweeds included Irish moss (*Chondrus crispus*), rockweed (*Ascophyllum nodosum*) and kelps. The history of each harvest is presented along with an analysis of the harvest methods, timing and intensity of the harvests, and standing stocks. Environmental effects on the standing stocks were also examined. One of the guiding principles of the assessment was the preservation of the habitat value of the seaweeds on bay-wide scales in the face of harvest pressure.

Information à l'appui de l'évaluation de l’état des stocks en ce qui concerne la récolte d'algues marines en Nouvelle-Écosse : mousse d'Irlande, fucus et varech.

RÉSUMÉ

Une analyse documentaire qui consistait à examiner plus de 200 publications en lien avec la récolte d'algues marines en Nouvelle-Écosse a été effectuée. Les macroalgues comprenaient la mousse d'Irlande (*Chondrus crispus*), le fucus (*Ascophyllum nodosum*) et le varech. L'historique de chaque récolte est accompagné d'une analyse des périodes et de l'intensité de la récolte, des méthodes employées ainsi que des biomasses. Les effets environnementaux sur la biomasse ont également été examinés. Un des principes directeurs de l'évaluation était la préservation de la valeur de l'habitat des macroalgues à l'échelle d'une baie malgré les pressions de la récolte.

INTRODUCTION

The government of Nova Scotia created regulations for marine plants in 1959 (*Nova Scotia Sea Plants Harvesting* Act). Federal marine plant harvesting regulations were not promulgated under Canada's *Fisheries Act* until 1978; when they were called the 'Atlantic Coast Marine Plant Regulations' (Chopin 1998; Pringle 1986).

These regulations were created long after a large, well established marine plant harvest had developed in Nova Scotia. Presently, the harvest of attached seaweeds is still controlled by the *Fisheries* Act; specifically Part IX of the *Atlantic Fishery Regulations* entitled 'Marine Plants'. The present version of these regulations was established in 1985, replacing the earlier Atlantic Coast Marine Plant Regulations. These federal marine plant regulations only apply to seaweeds (algae) growing attached to rocks – the harvest of loose drift material washed up on shore (wrack) is controlled by provincial regulations and a permit system specific to algal type and shore location.

The two most important marine plant (seaweed) harvests controlled by the federal marine plant regulations in Nova Scotia are those for Irish moss (*Chondrus crispus* Stackh., a 'red' seaweed) and rockweed (*Ascophyllum nodosum* (L.) Le Jolis, a 'brown' seaweed). Both species are primarily harvested along the rocky shores of southwest Nova Scotia, a region corresponding to Marine Plant Harvesting District 12 (Schedule XXVI under the *Atlantic Fishery Regulations*, Figure 1). Attached Irish moss and rockweed have both been harvested in D12 at a sustained annual rate of thousands of metric tonnes (mt) wet weight for decades. A much lower rate of harvest has occurred in D11; no significant harvest in D10.

Occasionally, the Department of Fisheries and Oceans Canada (DFO) marine plant harvest licences are also issued for 'kelp' - a mix of brown algal species most commonly including *Saccharina latissima* (L.) Lane, Mayes, Druehl et Saunders, *S. groenlandica* (Rosenvinge) Lane, Mayes, Druehl et Saunders, *Laminaria digitata* (Huds.) J.V. Lamour., and *Saccorhiza dermatodea* (Bach. Pyl.) Aresch. The harvest of attached kelp under the federal marine plant regulations has attracted some effort from time to time over recent decades, but the harvest rates have been low and sporadic. The harvest of kelp wrack (controlled by the province) enjoys a more sustained effort and appears to be the primary source of material for those interested in kelp in Nova Scotia in recent years.

The harvest 'season' for rockweed and kelps is presently not regulated. The harvest of Irish moss is regulated under the *Atlantic Fishery Regulations* by harvest district via 'close times'. In D12, the close time is November 1 to June 6 (i.e. the harvest is open June 7 to October 31); in D11, the close time is November 1 to June 30 (i.e. the harvest is open July 1 to October 31). The later opening time for D11 is probably related to a presumed later reproductive period for Irish moss in these colder eastern shore waters. These close times have existed since 1978. However, since 2007, the D12 opening has been delayed by Variation Order each year until the third Monday in June.

It is not good management practice to harvest seaweeds during their reproductive period. In general, *Ascophyllum* has a pronounced reproductive peak in May (it can be as late as June in more northerly waters; David Garbary, St. Francis Xavier University, pers. comm.) while *Chondrus* peaks in June / July and later on in the fall. Most of the harvest of *Chondrus* in D12 occurs right at the beginning of the season and through the early summer, tapering off as the weeks go by. *Ascophyllum* is similarly harvested with greatest effort in the first part of the season, but tends to be harvested through to late summer and later.

In the 1970s and 1980s, DFO Science Branch developed a research and monitoring program on seaweeds and other algae in the Atlantic provinces (primarily Nova Scotia and Prince Edward Island) involving three to five staff, field stations and tens of thousands of dollars in annual budgets. Most of DFO's science advice on seaweeds comes from these 'golden years'. The field stations are now long gone, and DFO Science staff have been reduced to just one person (a part-time file) with no research or field assessment budget for commercial seaweeds.

For the reasons described above, most formal stock status documentation on the seaweed harvest in Nova Scotia is at least twenty years old. DFO Fisheries Management (FAM) is aware of this situation, and pursued a formal 'Request for Science Information and/or Advice' to update marine plant stock status in Nova Scotia. The latest version of this request indicated a response deadline of March 31, 2012. The formal question from DFO Fisheries Management was:

> *FAM requests an update of the stock status of commercially fished species of marine plants, especially of Irish Moss, in the Nova Scotian portion of the Maritimes Region. Commercially fished species regulated under the Fisheries Act are primarily rockweed and Irish Moss, although there are occasional requests to harvest live kelp as well. (Dulse is a commercial species but is exempted from regulation under the FA. if harvested manually.) All of these species are also important to marine coastal ecosystems.*

BACKGROUND

Seaweed populations are different from fish and invertebrate populations targeted for harvest in that natural mortality does not usually drive variations in population size to any great extent. Algal biomass is usually the result of the available space on the shore with suitable physical conditions (temperature, salinity, wave exposure, hours of desiccation at low tide, etc.). Undisturbed seaweed populations tend to be stable over long periods of time, and the natural environment does not create wide fluctuations in standing stock over the short term (years) other than storm or ice scour events in the intertidal (applicable mainly to *Ascophyllum* and *Chondrus*), or 'outbreaks' of herbivores like sea urchins in the subtidal (applicable mainly to kelps).

Mortality due to herbivores usually does not cause wide fluctuations in algal biomass from year to year for *Ascophyllum* or *Chondrus*. However, herbivores may have some effect on the overall depth and extent of some *Chondrus* beds (see below). Disease also rarely effects algal populations on pristine shores.

Recruitment events tend to be predictable (e.g. spring production of conceptacles in rockweed) and do not vary widely from one year to the next, as compared to some fish (herring) or invertebrates (mussels). Overall, human activities cause the greatest fluctuations in algal populations, either through short term events like harvesting or deterioration in water quality, or via long term alterations such as climate change.

The seaweed harvests are also somewhat different from fish and invertebrate harvests in that seaweeds constitute important fish habitat (as defined by the *Fisheries Act*). Seaweeds offer important cover for adult and juvenile stages of a host of invertebrate and fish species, some of them directly commercially valuable or forage species for other commercially harvested organisms. Seaweeds are also important for both herbivore driven and detrital food webs. In effect, it is possible to argue that large scale (e.g. whole reef or bay wide) harvesting of seaweed constitutes a Harmful Alteration, Disruption or Destruction of fish habitat under the *Fisheries Act*.

For the reasons outlined above, Foster and Barilotti (1990) proposed that the harvest of seaweeds should be managed on the basis of ecosystem principles. Not only should there be the traditional efforts to determine the impact of harvest on the harvested population (changes in recruitment, survivorship and stability), but effects on the community (by-catch of invertebrates, removal of food for herbivores, habitat loss) need to be considered as well, along with ecosystem level effects such as loss of organic input (e.g. the detrital food web). Chambers et al. (1999) expanded upon these ideas to include the principles of landscape ecology when considering the value of seaweed habitat (and marine macrophyte habitat in general, including seagrasses), and the notion that all commercial algal harvests need to be managed following experimental principles due to the unpredictability of many environmental events.

There are a number of guiding principles for this assessment which provide a different direction from previous work on the subject:

1. *Habitat focus* – as mentioned above, seaweeds constitute important fish habitat. Included within this concept is the value of seaweeds in herbivore and detrital food webs. In an exploration of the habitat value of marine macrophytes under the *Fisheries Act*, Vandermeulen et al. (2012) expressed the DFO Habitat Management view that 'harmful alteration' of the habitat value of a marine macrophyte bed has occurred if it takes more than a year for it to recover its structure and integrity. 'Destruction' has occurred if the bed will not recover without intervention. Note that the term *structure* includes the three dimensional shape of the algal canopy.

   The terms 'harmful alteration' and 'destruction' have a regulatory context which is not directly applicable to the harvest of marine plants via licence from DFO. However, they can be used as a guide to develop a habitat protection objective for the harvest, within the spirit of DFO's development of ecosystem objectives for ecosystem based management (e.g. Curran et al. 2012). The habitat protection objective for this assessment is "*the structure and integrity of the original seaweed bed must recover within one year after harvest*".

2. *Scales of effect* – obviously, the habitat protection objective must be applied at the appropriate scale. It is best assessed at the scale of tens of meters, while the management of the harvest itself is prosecuted at the bay wide scale or larger (management districts, sectors or sub-sectors). For example, eelgrass is abundant in northern New Brunswick estuaries. Most of these same bays have oyster aquaculture sites which do impact the eelgrass. Where eelgrass and oyster aquaculture infrastructure overlap, the eelgrass tends to disappear. The present management stance for this situation (including other aspects of oyster aquaculture) is to restrict oyster aquaculture infrastructure to about 10% of the available area in each bay. Note the use of 'bay scale' in that logic.

   For this assessment, there needs to be a threshold – a proportion of the total bay area in which the habitat protection objective has *not* been met – that indicates significant habitat loss at a landscape scale. Unfortunately, that threshold is not available. As a surrogate measure, this assessment will highlight the *intensity* of harvest at bay wide scales. If the available evidence indicates a very intense harvest at that scale over a number of years, it is assumed that an undesirable level of habitat loss at a landscape scale has occurred.

3. *Landings data source* – historically, DFO Science was involved in collecting landings data for various algal harvests in Nova Scotia and these data were published (several papers cited in this assessment). However, this past practice set up a situation where

DFO Science held data which were slightly different from that held by other groups within DFO. For consistencies sake, especially to conform to long standing practices concerning the gathering of data and subsequent Q&A procedures, this assessment will use official DFO data held outside of DFO Science. The term 'DFO's data holdings' will be used for these data.

ASSESSMENT

IRISH MOSS (*CHONDRUS CRISPUS*)

General Biology

Chondrus populations occur low in the intertidal and into the shallow subtidal. They consist of individual plants which are either gametophytic (male or female) or tetrasporic (a plant specialized for haploid spore release, to generate new gametophytes). These two types of thalli are difficult to distinguish in the field, and both are indiscriminately harvested. Fronds get more branched (bushy) as they age and can reach 12 to 13 cm length and up to six years old (Pringle and Mathieson 1987; Sharp et al. 1986). The holdfasts of individual plants coalesce over time, forming extensive red crusts on rock (Taylor et al. 1981). New blades (gametophytic or tetrasporic) grow up from these crusts as older blades are lost (via senescence, wave action or harvesting) (Tveter and Mathieson 1976). Hence, *Chondrus* beds tend to be perennial.

To the non-specialist, *Chondrus crispus* is quite difficult to distinguish from the red algal species *Mastocarpus stellatus* (Stackh.) Guiry. These two species often overlap in their distributions and a harvester could inadvertently be collecting more *Mastocarpus* than *Chondrus*. The harvest of *Mastocarpus* should be avoided, as the plants are not as common as *Chondrus* and their biology is different (e.g. 'petrocelis' tetrasporic phase for *Mastocarpus*).

Stock Status: Landings Data

The history of landings for Irish moss in Atlantic Canada is dominated by global economic forces (Chopin 1998). The initial harvests in Nova Scotia were driven by an emerging interest in carrageenan, a polysaccharide with gelling properties. As that economic interest has fluctuated, in particular with the development of harvest / culture of other species of red algal carrageenophytes in other parts of the world, so has the harvest of Canadian *Chondrus* (Chopin 1986). Until the early 1970s, *Chondrus* was the world's main source of carrageenans and eastern Canada provided 65-70% of the supply. By 1992, *Chondrus* represented only 3.8% of harvested carrageenophytes worldwide (Chopin 1998).

In effect, the landings data for Nova Scotian *Chondrus* reflect varying effort from year to year rather than major fluctuations in actual standing stock. Other factors, like Pringle and Sharp (1986) noting that landings could be lower in some years due to a lack of suitable daytime low tides, seem very minor in comparison to effort driven by economics.

The landings in D12, the main harvest area for Nova Scotia, reflect these facts (Figure 2). Landings for D11 are very small and sporadic, with only four years of landings for the period 1975 to 2009 and a peak harvest in 2006 of only 90 mt. Landings for D11 may change in the future, as there has been more interest in harvesting *Chondrus* in this area in recent years.

The data for Figure 2 came from DFO data holdings. Unfortunately, these only start in 1975, just before federal harvesting regulations came into effect (1978).

A recent problem has developed with the data set. The 2010 harvest season saw the introduction of voluntary landings data sheets to be filled out by individual harvesters. These data were incomplete but used as the official landings data for 2010. It is strongly recommended that DFO data holdings go back to its original method of obtaining *Chondrus* landings data from buyers' sales slips, and correct the landings data from 2010 onwards. *Without this correction DFO Science will no longer have the appropriate time trend landings data to assist in the assessment of the stock in the future*.

Chopin and Ugarte (2006) present the history of *Chondrus* landings in eastern Canada under four distinct periods from the 1940s to 2002. A fifth time period to cover the most recent landings of the harvest has been added here.

Landings Period I – 1940s to 1964

Pringle (1986) reports that hand raking of *Chondrus* in Nova Scotia began as early as the mid-1920s. Craigie and Shacklock (1995) state that Irish moss was first shipped from Atlantic Canada in 1940. They consider that date to be the beginning of Canada's Irish moss industry. The amount was 4.5 dry mt[1].

Pringle and Semple (1980) also note that *Chondrus* harvesting in Nova Scotia began in the early 1940s. Reliable landings data were recorded starting in 1947 (Pringle 1986).

Chopin and Ugarte (2006) describe this period as one of slow growth in demand and landings. Harvesters were responsible for drying their catch prior to delivery to buyers. DFO (1967) provides province wide landings data (probably mainly from D12) that average about 2300 metric wet tonnes per year from 1940 to 1949, and about 6000 metric wet tonnes per year from 1950 to 1959. These data compare relatively well with the figure of Nova Scotia landings in Chopin and Ugarte (2006), which begins in 1948.

Landings Period II – 1965 to 1975

Sharp and Roddick (1982) state that the harvest of *Chondrus* in D12 in Nova Scotia became an important harvest for the local economy in the 1960s. Ffrench (1972) noted explosive growth in the Canadian landings as a whole from 1965-1969.

This was a decade of increasing demand, and buyers began to accept wet landings dockside (which continues to the present day). It was a short lived bonanza period. Chopin and Ugarte (2006) indicate landings of between 10,000 to over 15,000 t over this period.

Landings Period III – 1976 to 1990

Chopin and Ugarte (2006) describe this as a slowdown period due to international competition. Figure 2 indicates this trend[2]. Lower demand caused the labour force in Nova Scotia to move over to other fisheries. Federal regulations were established to protect standing stocks.

Pringle and Semple (1980) examined harvest areas for *Chondrus* in southwestern Nova Scotia. They listed 61 commercial *Chondrus* beds being utilized by 650 harvesters.

Sharp and Roddick (1982) present a good example of effort driving landings rather than actual standing stock fluctuations. They present landings data for Irish moss in southwestern Nova Scotia (D12) for the period 1960-80. They noted that historical D12 landings were about 7,000 to 12,000 mt wet weight per year, but in 1980 the landings were only 5769 t – the lowest in 20 years.

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[1] Pringle et al. (1990) use a factor of 0.22 to convert from wet to dry weight for *Chondrus* in Prince Edward Island.

[2] Chopin and Ugarte (2006) show similar values and trends in their figure.

Although they state standing stock was down by 25% (one site, unpublished data), and mention that the reduced landings in 1980 were related to poor weather and fewer daytime low tides – other, far more important, reasons for the lower landings in 1980 were competition for labour from more lucrative fisheries, fewer harvesters and prices not keeping up with inflation (Sharp and Roddick 1982). These observations are echoed by the Canadian Atlantic Fisheries Scientific Advisory Committee (1981b).

Interestingly, the Canadian Atlantic Fisheries Scientific Advisory Committee (1981a) report that harvesters would reduce effort markedly when standing stock decreased below 1.0 $kg{\cdot}m^{-2}$, it not being economically worth their effort (at the time) to harvest such beds. Some southwestern beds were below that level just prior to the harvest season of 1980; presumably due to environmental conditions (the possibility of chronic overharvesting was not explored).

In 1983, the D12 situation was re-evaluated and the Canadian Atlantic Fisheries Scientific Advisory Committee (1983) concluded that reduced harvesting effort and a reduction in the number of daytime low tides were the major factors causing reduced landings during the period 1980 through 1982. In other words, the slightly reduced standing stocks were only a minor driver in causing the reduced landings.

Landings Period IV – 1991 to 2002

Chopin and Ugarte (2006) describe even lower landings during this time period mainly due to even more pronounced competition from tropical countries producing different grades of carrageenan. Some Nova Scotia harvesters moved over to raking *Ascophyllum*. A deterioration of *Chondrus* beds in Nova Scotia was reported with no clear causes (environment shifts, harvest practice).

Figure 2 shows landings of less than 2000 t annually for most of this period. Chopin and Ugarte (2006) also show low landings in this range, but their values don't quite match DFO's data holdings. Sharp et al. (2008) present landings from 1948 to 2004. They note a 20 year decline in landings starting in 1980. Once again, their values are slightly off from DFO's data holdings.

Landings Period V – 2003 to present

The year 2003 appeared to be a low point in landings of *Chondrus* (Figure 2), even lower than some of the initial years of the harvest in the 1940s. Since 2004, however, landings have increased again, often going over the 2000 tonne mark. These are increased landings over Period IV.

It should be noted that the carrageenan extracted from *Chondrus* does have some properties of special interest to industry (Chopin 1986; Chopin and Ugarte 2006). It is unlikely that the demand for Nova Scotian *Chondrus* will dry up completely.

Stock Status: Standing Stock Data

Air photo analysis has been used to estimate standing stocks of seaweeds in Nova Scotia on a number of occasions. In an early attempt, Cameron (1950) undertook an aerial survey of the Cape Sable Island region and produced a map showing the inshore areas with *Fucus* / *Chondrus.* No biomass estimates were made.

MacFarlane (1952) describes a detailed survey of commercial algal biomass in southwest Nova Scotia. She reported that the biomass of the *Chondrus* beds varied from 5.4 to 11.8 $kg{\cdot}m^{-2}$ (assumed to be wet weight)[3]. This is a very high biomass (see below) and MacFarlane noted

[3] Similar data are reported in MacFarlane (1953a).

that the commercial harvest of Irish moss beds in the area was just developing at the time (refer to D12 landings data above). She also stated that more pure stands of *Chondrus*, with less fouled thalli, were found on more exposed shores. This same observation can be made today.

Although there is some evidence that MacFarlane may have been selectively sampling high density beds, in the early 1970s biomass estimates for *Chondrus* in southwestern Nova Scotia were 5 to 12 $kg{\cdot}m^{-2}$ wet weight (Pringle and Mathieson 1987), similar to MacFarlane's estimate two decades earlier.

In 1974 and 1975, the Nova Scotia Research Foundation undertook Irish moss surveys in the area between Yarmouth and Shelburne (Haggerty and Hellenbrand 1976). They report a maximum standing stock of 1.49 $kg{\cdot}m^{-2}$ (wet weight) just below chart datum, with substantially reduced biomass at slightly greater depths. The plants in deeper water were mixed in with other species, while shallow water beds were more pure. Most of the *Chondrus* was found in the area below Wedgeport and Cape Sable Island. The authors commented on MacFarlane's 1952 survey in the same area and suggest that the much lower biomass in 1974/75 could indicate a deterioration of the beds, or that "a standing crop of this size is typical of regularly harvested Irish moss beds" (Haggerty and Hellenbrand 1976). The latter comment is a very important statement, as *Chondrus* was heavily harvested throughout this area during the 1970s, and no estimates of standing stock in later years (see below) ever approach the biomass seen by MacFarlane (1952) or Pringle and Mathieson (1987).

Pringle (1979) states that the average standing stock of *Chondrus* in the beds of Lobster Bay was 436 g dry weight$\cdot m^{-2}$. Pringle and Semple (1980) using transects near Pubnico, established that *Chondrus* was present from +3.5 m above chart datum to -10.5 m below. The highest biomass, approximately 1 kg wet weight$\cdot m^{-2}$, was found between +1.5 and -7.0 m depths. They calculated a standing stock of approximately 2871 mt along 17 km of shoreline in the area. Similar standing stocks were suggested for the Barrington and Wedgeport areas. Landings data suggested that much of the available *Chondrus* was being harvested for this area of southwestern Nova Scotia as a whole.

The Canadian Atlantic Fisheries Scientific Advisory Committee (1981a) report that test beds of *Chondrus* in southwest Nova Scotia declined in harvestable standing stock from 2.5 $kg{\cdot}m^{-2}$ in 1978 to 1.8$kg{\cdot}m^{-2}$ in 1980. They suspected the decline was related to environmental conditions, although long term harvesting of these beds may have also been an important factor (see above).

Pringle and Sharp (1986) consider the primary commercial biomass of *Chondrus* in southwest Nova Scotia resides between +1 to -2 m depths. They cite a total of about 1600 ha of shallow water beds in the area with at least 50% *Chondrus* cover.

Mann (1973) studied the shore of St. Margaret's Bay (western portion of D11) and reported an average *Chondrus* standing stock of 3.49 kg fresh weight$\cdot m^{-2}$. Sharp et al. (2008) also surveyed *Chondrus* standing stocks in the western portion of D11 and determined that the average biomass that could be raked with a standard 5 mm rake was 0.9±0.5 wet kg m^{-2}. They conservatively estimate a total harvestable biomass of just over 387 mt wet weight from Pennant Point (near Halifax) to Medway Harbour (border with D12), a coastline distance of 128 km. This is a much lower biomass per km than for the D12 Pubnico, Barrington and Wedgeport areas mentioned above, as would be expected due to different environmental conditions.

Stock Status: Harvest Methods, Timing and Intensity Affecting Standing Stock

As mentioned previously, human activities are the most important drivers affecting long term changes in standing stock. Hence, harvest methods, timing and intensity are of primary importance in maintaining the health of the stocks. As mentioned at the beginning of this document, federal regulations to control the harvest were not promulgated until 1978.

Hand Rake Harvest Method

Irish moss is traditionally harvested by hand raking from a small boat. Hand raking while standing on shore is not recommended, as *Chondrus* is sensitive to trampling (Fletcher and Frid 1996).

As mentioned above, hand raking of *Chondrus* started in Nova Scotia as early as the mid-1920s

(Pringle 1986). Sharp and Roddick (1982) state that from the beginning of the D12 *Chondrus* harvest, most of the harvest has been by hand rake from skiffs at suitable low tides.

Constance MacFarlane was a pioneer phycologist in Atlantic Canada, and a keen field naturalist with a good eye for assessing the stock status of seaweeds, particularly *Chondrus.* In 1971, she reported that in some of the best *Chondrus* beds in Nova Scotia, too much raking was occurring. In particular, the same bed would first be harvested (sometimes repeatedly) with a rake of one tine spacing, and then raked again with rakes of finer tine spacing. These latter rakes would remove small blades which should have been left alone for future growth, and tear up the perennial crust from whence new blades would normally grow. Other seaweeds would come into the areas denuded by the fine tined rakes (DFO 1971).

MacFarlane noted that rake damage of this sort was extensive in some areas of Pubnico and Seal Island. She suggested that it might take several years of no harvest for the beds to recover (DFO 1971). In the same year, she recommended that a standard rake of appropriate design and tine spacing be used for the *Chondrus* harvest (MacFarlane 1971).

In a published survey of hand rakes used in D12 in 1975, Pringle and Mathieson (1987) report a tine spacing of 3.18 to 12.70 mm. Environment Canada (1975) reports that testing had begun on rakes with various tine spacing at sites in Pubnico and Halifax County. Angled tines with 4 mm spacing at the base and 12 mm spacing at the tip seemed more satisfactory than tines of finer spacing, which removed fronds of different age sizes (i.e. loss of immature plants).

In his review of the *Chondrus* harvest in the Lobster Bay area, Pringle (1979) stated that the harvesters were using rakes with a tine spacing of only 3.5 mm, a very fine spacing which harvested a large proportion of immature plants. He recommended increasing the distance between the tines.

Pringle and Semple (1978) determined that hand rake tine spacing was often too small in Nova Scotia, allowing too many immature plants to be harvested. They recommended a tine spacing of 7 mm (DFO 1993).

Sharp and Roddick[4].state that tine spacing on *Chondrus* rakes in southwest Nova Scotia ranged from 3.5 to 12.5 mm, with tine length from 6.2 to 12.5 cm. They note that a minimum tine spacing of 5 mm existed in regulation at the time of publication

The Canadian Atlantic Fisheries Scientific Advisory Committee (1983) also note that the 5 mm tine space regulation was in effect in 1983. They report a study to examine the effects of tine

[4] G. Sharp and D. Roddick's unpublished CAFSAC working paper "The effect of rake design and harvest frequency on yield in *Chondrus* beds in southwestern Nova Scotia", 1994.

spacing, up to 14 mm, in Lobster Bay. They noted that sub-optimal sized fronds (immature) were harvested at a rate of about 5% with a 5 mm rake, but less than that for rakes of larger tine spacing.

Pringle and Sharp (1986) report on the use of 5 mm tine spaced rakes in Nova Scotia (and the banning of rakes with <5 mm spacing). The 5 mm rakes harvested 5% or less immature fronds (compared to about 26% with older, more closely spaced rakes). The 5 mm rakes were also selective harvesting tools, removing about 40% of the harvestable biomass while taking only 10% of all fronds present (i.e. selectively removing the larger, older fronds – a positive management measure).

Pringle and Sharp (1986) also provide data demonstrating that rakes with 5 mm tine spacing remove significantly more *Chondrus* than rakes with 8 or 11 mm spacing. No significant difference was noted between the 8 and 11 mm rakes.

Sharp et al. (1986) report that by using a 5 mm hand rake, a *Chondrus* frond is not fully recruited into the harvest until it reaches 6 cm in length and has more than five dichotomies in its branching pattern. That represents a Class IV, or relatively mature plant, in their five point classification scheme for *Chondrus* thalli – although they do note recruits to the harvest can originate from Class II plants.

Sharp (1987b) confirmed that when *Chondrus* beds are raked with 5 mm tine spaced rakes in Nova Scotia, primarily larger plants from size class III to V are removed – leaving behind many smaller class I and II plants which are crucial for regrowth. Also, only 11% of the fronds present in the bed are removed by raking, so subsequent harvests in the same season can successfully remove plants acquired by regrowth - although with lowered catch rates on later harvests.

The present marine plant regulations (established in 1989 under the *Atlantic Fishery Regulations* (1985)) specify a tine spacing of no less than 5 mm for the harvest of Irish moss in D12. The same minimum tine spacing is required in all other harvesting districts in Maritimes Region through licence conditions.

Drag Rake Harvest Method

Drag raking (pulling rake-like trawls along the bottom with motorized boats) is commonly used to harvest *Chondrus* in Prince Edward Island. MacFarlane noted that drag raking was introduced to southwestern Nova Scotia in 1967 (MacFarlane 1971). She considered drag raking to be unsuitable and detrimental to Irish moss beds in the area (DFO 1971).

A modified drake rake design was extensively tested in southwestern Nova Scotia in 1974 (Thorne 1974). In 1975, approximately 20 drag rakers were active from Pinkney Point to Cape Sable Island (Environment Canada 1976).

Some drag raking (about 10% of effort) was still used in D12 in the early 1980s (Sharp and Roddick 1982). At that time drag raking was restricted to those whom had used this method prior to 1977 (Sharp and Roddick 1980).

Sharp and Roddick (1980) noted that drag raking in southwest Nova Scotia was mainly used to reach deeper *Chondrus* beds, those inaccessible by hand rake. They investigated the impact of drag raking in Lobster Bay (15kg rakes, 1.7 cm tine spacing) and found that rocks could be over turned by the device, but on average only 0.6 to 4.8% of the bottom was disturbed - similar results are described in Pringle and Sharp (1980). Rather than banning the drag rake method, they suggested redesigning it or replacing it with a lower impact device. Until that was accomplished, they advised no further increase in drag raking effort (i.e. hold at about 11% of total effort).

Drag raking must have still existed in southwest Nova Scotia in the mid-1980s, as Pringle and Sharp (1986) still cite 10% of effort in the area as drag rake. Pringle and Mathieson (1987) have an illustration of a typical drag rake used in D12 at the time.

The present marine plant regulations ban drag rakes in some areas of Prince Edward Island, but not Nova Scotia. However, under current DFO Maritimes Region marine plants licence conditions, harvesting is only authorized using hand-held rakes or tongs.

Mechanical Harvest Methods

An experimental mechanical *Chondrus* harvester developed on Prince Edward Island was tested in Pubnico in 1972 (Environment Canada 1973). By 1973, it was decided that mechanical harvesters may not be an economically viable method to harvest *Chondrus* (Environment Canada 1974). Further mechanical designs and tests are mentioned in Environment Canada (1975) and Costa (unpublished report).

Another mechanical harvester was tested in southwestern Nova Scotia in 1981 (Pace 1982). Mechanical devices to harvest *Chondrus* in Nova Scotia are not reported in the literature again, and it is assumed that they were never used in the commercial harvest of *Chondrus* in Nova Scotia. Sharp et al. (2008) state that no reasonable economic method of mechanically harvesting *Chondrus* has developed over the history of the Nova Scotia harvest.

Timing of Harvest

Pringle and Sharp (1986) report seasonal peak growth for *Chondrus* in Nova Scotia in May and June. Prior to the existence of federal regulations, the province of Nova Scotia maintained harvest season limits in the Lobster Bay area (and other parts of what is now known as D12) via regulations under the provincial '*Irish Moss Act*' of 1967. The dates of the season were June 1 to November 30[5]. These dates were essentially the 'off season' for the local lobster fishery. The provincial regulations also allowed the harvest only by licence and specified that harvesting methods should not endanger or destroy the holdfast.

In 1971, MacFarlane reported that harvesting too early in the spring was "once again becoming rather common in southwestern Nova Scotia" (Appendix IV in DFO (1971)). This raises the question of how well the existing provincial regulations were being enforced.

Harvesting too early cuts short the spring pulse of spore release by the plants, limiting the re-establishment of beds by this mechanism. Scrosati et al. (1994) indicate that the time of most reproductive effort and successful spore germination for *Chondrus* in our part of the world is June through November. June is a peak month for this reproductive effort.

The Canadian Atlantic Fisheries Scientific Advisory Committee (1983) analyzed catch rates and growth rates in D12 and determined that "a single annual season, with an opening date delayed to early July, would allow for the largest annual yields to be harvested".

Since 1978, the harvest season opening for D11 has been July 1 (Pringle and Sharp 1986).The opening of the D12 harvest used to be June 7. However, since 2007, the D12 opening has been delayed by Variation Order each year until the third Monday in June. The opening dates are now more consistent with protecting the stocks during peak growth and reproduction. However, harvesters are still persistent in requesting earlier openings for D12 (Vandermeulen, personal observation).

[5] R. Ffrench's unpublished report to the Provincial Departments of Fisheries NS, NB and PEI and to the Department of Fisheries and Forestry Canada "A current appraisal of the Irish moss industry", 1970).

Although the harvest season for *Chondrus* in Nova Scotia is quite long (about five months), effort is high only during the first three to five weeks of the season. Effort drops steadily after week five (Pringle and Sharp 1986).

Intensity of Harvest

Some examples of overly intense harvests and bed damage are provided in the 'Hand Rake Harvest Method' section above. In a novel series of experimental treatments on the shore in southwest Nova Scotia, MacFarlane (1952) simulated different intensities of harvest. The results are worth repeating here:

1. Scraping to remove basal discs of *Chondrus*, one meter wide area – area damaged, still recovering after 20 months from treatment date.
2. Scraping to remove basal discs of *Chondrus*, narrower area – intense removal of holdfasts, successional stages of various ephemeral algae culminating in extensive barnacle cover for about a year, followed by *Fucus.* At the time of the completion of the study almost two years later, *Chondrus* had not grown back.
3. Shearing with sheep shears – area relatively undamaged, 18 months after treatment no notable difference from control site.
4. Raking thoroughly, but not injuring basal discs - area relatively undamaged, six months after treatment no notable difference from control site.
5. Over-raking with damage to basal discs, leaving patches of bare rock - area damaged, still recovering after 20 months from treatment date.

Note that over-raking produces long term damage (years to recover) similar to experimental scraping that focused on the removal of basal disks. Also, raking with care allows the standing stock to recover within six months.

In the mid-1960s, MacFarlane noted damage to *Chondrus* beds in Nova Scotia she attributed to overharvesting. Her comment was that the beds could not be harvested satisfactorily again until four years after their scraping (DFO 1967).

Pringle and Semple (1980) demonstrated that *Chondrus* plants in southwest Nova Scotia take about two years to become reproductively mature and estimated it would take about four years for a bare patch in a *Chondrus* bed to fill in with harvestable plants and five to ten years for *Chondrus* to re-establish in barren areas.

MacFarlane (1952) also reported a phenomenon which is important to this analysis, an alternate 'stable state' where *Chondrus* is lost to coralline algal cover via over-raking:

> *Other areas which were severely and 'badly' raked, removing whole clumps of plants with their basal adherent layer, are now becoming filled in with such forms as Corallina officinalis, Lithothamnion spp., Ahnfeltia plicata, Cystoclonium purpurea, and Chordaria flagelliformis. In such places gastropods have increased in number, consuming large quantities of Chondrus sporelings and further hindering the rehabilitation of the bed.*

The above statement is very important as it describes a fundamental change in the state of the shore created by overharvesting as early as 60 years ago, only a decade after the *Chondrus* harvest became firmly established in Nova Scotia. The first two species in her list, *Corallina* and *Lithothamnion,* are calcified red algae that are very resistant to grazing by herbivores such as limpets and snails. *Lithothamnion* in particular forms a thin pink crust that will last for years under heavy grazing pressure, while all other algae are eaten away. The other algal species in her statement, *Ahnfeltia* and *Cystoclonium,* are relatively tough wiry perennial red algae often found in tide pools. *Chordaria* is a more ephemeral annual brown alga that might be expected to colonize a bare patch of shore.

This change in species composition has been described a number of times since MacFarlane's original observation. She repeats it again in 1958, when she reported that the invasion of *Chondrus* beds by *Corallina* (which grows as calcified upright rod like shoots) was common in some areas of Nova Scotia (MacFarlane 1958).

In 1975, the observation was made again that if *Chondrus* is scraped or cut off to the extent that holdfast material is removed, *Corallina* may take over the rock surface (Environment Canada 1975). The author has heard harvesters call this 'pink' or 'chalk' rock, which they say grows in at sites that have been over-raked and persists for years afterwards. The harvesters also describe limpets on the chalk rock, consistent with MacFarlane's observations 60 years ago.

Stock Status: Environmental Effects on Standing Stock

A number of environmental factors may affect the standing stock of *Chondrus*. Ice scour events may cause short term harm to *Chondrus* beds. MacFarlane (1952) reports that the particularly harsh winter of 1947/48 destroyed *Chondrus* beds near Pubnico. By the next summer, the annual brown alga *Chordaria* had colonized the area, and by the summer of 1950, *Fucus* had taken over as the dominant successional stage. *Chondrus* did not noticeably start to grow back in the area until summer 1951, four years later.

A particularly harsh scour event on Nova Scotia's eastern shore in the later winter of 1960/61 led to the complete loss of plants in some areas by the summer of 1961 (Environment Canada 1974). By 1965 (four years later), the beds had grown back enough to sustain a commercial harvest.

Repeated freezing events on successive winter low tides will likely damage or kill *Chondrus* thalli, limiting the extent of bed cover higher up onshore (Dudgeon et al. 1989). *Chondrus* holdfasts appear to tolerate freezing, and offer a source of new blades the following spring. However, if the holdfasts are damaged (as can occur with excessive raking) obtaining new spring blades after winter freezing are less likely (Dudgeon et al. 1990).

If *Chondrus* is removed, the brown alga *Fucus* may establish itself (Keser and Larson 1984). This implies that overharvesting *Chondrus* may lead to its replacement by *Fucus*, at least over the short term (years).

Moore and Miller (1983) found that *Chondrus* occurred at a higher fraction of field stations without sea urchins than with sea urchins. Data in their publication implies that sea urchin grazing may reduce the depth penetration of a *Chondrus* bed, and could prevent some beds from establishing on more protected shorelines (Miller 1985). Further evidence that sea urchins may control the presence / absence of *Chondrus* on some shores is provided by Scheibling and Raymond (1990).

Boller and Carrington (2006) studied the hydrodynamics of wave drag forces on *Chondrus*. They discovered that the canopy created by many individuals growing close together on a shore actually reduced drag forces on individual plants by 15-65%. This suggests that the removal of that canopy by hand raking will make the remaining plants and those adjacent to the harvested patch, more susceptible to removal by wave induced drag forces. The effect is especially pronounced for larger, bushy thalli (Boller and Carrington 2006; Pratt and Johnson 2002). Larger bushy thalli (mature plants) may not survive more than one year under natural conditions in southwest Nova Scotia (Bhattacharya 1985).

Thomas (1978) provides evidence that *Chondrus* may be sensitive to oil spills in Nova Scotia.

Garbary et al. (2011) provide an interesting insight which may aid in assessing the stock status of *Chondrus* in Nova Scotia. They found that in normal healthy populations, gametophytes dominate the population structure by at least 3:1 over the tetrasporic phase. If this ratio is lower, it indicates a population which is recovering from disturbance. Craigie and Pringle (1978) surveyed relative tetrasporophyte / gametophyte abundance in four populations of *Chondrus* in Prince Edward Island and discovered that the site with a significantly higher proportion of tetrasporophytes was raked extensively by harvesters. There is a relatively simple chemical test to differentiate gametophytic from tetrasporic individuals in a population (Brown et al. 2004). Therefore, a rapid field survey could be performed to locate *Chondrus* beds recovering from the disturbance of excessive harvest activity.

ROCKWEED (*ASCOPHYLLUM NODOSUM*)

General Biology

Ascophyllum populations are mainly intertidal, but can occur in the subtidal to a depth of -6 m in southwest Nova Scotia (Sharp 1987a). Individual plants are diploid; there is no alternate life cycle phase. The plants produce specialized reproductive 'buds' (receptacles) which become fertile in May in Atlantic Canada (Lazo and Chapman 1996; MacFarlane 1932), although this can occur a month earlier or later depending upon site and year. An individual frond consists of one main axis with a dichotomous branching pattern, along with numerous side branches (Sharp 1987a). Along each of these, gas filled swellings called vesicles occur at regular intervals. In general, new vesicles are added on an annual basis, so a vesicle count along any particular axis or branch provides an indication of its age. Growth along each main branch of the frond is distal, and length increases by about 10 to 20 cm per year (MacFarlane 1932; Sharp and Semple 1997). Growth rates are mediated, in part, by genetic differences in different populations (Stromgren 1986).

Ascophyllum fronds are relatively long lived (part of the reason why they outcompete *Fucus* species on many shores) and can reach 5-15 years of age (DFO 1998; Sharp 1987a). Large bushy plants can be over 700 g wet weight and more than 140 cm long (Ugarte et al. 2006). Although the plants are large, the vesicles allow them to float upright on high tides. Plants from exposed sites tend to be shorter and more bushy than plants from more sheltered sites (Sharp 1987a).

Like *Chondrus*, *Ascophyllum* thalli have holdfasts to attach to rocky substrates, although the holdfasts do not coalesce to the same extent as *Chondrus* holdfasts. These holdfasts can be very long lived, exceeding 40 years (DFO 1998) and be up to 7 cm in diameter (Baardseth 1955). If an *Ascophyllum* frond is cut off or lost due to wave action (or ice), new fronds can grow up from the remnant holdfast. This fact is exploited by the practice of cutting *Ascophyllum* during harvest such that a stub, and the holdfast, is left behind for regeneration.

Ascophyllum is unique in Atlantic Canada due to the fact that when it is present, it tends to dominate the intertidal of the coastline it occupies, often for many kilometers. Due to the habit and vegetative growth patterns mentioned above, rockweed beds are perennial and consistent coastal habitat features. *Ascophyllum* is most abundant in southwest Nova Scotia up to around the south shore, and tends to get less abundant along the eastern shore and northwards – probably due to increasing ice and wave exposure (Cousens 1986). Some beds do occur in Cape Breton (Cousens 1984).

The abundance of *Ascophyllum* in the intertidal indicates its relative importance as a primary producer at bay wide scales (Keser et al. 2005). In his evaluation of Cobscook Bay in Maine, Campbell (2004) calculated that benthic diatoms were far more important than phytoplankton as primary producers on a bay wide scale. Also, fucoid algae (dominated by *Ascophyllum*) fixed approximately the same amount of carbon on an annual basis as phytoplankton. Overall, *Ascophyllum* accounted for approximately 17% of the annual primary production in the bay. This value is quite extraordinary when one considers that the 'footprint' of *Ascophyllum* was only about 9% of the total area of the bay (Campbell 2004). The footprint for phytoplankton in the bay was approximately 10 times greater.

The fate of *Ascophyllum* biomass is also important on bay wide scales. Campbell (2004) determined that approximately 33% of total primary production in Cobscook Bay was exported as detritus, and a large portion of that may be of macroalgal origin (dominated by *Ascophyllum*). In a more detailed analysis, Vadas et al. (2004) determined that about 60% of the standing stock of *Ascophyllum* in Cobscook Bay was turned into detrital particles each year, a biomass of about four million grams of carbon. They concluded that fuciods like *Ascophyllum* were important, if not critical, to the productivity and energy flow in Cobscook Bay. Moreover, a large portion of that carbon moved through detrital pathways and this material may have played a large role in the secondary productivity of filter feeders in the bay such as scallops and soft shelled clams[6].

In another bay scale study, Josselyn and Mathieson (1978) calculated that the detrital pool created just by the dehiscence of *Ascophyllum* receptacles each spring amounted to 140 mt per year for the Great Bay Estuary System of New Hampshire and Maine. The decomposition rate of this material was rapid and provided about 4.6 t of nitrogen annually to the Great Bay Estuary System, an amount that could be significant to sheltered inlets within the system. Josselyn and Mathieson (1980) concluded that seaweeds (primarily *Ascophyllum*) "…comprise a major autochthonous input to the estuarine detrital pool of the Great Bay Estuary System and their total contribution exceeds that estimated by a comparison of abundance alone"[7].

Moreover, *Ascophyllum* is important habitat for fish, invertebrates and birds – some of which have direct commercial value (Black and Miller 1986; Black and Miller 1991; Black and Miller 1994; Canadian Atlantic Fisheries Scientific Advisory Committee 1993; Capone et al. 2008; Chadwick 1999; Colmen, 1940; Jorde and Ray 1988; Mann 1992; Minot 1980; Pavia et al. 1999; Rangeley 1994a; Rangeley 1994b; Rangeley and Kramer 1995; Rangely and Kramer 1998; Rangeley and Davies 2000; Seeley and Schlesinger 2012; Schmidt et al. 2011; Sharp et al. 2006; Thompson et al. 2002).

Kelly et al. (2001) report that harvesting *Ascophyllum* may lead to a significant reduction in associated sessile animals such as sponges and bryozoans. However, they were not able to discern an impact upon fish and large mobile epifauna. By-catch of *Littorina* does occur with the harvest of *Ascophyllum*, but the impact appears to be minor (Sharp et al. 1998). Seeley and Schlesinger (2012) list other by-catch species.

Particular care must be exercised to preserve the habitat value of *Ascophyllum* beds in the face of commercial harvest (DFO 1999; Sharp et al. 2006; Seeley and Schlesinger 2012). The habitat protection objective needs to be assessed for the rockweed harvest (see below).

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[6] Scallops will feed on brown algal detritus when phytoplankton populations are reduced (Seeley and Schlesinger 2012).

[7] Bradford (1989) calculated that detrital material from *Ascophyllum* represented 7.3% of the primary productivity of Passamaquoddy Bay.

Stock Status: Landings Data

Ascophyllum is harvested in Nova Scotia for animal fodder, fertilizers and other specialty products. In the early years, the polysaccharide alginic acid was an important extract. The harvest has been focused on southwest Nova Scotia (particularly Lobster Bay), and according to Sharp (1981) and Sharp (1987a) it began in 1959. Limited quantities were harvested as early as 1953 (MacFarlane1953b).

Since 1959, the *Sea Plants Harvesting Act* of Nova Scotia has made provision for exclusive licences for designated portions of the shoreline (Sharp et al. 1995). The licences gave a monopoly on the *Ascophyllum* resource to specific companies. Since the federal regulations came into effect (1978), federal harvesting rules apply, but the provincial licences and associated lease areas still exist (DFO 1998). The boundaries of the present lease areas are presented in Figure 3.

DFO has recently decided that it does not have full regulatory jurisdiction in these provincial lease areas. It is uncertain what DFO's role will be in these areas in the future, including the provision of scientific advice for the harvest. However, not all portions of the provincial shoreline are leased, and DFO continues to have full regulatory authority for the *Ascophyllum* harvest in unleased areas. For example, a small *Ascophyllum* harvest began on the eastern shore (east of Halifax) in 1992. This area is not controlled by provincial lease (DFO 1998).

As for *Chondrus*, the landings data for *Ascophyllum* reflect varying effort (market changes, mechanization) from year to year rather than major fluctuations in actual standing stock. DFO's data holdings for landings in D12 are shown in Figure 4; D11 landings in Figure 5. As for *Chondrus*, the D12 landings dominate. DFO's data holdings for *Ascophyllum* start in 1977 for D12, just prior to the establishment of the federal regulations in 1978. The harvest had established itself long before that (see below).

Similar to *Chondrus*, the landings history for *Ascophyllum* has been divided up into different periods by different authors. A summary is provided below.

Landings Period I – 1959 to 1971

Chopin (1998) and Chopin and Ugarte (2006) assert that this period began in 1959. They describe walk on cutting with knives or sickles at low tides; or harvesting from a boat with a toothed rake which eventually developed into a cutter rake with a sharp blade. Landings were stable but low. Chopin and Ugarte (2006) indicate landings around 5,000 wet tonnes per year for part of this time period. Sharp and Semple (1991) provide more detailed data indicating landings were frequently over 6,000 wet tonnes; Ugarte and Sharp (2012) present similar data. DFO (1998) consider this time period to be a development phase.

Landings Period II – 1972 to 1985

Chopin (1998) notes that this is the period when the use of 'Aqua Marine' mechanical harvesters by Scotia Marine Products Ltd. largely replaced hand-cutting (see 'Mechanical harvest' section below). Demand did not increase substantially so landings were similar to Period I. DFO (1998) saw this as the mechanization of the harvest with stable landings. DFO (1998) indicates average annual landings of about 5,000 t during this time period, with slightly higher landings in the earlier years. Sharp and Semple (1991) provide more detailed, but similar data. These values are also similar to those presented by Chopin and Ugarte (2006) and Ugarte and Sharp (2012).

Landings Period III – 1986 to 1992

Chopin (1998) records this as the period when a new corporate entity was formed, Pronova Biopolymers Ltd., which introduced a more efficient Norwegian suction cutter. Two more buyers also came on the scene and landings increased greatly. Recruitment overharvesting became a concern and the province redrew leased boundaries and added to the overall area under provincial lease. DFO (1998) describes this as a sharp expansion period, and show landings data similar to Figure 4. Chopin and Ugarte (2006) and Ugarte and Sharp (2012) show the same trend, but some of the values are not quite the same as the DFO data holdings shown in Figure 4.

Landings Period IV – 1993 to 2004

Chopin (1998) marks this period as a reversion to hand harvesting methods. Initially, landings dropped slightly from Period III. A triennial harvest pattern was established where beds were harvested at a 50% rate and then left fallow for three years. Pronova ceased operations in 1995. Harvesting in New Brunswick began in 1995 (Chopin 1998). Landings gradually increased throughout this period, reaching Period III levels by 2000 (Chopin and Ugarte 2006). Once again, Chopin and Ugarte (2006) and Ugarte and Sharp (2012) show the same trend in landings as Figure 4, but the numbers are slightly different – this could be because they present landings for all of Nova Scotia, not just D12. However, landings from the only other main harvest area (D11) are trivial in comparison.

Recent Landings – 2005 to Present

The hand rake harvest continues in Nova Scotia and landings peak at values even higher than that seen in Period III, in part due to expansion of harvest into new areas (Figure 4). Again, the data presented by Ugarte and Sharp (2012) do not match DFO's data holdings in Figure 4. The pressure on the *Ascophyllum* resource has reached an historical high and a harvest begins in Maine to supply the Canadian demand. The New Brunswick harvest continues at near capacity based upon a 17% harvest rate of accessible biomass (Vandermeulen, personal observation).

Stock Status: Standing Stock Data

MacFarlane (1952) provides one of the earliest estimates of standing stock for Nova Scotia, approximately 20 wet kg m^{-2} of *Ascophyllum* in the Yarmouth – Shelburne area with a peak of about 32 wet kg m^{-2} in the Mutton Islands and Tusket Wedge. These are historically high values which are not reported later on and may be due in part to MacFarlane's method of selecting the very best sites for biomass estimates, rather than more broadly representative sites. The plants were also frequently 180 to 210 cm long and up to 300 cm long (MacFarlane 1952). Environment Canada (1971) reported standing stocks of *Ascophyllum* in Shelburne and Yarmouth counties of approximately 7.5 to 22.5 wet kg m^{-2}.

Sharp (1981) recorded maximum standing crops of about 12 wet kg m^{-2} in the Lobster Bay area in the 1970s. Air photo analysis was used by Sharp and Carter (1986) to map some *Ascophyllum* beds in southwest Nova Scotia. No biomass estimates were made.

Sharp and Tremblay (1989) provide a figure indicating 380 t wet weight per km in the Lobster Bay area, 94 t wet weight per km along the south shore, and 59 t wet weight *Ascophyllum* per km on the eastern shore.

Sharp and Semple (1991) performed a stock assessment in southwest Nova Scotia using remote sensing and ground truthing. They provide data for Tusket / Wedgeport indicating a range of *Ascophyllum* biomass of about 4 to 17 wet kg m^{-2}. Annapolis Basin had an average biomass of 7 wet kg m^{-2} and some 'southern' sites (Baccaro, Shelburne, etc.) ranged between 4 to 18 wet kg m^{-2}.

DFO (1998) noted that the last comprehensive survey of *Ascophyllum* standing stocks in Nova Scotia was performed in 1988 via remote sensing (probably referring to Sharp and Semple (1991)). The province uses these numbers to the present day. DFO (1998) cites a biomass of about 8 to 12 wet kg m^{-2} in Lobster Bay. The standing stock on the south shore (a less harvested area) was about 5 to 9 wet kg m^{-2}.

More recently, *Ascophyllum* standing stock data has been presented by Ugarte et al. (2010). It is not certain how these numbers were generated or when the assessments were made:

1. Annapolis Basin – 35 hectares with a standing stock of 998 wet tonnes.
2. St. Mary's Bay – 93 hectares with a standing stock of 9,031 wet tonnes.
3. Lobster Bay – 1073 hectares with a standing stock of 91,758 wet tonnes.
4. South Shore – 677 hectares with a standing stock of 42,125 wet tonnes.
5. Eastern Shore - 1250 hectares with a standing stock of 50,000 wet tonnes.

Stock Status: Harvest Methods, Timing and Intensity Affecting Standing Stock

As noted for *Chondrus*, human activities are the most important drivers affecting long term changes in standing stock for *Ascophyllum*. Hence, harvest methods, timing and intensity are of primary importance in maintaining the health of the stocks.

Hand Rake Harvest Method

The *Ascophyllum* harvest began in Nova Scotia in 1959, and for the first decade of the harvest, scythes or sickles were used to collect the plants. By the early 1970s a mechanical harvest had begun (Sharp 1981; see below).

The hand rake harvest was never completely abandoned, however, and the early sickles or knives were eventually replaced by a cutter rake design with widely spaced tines backed by a cutting blade (Sharp 1987a). By 1994, the mechanical harvest had ceased and the hand rake harvest took over (Ugarte and Sharp 2001).

At the present time, hand harvesting by rake from small vessels is used for almost all of the harvest. Fletcher and Frid (1996) mention that *Ascophyllum* can be sensitive to trampling, suggesting that a hand rake harvest from shore should be discouraged.

Early on in the hand rake harvest, the province of Nova Scotia recognized the need for a standardized cutting height to protect the *Ascophyllum* resource. The *Nova Scotia Sea Plants Harvesting Act* specified a 5 inch (127 mm) cutting height for *Ascophyllum* (Environment Canada 1971). Years later, Environment Canada (1971) recommended 10 inches (25.4 cm) as a minimum cutting length[8].

However, the 1971 recommendation was ignored by DFO and the provincial five inch cutting height was adopted directly by the marine plant provisions of the federal *Atlantic Fishery Regulations,* which specify that a cutting action must be used in the harvest of *Ascophyllum* and the cut must be at least 127 mm above the holdfast. Modern rakes are designed with a built

[8] Interestingly, Boney (1965) records a personal communication with Constance MacFarlane that a 20 to 25 cm cutting height had been recommended for Nova Scotia.

in guard to prevent cutting shorter than 127 mm. The cutting action of a hand rake usually just removes the upper portions of the thalli, so more than 127 mm will be left behind.

The origin of the 5 inch cutting height is not clear and its value as a conservation tool is uncertain. For example, remnant *Ascophyllum* stubs of 127 mm height may not be able to regrow to any extent (Lazo and Chapman 1996). This observation was made as early as 1955, where Printz (1955) determined that close crop sickle harvesting of *Ascophyllum* showed no recovery even after several years. The short (a few centimeters in length) stubs left behind ultimately vanished.

It appears that if *Ascophyllum* is cut leaving a significant length of thallus behind (about 20 cm), survivorship can be about 75% (similar to uncut controls) independent of the intensity of the harvest (Lazo and Chapman 1996). However, this may not always be the case, and *Ascophyllum* cut to 15 or 25 cm may experience considerable mortality if not many growing points (apical or lateral) are left behind (Keser et al. 1981).

Printz (1955) carried out a harvesting experiment in the summer of 1952 where stubs of 5, 15 and 25 cm were observed after harvest. After two years, the 5 cm stubs stood unaltered, the 15 cm stubs showed some recovery, and the 25 cm stubs “gave the impression of being almost completely restored”. He noted that stubs will only recuperate or regrow if the apex (where the meristematic tissue resides) is left unharmed by the harvest.

In a following publication, Printz (1959) responded to observations in Norway that indicated areas with heavy *Ascophyllum* exploitation were not recovering. He noted that “In many localities it is already common to find beaches denuded of seaweed where the anticipated regrowth has failed to appear”. He also provided more details on the results of his 1952 experiment. The 25 cm stubs had produced new lateral shoots within one year, after two years the plants were about 40 cm in height and abundantly branched. He reiterated the fact that the 15 cm stubs had less satisfactory recovery, while the 5 cm stumps had not recovered even three years later.

Keser et al. (1981) ran a very similar experiment to Printz by experimentally harvesting *Ascophyllum* at different intensities, leaving stumps of zero (holdfast only),15 or 25 cm in length. The biomass of *Fucus vesiculosus* increased in areas where successive harvests of *Ascophyllum* were made to the holdfast level. Three successive annual harvests leaving 15 or 25 cm behind also yielded successively lower biomasses of *Ascophyllum*. This last result is corroborated by Sharp and Pringle (1990).

Mechanical Harvest Methods

A variety of mechanical harvesters have been used on *Ascophyllum* beds in southwest Nova Scotia over the years. Ang et al. (1993) note that a modified aquatic weed harvester[9] was first introduced in 1971, and later replaced by a more efficient Norwegian suction / cutter harvester in 1985[10]. Chopin and Ugarte (2006) have pictures of these harvesters in action.

Sharp (1981) calls the first mechanical harvester the ‘Aqua Marine’ harvester. By 1975/76, four Aqua Marine harvesters accounted for 80-90% of the harvest. In his evaluation of the hand harvest versus Aqua Marine harvest in the Lobster Bay area, Sharp (1981) noted that the mean cutting height of the mechanical harvester was about 35 cm.

[9] Commonly used in Canada to harvest nuisance accumulations of aquatic macrophytes in lakes and rivers.

[10] Descriptions of the design and operation of the mechanical harvesters can be found in Sharp (1987a).

The hand harvest averaged about 16% by weight of thalli with holdfasts attached (i.e. whole plants removed, mortality), while the mechanical harvest averaged about 2% (Sharp 1981). The issue of removing whole plants, plants with holdfasts attached, is an important one. If the entire plant with holdfast is removed, there is no chance for vegetative regeneration and the *Ascophyllum* bed will need to recover the loss of that thallus via diploid spore (zygote) settlement from other plants in the area with subsequent survival and growth – this is not a reliable source of new recruits to the harvest in the short term. The chances of a zygote surviving at all are very low, with the odds very much against the production of mature thalli from that zygote. Zygote based production of recruits for the harvest is unreliable and takes years, while vegetative regrowth is more certain and can occur under shorter time scales.

Careful consideration of whole thallus loss as a source of mortality is important in the management of an *Ascophyllum* harvest (Chadwick 1999). The rate of holdfast removal in the Nova Scotia harvest of *Ascophyllum* is controlled federally through the *Atlantic Fishery Regulations* (1985), which prohibit the possession of any rockweed plant to which the holdfast is attached. However, in lease areas, the *Nova Scotia Fisheries and Coastal Resources Act* of 1996 allows up to 15% holdfast content in landings of *Ascophyllum* by weight.

The presence of holdfasts in landings is dependent upon the type of substrate the plants are growing on and the quality of the cutting rakes used for harvest. If the substrate is friable, *Ascophyllum* thalli will be easily pulled off and holdfast content in the landings will go up. Dull cutting blades on rakes will pull rather than cut, and the holdfast incidence will go up in harvested plants. The 15% value is not particularly conservative, as on a firm substrate with well-maintained sharp knives it should be possible to routinely have less than 7% holdfast incidence by weight in landings (Vandermeulen, personal observation). Intuitively, one would expect higher holdfast content in the harvest from a powerful mechanical device over a human being with a rake (see below).

Sharp (1987a) commented on the early years of the first aquatic weed harvester and noted that once an area was harvested, it was re-harvested once the plants had grown back sufficiently. This could be as long as three years or as short as one year. He evaluated both harvesters and found the mean cutting height of the aquatic weed (Aqua Marine) harvester was about 35 cm above the holdfast, while the suction harvester cut at about 29 cm above the holdfast[11].

Ang et al. (1993) evaluated the Norwegian harvester at Pubnico Point and found that tagged shoots in harvested quadrats suffered a 42% mortality (i.e. entire plants with holdfasts removed) compared to 11% in control sites. This was a much higher rate of mortality than that recorded for the Aqua Marine harvester (above).

Mechanical harvesters were also used in Shelburne Bay (the south shore) in 1990 (Sharp and Semple 1997). By 1994, mechanical harvesters had ceased to operate in Nova Scotia (Ugarte and Sharp 2001). However, in 2010 and 2011 a suction type mechanical harvester was tested in an area just west of Halifax (Seeley and Schlesinger 2012). It is uncertain if this machine will be applied to a full commercial harvest.

Timing of Harvest

Lazo and Chapman (1996) report that *Ascophyllum* was harvested year-round in southwestern Nova Scotia at the time. Sharp (1987a) noted that mechanical harvesters in the area operated

[11] Kelly et al. (2001) assessed a suction type mechanical harvester in Ireland and noted the harvester left *Ascophyllum* plants with a length of about 50 cm.

seven to nine months of the year. There is no regulated closed time for the *Ascophyllum* harvest in Nova Scotia.

Intensity of Harvest

Thomas (1994) performed clearing experiments in the Bay of Fundy at Musquash Head by scraping, brushing and then sterilizing a 5 m wide band of shore running from the top of the intertidal zone to the bottom of the mid-littoral in 1979. The area was then surveyed on at least an annual basis until 1988. Normally, *Ascophyllum* dominated on this shore from just above the low tide mark through most of the mid-intertidal zone, with *Chondrus* dominating the low water mark and *Fucus vesiculosus* dominating the upper half of the intertidal. After the clearing exercise, *Ascophyllum* did not return - it was replaced by *Fucus* species (primarily *F. vesiculosus*) for the decade of the observations. Similar results were reported by an *Ascophyllum* removal experiment in England with observations spanning 12 years (Jenkins et al. 2004).[12]

In a shorter term *Ascophyllum* removal experiment (four years of observations), Cervin et al. (2004) also observed *Fucus* invading denuded areas, although they observed some evidence of recruitment of *Ascophyllum* back into denuded areas over time. The recruitment appeared to be independent of the presence of herbivores. Compare this to the results of Keser et al. (1981), whom discovered that high densities of *Littorina littorea* corresponded with poor recovery of *Ascophyllum* after intensive harvest (scraped plots).

Kelly et al. (2001) monitored an intensive (approximately 70% cover reduced to 30%) hand cut harvest of *Ascophyllum* in Ireland and noted a significant increase in *Fucus vesiculosus* abundance in the area after the harvest.

It is clear from the above observations that bed destruction or an overharvest of *Ascophyllum* at any one particular site may take years to recover back to a commercially viable standing stock[13]. In the meantime, the original fish habitat value of the *Ascophyllum* bed has been reduced or lost altogether and the habitat protection objective not met (see 'background' section of this document).

There is strong evidence indicating that *Ascophyllum* has been routinely heavily harvested in southwest Nova Scotia at bay wide scales, even well before the purported beginning of the harvest in 1959[14]. As early as 1952, MacFarlane (1952) noted that *Fucus vesiculosus* would invade overharvested areas in Nova Scotia, and that "under present harvesting conditions it requires at least three years before full recovery of a harvested *Ascophyllum* area". In other words, from the very beginning of the *Ascophyllum* harvest in Nova Scotia, harvesters were employing the old European style of harvest for *Ascophyllum* – completely denuding an area and then waiting three years (or more) for it to grow back[15] (Canadian Atlantic Fisheries

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[12] In Iceland, *Ascophyllum* took seven to eight years to recover from a removal experiment and associated understory algae had not recovered even 20 years later (Ingolfsson and Hawkins 2008).

[13] Baardseth (1970) in his major review of *Ascophyllum* biology noted that a harvest obtained by scraping the rocks ruins the beds for many years. Even cutting to leave stumps behind still often took three to six years before the beds could be harvested again.

[14] Sharp (1987a) mentions overharvesting with hand cutting methods in southwest Nova Scotia in the early years of the industry.

[15] Hession et al. (1998) indicate that this remains the modern practice in Ireland. The plants are harvested, and then three, four or more years must pass before they can be harvested again. Eschmann and Stengel (2011) state that recovery of *Ascophyllum* after this style of harvest in Ireland is very slow and "that full biomass recovery is not ensured by the current practice of tri-annual harvesting regimes".

Scientific Advisory Committee 1993). Chopin (1998) states that a triennial harvest pattern, 50% removal and then a three year fallow period, was firmly established in Nova Scotia in the 1990s. All of this evidence indicates an undesirable level of habitat loss at a landscape scale.

In a consultant's report to the then Nova Scotia Department of Fisheries Cunningham (1990) describes the results of field observations in southwest Nova Scotia in the summer of 1990. He describes numerous instances of overharvesting *Ascophyllum* at a bay wide scale – all indicating an undesirable level of habitat loss at a landscape scale. Here are some examples:

- Goat Island and Vicinity – "…recently harvested and there was no weed left."
- Thornes Cove – "The beds at this cove and nearby were completely depleted."
- Bear Island – "Examining several beds in the Deep Brook area we found them all harvested with the exception of a few small patches. Very little biomass is left behind, perhaps less than 2%".
- Pinkney's Point – "At present it would be very difficult to harvest any Asco in an economical manner."
- Inner Spectacle Island – "…has been really overharvested."
- Murder Island – "…has been severely harvested…"
- East side of Goose Bay – "…very heavily harvested…"
- Tusket River, western shore – "The whole area has been heavily harvested during the past several years…"
- The Tittle – "Most of the usual places were so harvested that the weed was too short to bother with."
- Rocko Point and Abram's River – "There is little of value to count as available weed at this point."
- Etoile Island – "The island has been heavily harvested…"
- Pubnico Harbour western shore – "Very little Asco available."
- Goodwins Island, Solomons Island, Egg Island, Vigneau Island – "The harvest has been heavy and complete…"
- Port Latour – "…heavily harvested…"

Environment Canada (1971) report that on Cape Sable island some of the best *Ascophyllum* beds in the province were seriously depleted in the mid-1950s when a large number of plants were removed, holdfast and all, by pulling with Irish moss rakes.

In another example of intense harvest, Sharp (1987a) described the practice of mechanically harvesting a population at a site, and then returning one to three years later and re-harvesting if the population had appeared to recover from the first harvest. Environment Canada (1973) indicate that full recovery after a harvest with the Aqua Marine mechanical harvester took four years.

Historically then, from the first rake harvests through to mechanization, the management regime routinely allowed an intense harvest of *Ascophyllum* on many shores in southwest Nova Scotia which took years to recover. The evidence strongly indicates that this took place at bay-wide scales, suggesting that an undesirable level of habitat loss had occurred at a landscape scale.

Sharp (1981 and 1987a) also noted that mechanical harvesters leave a remnant biomass of 40% - that is a very high rate of removal of available biomass (60%). Sharp and Semple (1991) calculated that mechanical harvesters in Lobster Bay removed 53 to 63% of the crop.

A particularly egregious example of overharvesting in Nova Scotia is the case of Annapolis Basin (DFO 1998). The *Ascophyllum* harvest began here in the 1960s using sickles while walking on shore – a practice that remains to the present day. Although the sickle method leaves a stump of about 20 cm in length (compared to the regulation of 12.7 cm), the practice of harvesting while walking on shore at a low tide can lead to a very intense harvest. Almost every plant can be seen and accessed for cutting by this method, as compared to a harvest by boat with a hand rake (now used everywhere else in Nova Scotia) where not all plants can be seen and the action of the rake is far less efficient at removing biomass.

Severe overharvesting was noted in Annapolis Basin between 1988 and 1991 - about 80 to 90% harvest rate, or more (Sharp and Semple 1991), prompting a full closure of the basin in 1995 (DFO 1998). The closure is further evidence that an undesirable level of habitat loss had occurred at a landscape scale.

The closure has since been lifted, but a harvest rate of about 50% remained in the 1990s (DFO 1998). Presently, the walk on harvest in Annapolis Basin has an exploitation rate of 60 – 80% with a fallow period of three to four years (Ugarte and Sharp 2012). If *Ascophyllum* is harvested at a rate of 50% or more, the recovery time until the next viable harvest is three to five years (DFO 1998). All of this indicates that there is still an undesirable level of habitat loss at a landscape scale in Annapolis Basin. The Annapolis harvest is run by provincial lease[16].

In New Brunswick, the potential for overharvest was recognized, and when provincial and federal agencies jointly established the *Ascophyllum* harvest there in the early 1990s they set an area based harvest limit of 17% of standing stock. The 17% limit allows the New Brunswick harvest to reduce the potential for intense harvest and the associated loss of habitat protection at a landscape scale. However, even with an overarching 17% 'rule', Ugarte et al. (2006) admit that local patches of *Ascophyllum* may be harvested at a rate of up to 50%.

Ugarte et al. (2006) attempted to address the potential habitat impacts of a local 50% patch harvest by emulating this removal rate in the field with a standard cutter rake. They found the rake gear rarely impacted *Ascophyllum* clumps below 50 g or 60 cm in length. Clumps larger than 300 g and 130 cm were reduced by up to 55% of their length and 78% of their biomass. The loss of the upper portions of the tallest plants is significant, as most of the biomass is found in the distal portions of the plants (clumps). They state that these structural (habitat) canopy changes were short lived, as biomass recovered one year after the harvest.

However, their conclusion of short term canopy changes is flawed as the new biomass they refer to came mainly from growth and branching of shorter shoots near the base of the main portions of the plant[17]. Only one of their harvested plots regained its average pre–harvest clump length after one year. The other two harvested plots did not regain their pre-harvest length even two years later (Ugarte et al. 2006). In other words, the regrowth to pre-harvest biomass after

[16] A similar overharvest from 'walk on harvesting' occurred in nearby St. Mary's Bay in the same time period (Sharp and Semple 1997).

[17] Baardseth (1970) has a particularly good figure illustrating this phenomenon.

one year was simply a production of shorter bushy plants[18], rather than a recovery of the original elongated canopy with most of its biomass in the upper portions of the canopy.[19,20]

The origin of the New Brunswick 17% harvest rate is also somewhat flawed. It came about as a back of the envelope calculation based upon the observation that an Ascophyllum bed hit by a 50% harvest rate may take about three years to recover (Sharp and Semple 1992). Therefore, 50÷3=16.7 and it was assumed a 17% annual harvest could recover within one year (Seeley and Schlesinger 2012). The 17% annual harvest rate is considered to be excessive by Seeley and Schlesinger (2012), whom present a case against it based upon net primary production.

Even the limited protection of the 17% 'rule' does not exist in Nova Scotia, where the present hand rake harvest routinely takes 20 to 30% of standing stock (Sharp and Semple 1991; Sharp and Semple 1997; DFO 1998) or, in the case of Annapolis Basin, even more. Sharp (1987a) states that overharvesting by hand did occur even in the early years of the D12 harvest.

Sharp and Tremblay (1989) imply that overharvesting was a long standing chronic problem when they state that the reasons for their assessment of Ascophyllum resources in Nova Scotia include "...local problems with 'overharvesting' and a general breakdown in normal harvesting strategies." Sharp et al. (1995) note that "Exploitation rates above 20% are possible and can lead to a slow but steady decline in the productive capacity of the resource". Also, Ugarte and Sharp (2012) state that once the Ascophyllum exploitation rate goes above 35%, a pulse harvest strategy is required (i.e. the beds must be left fallow between harvests).

Stock Status: Environmental Effects on Standing Stock

Although *Littorina littorea* does not consume *Ascophyllum*, the movements of this common snail may dislodge juvenile plants to a significant extent (Watson and Norton 1985). Another species in this genus, *Littorina obtusata,* is a known herbivore of *Ascophyllum* (Borell et al. 2004; Coleman et al. 2007). Grazing damage from this snail, in the form of open wounds on the thalli, can be extensive (Sharp 1981). Intensive hand harvesting of *Ascophyllum* may reduce the abundance of *Littorina obtusata* (Kelly et al. 2001).

Grazing damage increases the probability of breakage in *Ascophyllum* thalli (Toth and Pavia 2006), especially for shorter fronds (Viejo and Aberg 2003). This suggests that cutting *Ascophyllum* short for harvest may increase the loss of fronds by subsequent grazing damage.

Wave action is a major source of mortality for newly settled *Ascophyllum* zygotes (Vadas et al. 1990). They state that "These and earlier observations on the long term lack of colonization of denuded shores suggest that successful recruitment is highly episodic on all but the most sheltered shores".

Ascophyllum is relatively sensitive to ice scour and usually occurs in areas with infrequent or no ice scour, while *Fucus vesiculosus* dominates in similar intertidal areas with frequent ice scour

[18] Baardseth (1955) also noted the production of bushy plants after harvest.

[19] Similar results were obtained by Ang et al. (1996) in their evaluation of the Norwegian suction cutter. The original canopy structure of the *Ascophyllum* bed did not return even three years after the experimental mechanical harvest.

[20] During a review meeting of this assessment document, industry presented size class data from >7,000 plants collected in the Lobster Bay area in 1998-2000. The tallest plants found were >180 cm in length and they were rare. MacFarlane (1952) *frequently* found plants of 180 – 210 cm (and even over 300 cm) in the same area. This evidence is consistent with the concept that the plants had become shorter and bushier due to over 40 years of harvest pressure.

(Sharp 1987a). *Ascophyllum* is also sensitive to sand scour or burial (Daly and Mathieson 1977).

The southern limit for *Ascophyllum* is Long Island Sound, USA (Keser et al. 2005). Above 25°C, growth rates for *Ascophyllum* can decrease rapidly (Keser et al. 2005). A temperature of 30 to 35°C is lethal to *Ascophyllum* (Stromgren 1977). Ugarte et al. (2010) feel that climate change had begun to affect *Ascophyllum* beds in Canada by the early 2000s. They noted unusual ice patterns, increased abundance of *Fucus vesiculosus* and massive intertidal recruitment of mussels as negative impacts associated with climate change (Ugarte et al. 2009).

The abundance of *Ascophyllum* versus mussels on any one shore seems to be mediated by exposure (high water flow). On more exposed shores mussels may predominate, as the higher water flow may limit the influence of consumers such as crabs and snails (Bertness et al. 2002).

Ascophyllum shows some tolerance to limited exposure to weathered crude oil (Sjotun and Lein 1993).

KELP

General Biology

As mentioned in the Context section of this paper, 'kelp' refers to a mix of species including *Saccharina latissima, S. groenladica, Laminaria digitata*, and *Saccorhiza dermatodea*. Some would even include *Agarum clathratum* Dumort. and *Alaria esculenta* (L.) Grev. All of these species belong to the brown algal orders Laminariales or Tilopteridales. The taxonomy, and hence the names, of these species changes from time to time. To the non-specialist, it is very easy to confuse some of these species. It should be assumed that a harvest of 'kelp' will include a mix of these species. All kelps are subtidal in distribution, although some populations can extend into the low intertidal.

The kelps all have a life history where a large diploid 'sporophyte' generation alternates with a microscopic haploid 'gametophyte' generation. The male gamete fertilizes an egg held on a branch of a female gametophyte. The resulting zygote develops in-situ to form a new sporophyte attached to the substratum by a holdfast. Mature sporophytes develop reproductive patches on their blades called sori, where zoospores are formed by meiosis. The zoospores settle on the bottom to form male and female gametophytes.

The macroscopic sporophyte is the plant which is harvested. It consists of a holdfast, stipe, and blade. Large *Laminaria* plants can be 10 m in length or more, and weight over 2 kg (Chapman 1987; Sharp and Carter 1986). Most Nova Scotia kelps are not that long lived (up to three or four years old; Chapman 1984, 1986)[21]. The holdfasts of kelps do not coalesce as in *Chondrus* and *Ascophyllum*, and only one stipe with attached blade is associated with each holdfast. Therefore, the kelp holdfast does not offer the potential for vegetative regrowth after harvest. Once a kelp thallus is harvested, there is no vegetative regrowth from the 'stub' left behind.

The re-establishment of a kelp bed after harvest is completely dependent upon the settlement and growth of a new generation of gametophytes arising from the long distance transport of zoospores from other kelp beds in the bay (or farther afield). This is an important fact which must be considered in the management of a kelp harvest. Although a kelp bed may look like an

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[21] Always ahead of her time, MacFarlane (1952) tagged *Laminaria* sporophytes on Old Woman Shoal in October 1949, and found only about 3% of *Laminaria longicruris* (now included in *S. latissima*) and 15% of *L. digitata* survived to July 1950.

enduring structure, its reestablishment after harvest (or other destructive forces) is not guaranteed (Johnson and Mann 1988; Vandermeulen 2005).

As for *Ascophyllum*, kelps can be important primary producers at bay wide scales. Kelps are an important food source for herbivores such as sea urchins, and provide substantial amounts of dissolved and particulate carbon for detrital food webs (Chambers et al. 1999; Chapman 1987; Duggins and Eckman 1994; Fredriksen 2003; Koop et al. 1982; Mann 1972a, 1972b, 1973; Miller and Mann 1973; Stuart et al. 1981, 1982; Vandermeulen 2005).

Moreover, there is overwhelming evidence that kelps provide important habitat for fish and invertebrates, including commercial species such as lobster (Bologna and Steneck 1993; Christie et al. 2003; Colmen 1940; Lazzari and Stone 2006; Steneck et al. 2002). It is important to use the habitat protection objective as a minimal level of protection when harvesting kelps. The primary production and habitat value of kelps suggest caution for any harvest plan.

Stock Status: Landings Data

DFO's data holdings do not include landings data for kelp in Nova Scotia. Pringle and Semple (1980) state that *Laminaria* had been actively harvested in southwest Nova Scotia between Cape Sable Island and Pinkney Point for 45 years. Sharp (1980) describes the industry starting in 1940, he describes collection centers at Clarks Harbour and Dog Island.

MacFarlane (1953b) records shipments of kelp from Clarke's Harbour from 1942 to 1949. For this same time period for southwestern Nova Scotia Sharp (1980) had estimated maximum landings of 5,000 to 6,000 wet tonnes per year; Pringle and Sharp (1980) cite 5,500 wet tonnes per year; and Sharp and Carter (1986) report maximum landings of 3,000 t per year. The plants were harvested for the gelling agent sodium alginate.

Sharp (1980) records only sporadic, limited harvests of kelp from 1949 to 1980. He mentions some harvest in the mid-1960s, 1974 and 1978. Chapman (1987) reports only minor harvests of 20 to 300 t per year since 1949. These latter harvests were mainly for the health food industry (Chapman 1987). Since 1990, the sporadic efforts to harvest kelp continued:

- 1995, some kelp was harvested in the Larry's River area (eastern Nova Scotia). The harvest was for experimental production of 'roe on kelp' (herring spawn on kelp blades), a traditional delicacy in western Canada. The amount was approximately 7 t.
- 1997, a DFO marine plant harvest licence was issued for approximately 7 t of kelp in the Cape Canso area. The harvest was for roe on kelp.
- 1997 and 2011, licence issued to remove kelp from two shipwrecks in Louisbourg Harbour, amount not specified.

Stock Status: Standing Stock Data

Cameron (1950) also looked for *Laminaria* during his aerial survey of the Cape Sable Island region (mentioned in the *Chondrus* section above). A map was presented, but no biomass estimates were made.

MacFarlane (1952) surveyed southwestern Nova Scotia and calculated *Laminaria* spp. standing stocks of 12 to 29 $kg \cdot m^{-2}$ wet weight in the best beds. She stated that Cape Sable Island was one of the best *Laminaria* producing areas. MacFarlane (1953a) estimated 26 to 128 t per acre (11 to 52 t per hectare) of *Laminaria* spp. in the area of Yarmouth / Shelburne.

In his classic work on St. Margaret's Bay, Mann (1972a, 1973) determined that the bulk of algal biomass in the bay was in subtidal kelps, *Laminaria digitata, L. longicruris* (now *Saccharina* *latissima*), and *Agarum*. As is typical for the species, *L. digitata* was found on more exposed shores. He records a peak biomass for the kelps as 16 $kg \cdot m^{-2}$ wet weight[22].

Pringle and Semple (1980) measured a mean standing crop of 0.9 $kg \cdot m^{-2}$ wet weight *L. longicruris* and 0.4 $kg \cdot m^{-2}$ wet weight *L. digitata* on a strip of shoreline in the area of west Pubnico Peninsula in the summer of 1975.

McPeak (1980) described a SCUBA based survey for kelps in 1977 in the region of Lower Woods Harbour that recorded a biomass of between about 3 to over 15 $kg \cdot m^{-2}$ wet weight. *Laminaria digitata* and *L. longicruris* dominated.

Moore and Miller (1983) and Moore et al. (1986) surveyed the Atlantic coast of Nova Scotia for sea urchins and kelp. They found that kelp could be found anywhere that a rocky or hard bottom existed along with moderate or higher exposure regimes (e.g. wave impacted shores).

Sharp and Carter (1986) performed a survey of kelp in southwest Nova Scotia (a small area in the islands off of Woods Harbour) using aerial photography with SCUBA based ground truthing. They report an average biomass of 42.2 t per hectare. About 40% of the biomass was *Laminaria digitata*, and 60% *Laminaria longicruris* (which has now been absorbed into the taxon *Saccharina latissima*). A peak biomass (both species together) of about 5.5 $kg \cdot m^{-2}$ wet weight occurred between chart datum to -5 m. They found *Alaria esculenta* in shallower water, averaging 0.2 $kg \cdot m^{-2}$, *Saccorhiza dermatodea* had a similar vertical distribution and weight. *Agarum cribosum* (our *Agarum* is now considered to be *A. clathratum*) was restricted to water depths of -10 m or more, with an average biomass of 0.1 $kg \cdot m^{-2}$.

At about the same time, Mouchot et al. (1987) did an experimental trial of a fluorescence line imager sensor in southwest Nova Scotia, a small portion of Lobster Bay. They provide an image indicating the presence of kelps, but no biomass estimates.

Chapman (1987) cites a standing crop of 17.0 $kg \cdot m^{-2}$ for *Laminaria longicruris* in the region of Chebogue – Cape Sable.

Stock Status: Harvest Methods, Timing and Intensity Affecting Standing Stock

Environment Canada (1971) note that in the mid- to late 1940s *Laminaria* was harvested by hand sickle near Cape Sable Island. Sharp (1980) confirms this observation and adds that storm tossed material was also collected. MacFarlane (1952) experimentally cut *Laminaria* sporophytes in an area east of Northern Twin Island. The bed appeared to recover a year later.

A large drag rake was developed and used very early on in the kelp harvest, it was a piece of oak about 1.5 m wide with steel rods as tines spaced about 7.5 – 12.5 cm apart. The oak bar was attached at right angles to a large metal bar. The metal bar was pulled by a line attached to a lobster boat with a winch (Sharp 1980).

Pringle and Sharp (1980) evaluated this drag rake and determined that 98% of the harvest was whole plants of *Laminaria longicruris* (i.e. *Saccharina latissima*). The drag rake method removed the larger plants in the population, plants averaging 5.0 m in total length. The residual population averaged 2.3 m in length (Pringle and Sharp 1980). Boulders up to 52 x 30 cm were displaced.

The harvest of kelp in Nova Scotia is essentially a harvest of entire plants (Chapman 1984). Even if extreme care was taken to hand harvest just part of the blade portion of the plants (the

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[22] Mann provides a wet weight to dry weight conversion factor of between 10 to 27%, depending upon the part of the plant (blade or stipe) being weighed.

only method which would allow regrowth of the plants), regrowth would be slow (Chapman and Craigie 1978).

Smith (1986) used SCUBA divers to experimentally hand harvest *Laminaria digitata* and *Saccharina latissima* off Ram Island, Lobster Bay. A complete harvest of whole plants was performed. The *Saccharina* recovered to 96% of pre-harvest standing crop by one year. *Laminaria digitata* took two years to recover.

Sharp and Pringle (1990) insist that a kelp drag rake rarely touches bottom during operation, and noted a good pulse of pre-recruit kelp thalli six months after a commercial drag rake harvest. Biomass recovered to pre-harvest levels within one year[23]. Kelp drag rake impacts on lobster were not clear.

Mechanical Harvest Methods

Sharp (1980) describes and illustrates a stern mounted mechanical harvester for kelp developed in 1946 and used in southwest Nova Scotia. Sharp and Pringle (1990) evaluated an odd, spinning auger type of mechanical harvester tested in Ledge Harbour, Lobster Bay. The machine reduced *Laminaria longicruris* (i.e. *Saccharina latissima*) biomass by 45% and stipe density by 68%. The machine left behind truncated stipes and blades, plus a reduced canopy. Bottom disturbance was noted as well.

Timing of Harvest

In the 1940s, the southwest Nova Scotia kelp harvest began in the early summer after the lobster season and continued into the winter. The raw material was shipped to Rockland, Maine for processing (Sharp 1980).

The Canadian Atlantic Fisheries Scientific Advisory Committee (1986) recommended that the kelp harvest season be between June and November, though this would require further study. At present, there are no seasonal controls on kelp harvest, though a limited harvest period may be, and has been in the past, prescribed through licence conditions.

Intensity of Harvest

There is insufficient harvest information to determine if kelp has been more intensely harvested, or over harvested, in some sites during specific years. The Canadian Atlantic Fisheries Scientific Advisory Committee (1986) recommended that “To protect the reproductive potential of kelp beds, a harvest should not extend beyond 0.5 km from a spore source and a buffer zone of mature populations equivalent to the harvested area should remain abutting the harvest zone.” They also suggested an 18 month fallow period between harvests, or a four year harvest cycle with two year intervals between harvesting of adjacent areas. This style of harvest would not be recommended at the present time, as it is inconsistent with this papers habitat protection objective.

In 2011, the conditions of licence for kelp (the Louisbourg licence mentioned above) included:

- No plants will be harvested with a total length less than 1 m,
- Sharp cutting tools shall be used to cut the plant above the holdfast,
- No more than 30% of the bed can be harvested,
- An area of no more than 15 m in any direction may be harvested, and

[23] Vea and Ask (2011) describe a long standing trawl harvest for kelps in Norway.

- There must be a minimum un-harvested buffer of kelp between patches of 15 m.

The above conditions should serve to prevent a harvest which is too intense. There is no conservation value to the kelp bed itself in leaving holdfasts behind as the stub will die back in any case. However, many invertebrates and small fish are associated with kelp holdfasts – so over the short term it is important to preserve this aspect of the habitat value of the original kelp plant.

It may be far better to harvest the blade portion above the transition zone, as is designated by provincial license conditions in British Columbia (minimum of 10 cm of blade must be left above the transition zone; Gary Saunders, University of New Brunswick, pers. comm.).Leaving 10 cm of blade could improve recovery (seasonal issue) and may also extend the integrity of the holdfast habitat.

Stock Status: Environmental Effects on Standing Stock

Kelps may experience photo-inhibition at low tides under strong sunlight (Gevaert et al. 2003). The author has often seen 'bleached' thalli of *Laminaria* / *Saccharina* when SCUBA diving in the shallows in the summer in Nova Scotia.

Photosynthesis in *Saccharina* from Maine drops off quite rapidly at 25°C or above, and death follows within a week or so – especially for plants under nitrogen limitation (Gerard 1997a). *Saccharina* germlings from Maine have optimal growth at 12°C and reduced growth at 20°C (Gerard 1997b). *Saccharina* appears to photosynthesize best at lower temperatures, around 10 to 15°C, and will perform well at temperatures as low as 5°C or even 0°C (Davison 1987; Davison et al. 1991).

The southern limit for species of *Laminaria* appears to be Long Island Sound, USA (Egan and Yarish 1988). This is a deep-water population apparently surviving due to the colder temperatures in that depth zone. Interestingly, the 'hollow stipe' form of *Saccharina latissima* (which used to be considered a form of *Laminaria longicruris*) seems to be restricted to waters with temperatures less than 5°C in winter (Egan and Yarish 1988).

Boden (1979) determined that the best depth for growth of *Saccharina* in Maine was at about its mid-range of subtidal depth distribution. Low levels of nitrate and high temperatures probably limited growth in the shallow subtidal; while attenuated illumination at depth (below 17 m) slowed growth substantially.

Under unfavourable conditions of wounding, overcrowding or high temperature, a bacterium can invade *Laminaria* thalli and cause a 'rot disease' (Meili 1991). *Saccharina* thalli can become deformed by an infection of the microscopic brown alga *Streblonema* (Peters and Schaffelke 1996). Endophytic algal infections can be quite extensive in kelp populations (Ellertsdottir and Peters 1997).

Kelps are susceptible to a wide variety of herbivores including sea urchins (which can completely destroy kelp beds in Nova Scotia for long periods of time[24]), and snails such as *Lacuna vincta*, which can also cause significant damage at the bed scale (Fralick et al. 1971; Johnson and Mann 1986; Johnson and Mann 1988; Vandermeulen 2005). The lower depth limit of kelp beds may be controlled by the presence of sea urchins. Urchins are able to stay attached to the bottom in deeper, less turbulent waters, grazing back kelps in this zone. In shallower waters, however, the effects of wave action are more pronounced and urchins cannot

[24] Chapman 1981, 1987; Johnson and Mann 1988; Lang and Mann 1976; Meidel and Scheilbling 1998; Miller 1985; Scheibling et al. 1999; Steneck et al. 2002.

'hang on' in this zone, allowing kelp beds to flourish in the more turbulent shallows (Konar and Estes 2003; Moore et al. 1986).

Steneck et al. (2002) note that the introduced bryozoan *Membranipora membranacea* can harm kelps by covering the blade, and the invasive green alga *Codium fragile* ssp. *tomentosoides* can interfere with kelp bed dynamics. *Membranipora* can cause extensive defoliation of *Laminaria / Saccharina* (Lambert et al. 1992; Saunders and Metaxas 2008). *Membranipora* can also negatively impact spore output from Nova Scotian *Saccharina latissima* (Saier and Chapman 2004).

Urchins prefer kelp over *Codium* (Scheibling and Anthony 2001), and could preferentially graze kelps away, leaving *Codium* behind (Sumi and Scheibling 2005). Once *Codium* is established, it can prevent recolonization by kelps (Scheibling and Gagnon 2006)[25]. Different assemblages of macro-invertebrates are associated with a canopy of *Codium* versus *Laminaria / Saccharina* (Schmidt and Scheibling 2007).

CONCLUSIONS

IRISH MOSS (*CHONDRUS CRISPUS*)

As a whole, the *Chondrus* populations found in southwestern Nova Scotia are not under immediate threat from overharvesting or environmental factors. However, there are chronic indications of site specific overharvesting, a situation which is likely to get worse as landings since 2004 have been higher than that recorded for most of the 1990s. The following recommendations are intended to protect this harvest:

1. DFO's data holdings should fill in early data gaps on landings and decide upon 'official' landings for the period 1947 to 1974.
    a. DFO's data holdings for Irish moss only begin in 1975, decades after the establishment of the harvest.
    b. Several publications provide landings data for the early years of the harvest.
    c. Early landings were substantial, peaking at over 15,000 t. These data provide context for perceived overharvest impacts in the past and in the future.
    d. The reliability of some of the early landings data is uncertain. However, there is greater management value in including them in analyses rather than ignoring them.
2. DFO's data holdings should not include the voluntary harvester landings data sheets implemented in 2010. DFO's data holdings should recalculate landings for 2010 and following years based upon its traditional method of gathering landings data from buyer records. *Without this correction DFO Science will no longer have the appropriate time trend landings data to assist in the assessment of the stock in the future*.
    a. The harvester landings data sheets are voluntary and not all harvesters fill them out. Hence, the landings are under reported.
    b. All historical landings data for Irish moss have been gathered from buyers' sales slips. To maintain the validity of this long term data set, the traditional DFO data holding method of gathering landings data should be continued.
    c. There is some uncertainty in the landings values embedded in the traditional DFO data holdings landings record (published values from other authors do not quite match DFO's

[25] Chapman (1987) notes that red algal understory species (e.g. *Chondrus, Phyllophora, Ceramium*) can inhibit the establishment of *Laminaria* beds as well.

data holdings). However, DFO's data holdings should be considered the official DFO position backed by consistent data acquisition, QA/QC and archiving.

3. Harvester landings data sheets should be made mandatory.
    a. This information could be a valuable supplement to DFO's data holdings.
    b. The harvester landings data sheets contain data fields for the harvest location of the landed plants. This is a finer level of spatial information than that provided by DFO's data holdings.
    c. Reef or beach specific harvest information allows for the identification of chronically harvested areas on a fine scale. Site specific management action is then possible to prevent overharvesting.
4. D12, and possibly D11, should have at least three sites where the Irish moss harvest is permanently closed.
    a. All portions of D12 and 11 are presently available to harvesters during the open season. Hence, there are no 'control' sites for an evaluation of the impacts of the harvest.
    b. Long term closed areas allow for an evaluation of harvest impacts versus environmental impacts on standing stocks. Without closed areas, these two types of impacts remain confounded[26].
    c. The closed areas do not need to be large (a small island or reef would suffice).
    d. The closed areas should be easily recognizable and accessible by fisheries officers.
5. New *Chondrus* standing stock data should be collected in the Lobster Bay area.
    a. Lobster Bay has a long history of harvest pressure and has not been surveyed in over 25 years.
    b. There are indications in the literature that standings stocks in Lobster Bay may be lower than in the past due to chronic harvest impacts.
6. The Lobster Bay standing stock survey should be designed to test for evidence of overharvest.
    a. The proportion of coralline algal cover (and associated animals and plants) within long term harvested *Chondrus* beds should be compared to reference sites.
    b. The gametophyte / tetrasporophyte ratio in long term harvested beds should be compared to reference sites using the chemical test of Brown et al. (2004).
7. Shore based walk on harvest of *Chondrus* should be discouraged.
    a. Although the traditional harvest is by boat with hand rake, the potential for a walk on intense harvest should be discouraged.
    b. *Chondrus*, and the intertidal in general, are sensitive to trampling by humans on foot or with vehicles.
8. The 5 mm minimum tine spacing for rakes presently found in licence conditions should be retained and rigorously enforced.
    a. Minor changes in tine spacing (a reduction of a millimeter or so) can have profound negative harvest impacts.
    b. Tine spacing >5 mm may not have significant conservation value.

[26] When the rockweed harvest was established in New Brunswick, closed areas were established specifically for this reason.

9. If the drag rake harvest method for *Chondrus* is re-introduced to the Nova Scotian harvest, it should be scientifically assessed prior to implementation.
    a. Drag rakes were routinely used in the past Irish moss harvest in Nova Scotia.
    b. There are potential benthic and *Chondrus* specific impacts with the use of drag rakes which may be altered by gear design.
10. If mechanical harvesters are re-introduced to the Nova Scotian *Chondrus* harvest, they should be scientifically assessed prior to implementation.
    a. Mechanical harvesters have been tested in the past and are not presently banned by regulation.
    b. Mechanical harvester impacts will be specific to the gear design.
11. The D12 close time should be re-evaluated to ensure adequate protection of periods of peak growth and reproductive effort.
    a. A similar recommendation was made in 1983 by the Canadian Atlantic Fisheries Scientific Advisory Committee.
    b. The historically regulated start of the D12 *Chondrus* harvest (June 7^{th}) coincides with a period of peak growth and reproductive effort. By Variation Order, the harvest currently starts slightly later, on the third Monday of June.
    c. Delaying the harvest to the D11 start time (July 1^{st}) would offer additional protection to the D12 beds during the month of June. However, given the very broad reproductive period of *Chondrus* in Nova Scotia, delaying the harvest until July may not have significant conservation value.
    d. The re-evaluation should also consider seasonal habitat use of associated animals. Harvest timing in terms of the highest habitat value (i.e. for juveniles of invertebrates and fish species) is not known and should be evaluated.

ROCKWEED (*ASCOPHYLLUM NODOSUM*)

Ascophyllum populations are important as habitat and primary producers on bay wide scales. As a result, an overharvest of *Ascophyllum* could lead to an undesirable level of habitat loss at a landscape scale. This is an important perspective which has not been stressed in earlier assessments of the *Ascophyllum* harvest in Nova Scotia.

Upon application of the habitat protection objective described at the beginning of this report, the Nova Scotian harvest of *Ascophyllum* has been found to have the potential for undesirable habitat impacts at a landscape scale. Moreover, in some years in some bays the gear type and intensity of harvest may have been harmful to the resource itself. There is a pressing need to overhaul the harvest of *Ascophyllum* in Nova Scotia, particularly if these populations may be sensitive to climate change as indicated in the literature. The following recommendations are intended to protect this harvest and habitat:

1. DFO's data holdings should fill in early data gaps on landings and decide upon 'official' landings for the period 1959 to 1976.
    a. DFO's data holdings for *Ascophyllum* only begin in 1977, decades after the establishment of the harvest.
    b. Several publications provide landings data for the early years of the harvest.
    c. The reliability of some of the early landings data is uncertain. However, there is greater management value in including them in analyses rather than ignoring them.
    d. There is some uncertainty in the landings values embedded in the traditional DFO data holdings landings record (published values from other authors do not quite match the

DFO data). However, DFO's data holdings should be considered the official DFO position backed by consistent data acquisition, QA/QC and archiving.

2. D12, and possibly D11, should have at least three sites where the *Ascophyllum* harvest is permanently closed.
    a. All portions of D12 and 11 are presently available to harvesters during the open season. Hence, there are no 'control' sites for an evaluation of the impacts of the harvest.
    b. Long term closed areas allow for an evaluation of harvest impacts versus environmental impacts on standing stocks. Without closed areas, these two types of impacts remain confounded[27].
    c. The closed areas do not need to be large (a moderately sized bay or island would suffice).
    d. The closed areas should be easily recognizable and accessible by fisheries officers.
3. New *Ascophyllum* standing stock data should be collected in the Lobster Bay area.
    a. Lobster Bay has a long history of harvest pressure and has not been surveyed in over 20 years.
    b. There are indications in the literature that standings stocks in Lobster Bay may be lower than in the past due to chronic harvest impacts.
4. The Lobster Bay standing stock survey should be designed to test for evidence of overharvest.
    a. The proportion of 'short and bushy' thalli within long term harvested *Ascophyllum* beds should be compared to reference sites.
5. Shore based walk on harvest of *Ascophyllum* should be discouraged.
    a. Although the traditional harvest is by boat with hand rake, a walk on harvest of *Ascophyllum* does exist in Annapolis Basin and it has a history of intense harvest.
    b. *Ascophyllum*, and the intertidal in general, are sensitive to trampling by humans on foot or with vehicles.
6. The present regulated minimum cutting height of 127 mm should be replaced with a cutting height of 254 mm.
    a. The origin of the 127 mm minimum cutting height is unclear and its value as a conservation tool is uncertain.
    b. Several publications indicate that a minimum cutting height of 254 mm would be more protective of the resource.
    c. The 254 mm value was already recommended by Environment Canada (then responsible for the harvest) in 1971.
    d. The 254 mm minimum cutting height should be applied to all parts of Nova Scotia.
7. The issue of holdfast content in *Ascophyllum* landings should be revisited. The present 15% provincial rule is not particularly conservative. Landings of 7% holdfast content by weight or less are quite achievable with proper gear.

[27] When the rockweed harvest was established in New Brunswick, closed areas were established specifically for this reason.

8. If mechanical harvesters are re-introduced to the Nova Scotian *Ascophyllum* harvest, they should be scientifically assessed prior to implementation.
    a. Mechanical harvesters have been extensively used in the past and are not presently banned by regulation.
    b. Mechanical harvester impacts will be specific to the gear design.
9. Close times for the *Ascophyllum* harvest should be established.
    a. Re-evaluating the need for seasonal closures to adequately protect periods of peak growth and reproductive effort, as well as seasonal habitat use of associated animals.
10. Harvest rates need to be re-evaluated.
    a. The historical (pre-2000s) harvest rates indicate potential undesirable *Ascophyllum* bed habitat value impacts at a landscape scale, taking years to recover.
    b. High harvest levels have continued in the Annapolis Basin, and a reassessment of this area would be useful in the determination of the current status of rockweed and potential long term impacts on habitat/ecosystem.
    c. In Nova Scotia, the present industry harvest rates of approximately 25% of the harvestable biomass are demonstrated to be able to maintain the yield (biomass) of rockweed in leased areas for the last 17 years (Raul Ugarte, pers. comm.). However, there is no available information to determine whether this rate is detrimental to the habitat value that rockweed provides to associated plants and animals on bay-wide scales.

KELP

Kelp populations provide important habitat and primary production on bay wide scales, and many would consider kelp beds to be very important to the nearshore ecology of Nova Scotia, particularly with their links to commercial species of fish and invertebrates. Caution is recommended for any harvest of kelps, especially since kelp beds are prone to natural destruction by sea urchins in Nova Scotia.

Large scale impacts due to the harvest of kelps in Nova Scotia are lacking due to the sporadic, almost non-existent harvest of intact plants at the present time. However, in the 1940s approximately 5,000 wet tonnes per year were harvested in southwest Nova Scotia and a return to those levels would require close scrutiny, including a bay by bay assessment of standing stocks prior to harvest. The following recommendations should be used to guide a future harvest:

1. Standing stock data (including species composition) should be obtained immediately prior to any harvest of kelps, even if the kelp bed was harvested in a previous year.
2. A seasonal survey of invertebrate and fish species utilizing the kelp bed should be performed prior to harvest.
3. DFO’s data holdings should record landings data for any commercial kelp harvest in Nova Scotia, even small amounts.
4. Hand cutting by SCUBA is recommended as a ‘low impact’ harvest method.
    a. Cutting plants with a sharp instrument minimally 10 cm above the “transition zone” (i.e. just above the stipe / blade juncture).
5. If drag rakes are re-introduced as a harvest method for kelps, they should cut minimally 10 cm above the transition zone and be scientifically assessed prior to implementation.

   a. Drag rakes have been extensively used in the past and are not presently banned by regulation.
   b. Drag rake impacts (on kelp populations, benthos and by-catch) will be specific to the gear design.

6. If mechanical harvesters are re-introduced to the Nova Scotian kelp harvest, they should cut minimally 10 cm above the transition zone and be scientifically assessed prior to implementation.

   a. Mechanical harvesters have been used in the past and are not presently banned by regulation.
   b. Mechanical harvester impacts (on kelp populations, benthos and by-catch) will be specific to the gear design.

7. Close times for the kelp harvest should be established.

   a. The Canadian Atlantic Fisheries Scientific Advisory Committee in 1986 recommended matching D12 closed times.
   b. Use of seasonal closures to adequately protect periods of peak growth (spring time) and reproductive effort, as well as seasonal habitat use of associated animals.

8. The conditions of licence for a harvest of kelp should at least include the following:

   a. Consistency with current DFO ecosystem objectives.
   b. No plants will be harvested with a total length less than 1 m.
   c. Sharp cutting tools shall be used to cut the plant minimally 10 cm above the transition zone.
   d. No more than 30% of the bed can be harvested (20% is used in British Columbia; Gary Saunders, pers. comm.).
   e. An area of no more than 15 m in any direction may be harvested.
   f. There must be a minimum 15 m un-harvested buffer of kelp between harvested patches.
   g. If the kelp bed was previously harvested, and the standing stock[28] has not returned to pre-harvest levels after one year, no further harvest of the bed is allowed.

REFERENCES

Ang, P., Sharp, G., and Semple, R. 1993. Changes in the population structure of *Ascophyllum nodosum* (L.) Le Jolis due to mechanical harvesting. Hydrobiologia, 260/261: 321-326.

Ang, P., Sharp, G., and Semple, R. 1996. Comparison of the structure of populations of *Ascophyllum nodosum* (Fucales, Phaeophyta) at sites with different harvesting histories. Hydrobiologia, 326/327: 179-184.

Baardseth, E. 1955. Regrowth of *Ascophyllum nodosum* after harvesting. Institute for Industrial Research and Standards, Dublin, Ireland.

Baardseth, E. 1970. Synopsis of biological data on knobbed wrack *Ascophyllum nodosum* (Linnaeus) Le Jolis. FAO Fisheries Synopsis, 38: 1-38.

Bertness, M., Trussell, G., Ewanchuk, P., and Silliman, B. 2002. Do alternate stable community states exist in the Gulf of Maine rocky intertidal zone? Ecology, 83: 3434-3448.

[28] ‘Standing stock’ in this instance is being used as a surrogate measure of the production and habitat value of the original kelp bed. Since individual kelps are fast growing and short lived, the canopy structure and other aspects of the beds ‘ecosystem services’ should be linked to standing stock.

Bhattacharya, D. 1985. The demography of fronds of *Chondrus crispus* Stackhouse. Journal of Experimental Marine Biology and Ecology, 91: 217-231.

Black, R., and Miller, R. 1986. *Ascophyllum* harvesting and use of the intertidal by Finfish. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document, 86/15.

Black, R., and Miller, R. 1991. Use of the intertidal zone by fish in Nova Scotia. Environmental Biology of Fishes, 31: 109-121.

Black, R., and Miller, R. 1994. The effects of seaweed harvesting on fishes: A response. Environmental Biology of Fishes, 39: 325-328.

Boden, G. 1979. The effect of depth on summer growth of *Laminaria saccharina* (Phaeophyta, Laminariales). Phycologia, 18: 405-408.

Boller, M., and Carrington, E. 2006. In situ measurements of hydrodynamic forces imposed on *Chondrus crispus* Stackhouse. Journal of Experimental Marine Biology and Ecology, 337: 159-170.

Bologna, P., and Steneck, R. 1993. Kelp beds as habitat for American lobster *Homarus americanus.* Marine Ecology Progress Series, 100: 127-134.

Boney, A. 1965. Aspects of the biology of the seaweeds of economic importance. Advances in Marine Biology, 3: 105-253.

Borell, E., Foggo, A., and Coleman, R. 2004. Induced resistance in intertidal macroalgae modifies feeding behaviour of herbivorous snails. Oecologia, 140: 328-334.

Bradford, B. 1989. A demonstration of possible links for a detrital pathway from intertidal macroalgae in the Bay of Fundy. M.Sc. Thesis, Acadia University, Wolfville, Nova Scotia. 188 p.

Brown, M., Neish, A., and Harwood, D. 2004. Comparison of three techniques for identifying isomorphic phases of *Chondrus crispus* (Gigartinaceae). Journal of Applied Phycology, 16: 447-450.

Cameron, L. 1950. The use of aerial photography in seaweed surveys. Photogrammetric Engineering, 16: 493-501.

Campbell, D. 2004. Evaluation and emergy analysis of the Cobscook Bay Ecosystem. Northeastern Naturalist, 11: 355-424.

Canadian Atlantic Fisheries Scientific Advisory Committee. 1981a. Advice on some invertebrate and marine plant stocks. Canadian Atlantic Fisheries Scientific Advisory Committee Advisory Document, 81/1.

Canadian Atlantic Fisheries Scientific Advisory Committee. 1981b. Advice on the management of Irish moss (*Chondrus*) stocks off southwestern Nova Scotia. Canadian Atlantic Fisheries Scientific Advisory Committee Advisory Document, 81/15.

Canadian Atlantic Fisheries Scientific Advisory Committee. 1983. Advice on the management of Irish moss (*Chondrus*) stocks off southwestern Nova Scotia. Canadian Atlantic Fisheries Scientific Advisory Committee Advisory Document, 83/5.

Canadian Atlantic Fisheries Scientific Advisory Committee. 1986. Advice on the harvesting of southwest Nova Scotian kelp resources. Canadian Atlantic Fisheries Scientific Advisory Committee Advisory Document, 86/23.

Canadian Atlantic Fisheries Scientific Advisory Committee. 1993. Rockweed in southwestern New Brunswick. Canadian Atlantic Fisheries Scientific Advisory Committee Advisory Document, 92/13.

Capone, M., Grizzle, R., Mathieson, A., and Odell, J. 2008. Intertidal oysters in northern New England. Northeastern Naturalist, 15: 209-214.

Cervin, G., Lindegarth, M., Viejo, R., and Aberg, P. 2004. Effects of small-scale disturbances of canopy and grazing on intertidal assemblages on the Swedish west coast. Journal of Experimental Marine Biology and Ecology, 302: 35-49.

Chadwick, M. 1999. Proceedings of the Maritimes Regional Advisory Process of rockweed stocks. Fisheries and Oceans Canada. Canadian Stock Assessment Proceedings Series, 99/36.

Chambers, P., DeWreede, R., Irlandi, E., and Vandermeulen, H. 1999. Management issues in aquatic macrophyte ecology: A Canadian perspective. Canadian Journal of Botany, 77: 471-487.

Chapman, A. 1981. Stability of sea urchin dominated barren grounds following destructive grazing of kelp in St. Margaret's Bay, eastern Canada. Marine Biology, 62: 307-311.

Chapman, A. 1984. Reproduction, recruitment and mortality in two species of *Laminaria* in southwest Nova Scotia. Journal of Experimental Marine Biology and Ecology, 78: 99-109.

Chapman, A. 1986. Age versus stage: An analysis of age- and size-specific mortality and reproduction in a population of *Laminaria longicruris* Pyl. Journal of Experimental Marine Biology and Ecology, 97: 113-122.

Chapman, A. 1987. The wild harvest and culture of *Laminaria longicruris* in eastern Canada. *In* Case studies of seven commercial seaweed resources. Edited by M. Doty, J. Caddy, and B. Santelices. FAO Fisheries Technical Paper, 281. pp. 193-237.

Chapman, A., and Craigie, J. 1978 Seasonal growth in *Laminaria longicruris*: Relations with reserve carbohydrate storage and production. Marine Biology, 46: 209-213.

Chopin, T. 1986. The red alga *Chondrus crispus* Stackhouse (Irish moss) and carrageenans - A review. Canadian Technical Report of Fisheries and Aquatic Sciences 1514. 69 p.

Chopin, T. 1998. The seaweed resources of eastern Canada. *In* Seaweed resources of the world. Edited by A. Critchley, and M. Ohno. Japan International Cooperation Agency, Yokosuka, Japan. pp. 273-302.

Chopin, T., and Ugarte, R. 2006. The seaweed resources of eastern Canada. *In* World seaweed resources: An authoritative reference system. Edited by A. Critchley, M. Ohno, and D. Largo. A multimedia, interactive DVD-ROM. ETI BioInformatics, Amsterdam, The Netherlands.

Christie, H., Jorgensen, N., Norderhaug, K., and Waage-Nielsen, E. 2003. Species distribution and habitat exploitation of fauna associated with kelp (*Laminaria hyperborea*) along the Norwegian coast. Journal of the Marine Biological Association of the United Kingdom, 83: 687-699.

Coleman, R., Ramchunder, S., Moody, A., and Foggo, A. 2007. An enzyme in snail saliva induces herbivore-resistance in a marine alga. Functional Ecology, 21: 101-106.

Colmen, J. 1940. On the faunas inhabiting intertidal seaweeds. Journal of the Marine Biological Association of the United Kingdom, 24: 129-183.

Cousens, R. 1984. Estimation of annual production by the intertidal brown alga *Ascophyllum nodosum* (L.) Le Jolis. Botanica Marina, 27: 217-227.

Cousens, R. 1986. Quantitative reproduction and reproductive effort by stands of the brown alga *Ascophyllum nodosum* (L.) Le Jolis in south-eastern Canada. Estuarine, Coastal and Shelf Science, 22: 495-507.

Craigie, J., and Pringle, J. 1978. Spatial distribution of tetrasporophytes and gametophytes in four Maritime populations of *Chondrus crispus*. Canadian Journal of Botany, 56: 2910-2914.

Craigie, J., and Shacklock, P. 1995. Culture of Irish moss. *In* Cold-water aquaculture in Atlantic Canada. Edited by A. Boghen. The Tribune Press, Sackville, New Brunswick. pp. 365-390.

Cunningham, W. 1990. An assessment of *Ascophyllum nodosum* resources in selected areas of Annapolis, Digby, Yarmouth and Shelburne Counties from a commercial perspective. Consultant report to Nova Scotia Department of Fisheries.

Curran, K., Bundy, A., Craig, M., Hall, T., Lawton, P., and Quigley, S. 2012. Recommendations for science, management, and an ecosystem approach in Fisheries and Oceans Canada, Maritimes Region. Fisheries and Oceans Canada. Canadian Science Advisory Secretariat Research Document, 2012/061.

Daly, M., and Mathieson, A. 1977. The effects of sand movement on intertidal seaweeds and selected invertebrates at Bound Rock, New Hampshire, USA. Marine Biology, 43: 45-55.

Davison, I. 1987. Adaptation of photosynthesis in *Laminaria saccharina* (Phaeophyta) to changes in growth temperature. Journal of Phycology, 23: 273-283.

Davison, I., Greene, R., and Podolak, E. 1991. Temperature acclimation of respiration and photosynthesis in the brown alga *Laminaria saccharina*. Marine Biology, 110: 449-454.

DFO. 1967. Minutes of the meeting to further the development of the Canadian marine plants industry. A report of the Industrial Development Service. 50 p.

DFO. 1971. Marine plants experimental station Miminegash Prince Edward Island: Annual Report 1970-71. A report of the Industrial Development Branch. 53 p.

DFO. 1993. Irish moss. Underwater World #6. 6 p. ISBN 0-662-20549-9.

DFO. 1998. Rockweed in the maritimes. DFO Science Stock Status Report, C3-57.

DFO. 1999. The impact of the rockweed harvest on the habitat of southwest New Brunswick. DFO Maritimes Regional Habitat Status Report, 99/2E.

Dudgeon, S., Davison, I., and Vadas, R. 1989. Effect of freezing on photosynthesis of intertidal macroalgae: relative tolerance of *Chondrus crispus* and *Mastocarpus stellatus* (Rhodophyta). Marine Biology, 101: 107-114.

Dudgeon, S., Davison, I., and Vadas, R. 1990. Freezing tolerance in the intertidal red algae *Chondrus crispus* and *Mastocarpus stellatus*: Relative importance of acclimation and adaptation. Marine Biology, 106: 427-436.

Duggins, D., and Eckman, J. 1994. The role of kelp detritus in the growth of benthic suspension feeders in an understory kelp forest. Journal of Experimental Marine Biology and Ecology, 176: 53-68.

Egan, B., and Yarish, C. 1988. The distribution of the genus *Laminaria* (Phaeophyta) at its southern limit in the Western Atlantic Ocean. Botanica Marina, 31: 155-161.

Ellertsdottir, E., and Peters, A. 1997. High prevalence of infection by endophytic brown algae in populations of *Laminaria* spp. (Phaeophyceae). Marine Ecology Progress Series, 146: 135-143.

Environment Canada. 1971. Proceedings: Meeting on the Canadian Atlantic Seaweeds Industry, October 5-6, 1971, Charlottetown, Prince Edward Island. Industrial Development Branch, Ottawa, Ontario. 149 p.

Environment Canada. 1973. Marine plants experimental station Miminegash Prince Edward Island: Annual Report 1972-73. Industrial Development Branch, Ottawa, Ontario. 56 p.

Environment Canada. 1974. Marine plants experimental station Miminegash Prince Edward Island: Annual Report 1973-74. Industrial Development Branch, Ottawa, Ontario. 56 p.

Environment Canada. 1975. Marine plants experimental station Miminegash Prince Edward Island: Annual Report 1974-75. Industrial Development Branch, Ottawa, Ontario. 99 p.

Environment Canada. 1976. 1975 Report. Resource Development Branch, Ottawa, Ontario.

Eschmann, C., and Stengel, D. 2011. Recovery of *Ascophyllum nodosum* after harvesting in Ireland and potential interactions with climate change. 4th Congress of the International Society for Applied Phycology, Program and Abstracts, June 19-24, 2011, Halifax, Nova Scotia. 94 p.

Ffrench, R. 1972. The demand for Canadian seaweeds with special reference to Irish moss. Canadian Journal of Agricultural Economics, 20: 1-6.

Fletcher, H., and Frid, C. 1996. Impact and management of visitor pressure on rocky intertidal algal communities. Aquatic Conservation: Marine and Freshwater Ecosystems, 6: 287-297.

Foster, M., and Barilotti, D. 1990. An approach to determining the ecological effects of seaweed harvesting: a summary. Hydrobiologia, 204/205: 15-16.

Fralick, R., Turgeon, K., and Mathieson, A. 1971. Destruction of kelp populations by *Lacuna vincta* (Montagu). The Nautilus, 88: 112-114.

Fredriksen, S. 2003. Food web studies in a Norwegian kelp forest based on stable isotope (Delta C-13 and delta N-15) analysis. Marine Ecology Progress Series, 260: 71-81.

Garbary, D., Tompkins, E., White, K., Corey, P., and Kim, J. 2011. Temporal and spatial variation in the distribution of life history phases of *Chondrus crispus* (Gigartinales, Rhodophyta). Algae, 26: 61-71.

Gerard, V. 1997a. The role of nitrogen nutrition in high-temperature tolerance of the kelp, *Laminaria saccharina* (Chromophyta). Journal of Phycology, 33: 800-810.

Gerard, V. 1997b. Environmental stress during early development of kelp sporophytes (*Laminaria saccharina*): how long do effects persist? Journal of Applied Phycology, 9: 5-9.

Gevaert, F., Creach, A., Davoult, D., Migne, A., Levavasseur, G., Arzel, P., Holl, A., and Lemoine, Y. 2003. *Laminaria saccharina* photosynthesis measured in situ: Photoinhibition and xanthophyll cycle during a tidal cycle. Marine Ecology Progress Series, 247: 43-50.

Haggerty, L., and Hellenbrand, K. 1976. Irish moss survey in southwest Nova Scotia. Nova Scotia Research Foundation. 73 p.

Hession, C., Guiry, M., McGarvey, S., and Joyce, D. 1998. Mapping and assessment of the seaweed resources (*Ascophyllum nodosum, Laminaria* spp.) off the west coast of Ireland. Marine Institute, Marine Resource Series, 5.

Ingolfsson, A., and Hawkins, S. 2008. Slow recovery from disturbance: a 20 year study of *Ascophyllum* canopy clearances. Journal of the Marine Biological Association of the United Kingdom, 88: 689-691.

Jenkins, S., Norton, T., and Hawkins, S. 2004. Long term effects of *Ascophyllum nodosum* canopy removal on mid shore community structure. Journal of the Marine Biological Association of the United Kingdom, 84: 327-329.

Johnson, C., and Mann, K. 1986. The importance of plant defence abilities to the structure of subtidal seaweed communities: The kelp *Laminaria longicruris* de la Pylaie survives grazing by the snail *Lacuna vincta* (Montagu) at high population densities. Journal of Experimental Marine Biology and Ecology, 97: 231-267.

Johnson, C., and Mann, K. 1988. Diversity, patterns of adaptation, and stability of Nova Scotian kelp beds. Ecological Monographs, 58: 129-154.

Jorde, D., and Ray, B.J. 1988. Efficiency of nutrient use by American Black Ducks wintering in Maine. The Journal of Wildlife Management, 52: 209-214.

Josselyn, M., and Mathieson, A. 1978. Contribution of receptacles from the fucoid *Ascophyllum nodosum* to the detrital pool of a north temperate estuary. Estuaries, 1: 258-261.

Josselyn, M., and Mathieson, A. 1980. Seasonal influx and decomposition of autochthonous macrophyte litter in a north temperate estuary. Hydrobiologia, 71: 197-208.

Kelly, L., Collier, L., Costello, M., Diver, M., McGarvey, S., Kraan, S., Morrissey, J., and Guiry, M. 2001. Impact assessment of hand and mechanical harvesting of *Ascophyllum nodosum* on regeneration and biodiversity. Marine Institute, Marine Resource Series, 19.

Keser, M., and Larson, B. 1984. Colonization and growth dynamics of three species of *Fucus*. Marine Ecology Progress Series, 15: 125-134.

Keser, M, Vadas, R., and Larson, B. 1981. Regrowth of *Ascophyllum nodosum* and *Fucus vesiculosus* under various harvesting regimes in Maine, USA. Botanica Marina, 24: 29-38.

Keser, M., Swenarton, J., and Foertch, J. 2005. Effects of thermal input and climate change on growth of *Ascophyllum nodosum* (Fucales, Phaeophyceae) in eastern Long Island Sound (USA). Journal of Sea Research, 54: 211-220.

Konar, B., and Estes, J. 2003. The stability of boundary regions between kelp beds and deforested areas. Ecology, 84: 174-185.

Koop, K., Carter, R., and Newell, R. 1982. Mannitol-fermenting bacteria as evidence for export from kelp beds. Limnology and Oceanography, 27: 950-954.

Lambert, W., Levin, P., and Berman, J. 1992. Changes in the structure of a New England (USA) kelp bed: the effects of an introduced species? Marine Ecology Progress Series, 88: 303-307.

Lang, C., and Mann, K. 1976. Changes in sea urchin populations after the destruction of kelp beds. Marine Biology, 36: 321-326.

Lazo, L., and Chapman, A. 1996. Effects of harvesting on *Ascophyllum nodosum* (L.) Le Jol. (Fucales, Phaeophyta): a demographic approach. Journal of Applied Phycology, 8: 87-103.

Lazzari, M., and Stone, B. 2006. Use of submerged aquatic vegetation as habitat by young-of-the-year epibenthic fishes in shallow Maine nearshore waters. Estuarine Coastal and Shelf Science, 69: 591-606.

MacFarlane, C. 1932. Observations on the annual growth of *Ascophyllum nodosum*. Proceedings of the Nova Scotian Institute of Science, 18: 27-33.

MacFarlane, C. 1952. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. Canadian Journal of Botany, 30: 78-97.

MacFarlane, C. 1953a. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. Proceedings of the International Seaweed Symposium, 1: 72-73.

MacFarlane, C. 1953b. The seaweed resources of the Atlantic provinces of Canada. Proceedings of the International Seaweed Symposium, 1: 104-107.

MacFarlane, C. 1958. Studies in distribution and prevalence of some Gigartinales in Nova Scotia. Proceedings of the International Seaweed Symposium, 3: 28-29.

MacFarlane, C. 1971. The importance of conservation of the seaweed resource. *In* Proceedings: Meeting on the Canadian Atlantic Seaweeds Industry. Edited by Environment Canada. pp. 43-58.

Mann, K. 1972a. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. I. Zonation and biomass of seaweeds. Marine Biology, 12: 1-10.

Mann, K. 1972b. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. II. Productivity of the seaweeds. Marine Biology, 14: 199-209.

Mann, K. 1973. Seaweeds: Their productivity and strategy for growth. Science, 182: 975-981.

Mann, K. 1992. The extent and importance of rockweed as a habitat for finfish, shellfish and other species. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document, 92/116.

McPeak, R.H. 1980. A preliminary assessment of the *Laminaria* resource near Lower Woods Harbour, Nova Scotia, during July 1977. *In* Proceedings of the workshop on the relationship between sea urchin grazing and commercial plant / animal harvesting. Edited by J. Pringle, G. Sharp, and J. Caddy. Canadian Technical Report of Fisheries and Aquatic Sciences 954. pp. 180-193.

Meidel, S., and Scheibling, R. 1998. Annual reproductive cycle of the green sea urchin, *Strongylocentrotus droebachiensis*, in differing habitats in Nova Scotia, Canada. Marine Biology, 131: 461-478.

Meili, D. 1991. The effects of the environmental factors on *Laminaria* disease caused by alginic acid decomposing bacteria. Acta Oceanologica Sinica, 11: 123-130.

Miller, R. 1985. Succession in sea urchin and seaweed abundance in Nova Scotia, Canada. Marine Biology, 84: 275-286.

Miller, R., and Mann, K. 1973. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. III. Energy transformations by sea urchins. Marine Biology, 18: 99-114.

Minot, E. 1980. Tidal, diurnal and habitat influences on Common Eider rearing activities. Ornis Scandinavica, 11: 165-172.

Moore, D., and Miller, R. 1983. Recovery of macroalgae following widespread sea urchin mortality with a description of the nearshore hard-bottom habitat on the Atlantic coast of Nova Scotia. Canadian Technical Report of Fisheries and Aquatic Sciences 1230. 94 p.

Moore, D., Miller, R., and Meade, L. 1986. Survey of shallow benthic habitat: Eastern shore and Cape Breton, Nova Scotia. Canadian Technical Report of Fisheries and Aquatic Sciences, 1546.

Mouchot, M., Sharp, G., and Lambert, E. 1987. L'utilization du 'Fluorescence Line Imager' (FLI) pour la cartographie thematique des vegetaux marins submerges. Proceedings of the 11th Canadian Symposium on Remote Sensing. pp. 699-708.

Pace, D. 1982. Development and evaluation of a roller-belt harvester for Irish moss in Atlantic Canada. Fisheries Development Branch Contract, 15C81-00177.

Pavia, H., Carr, H., and Aberg, P. 1999. Habitat and feeding preferences of crustacean mesoherbivores inhabiting the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. and its epiphytic macroalgae. Journal of Experimental Marine Biology and Ecology, 236: 15-32.

Peters, A., and Schaffelke, B. 1996. *Streblonema* (Ectocarpales, Phaeophyceae) infection in the kelp *Laminaria saccharina* (Laminariales, Phaeophyceae) in the Western Baltic. Hydrobiologia, 326/327: 111-116.

Pratt, M., and Johnson, A. 2002. Strength, drag, and dislodgment of two competing intertidal algae from two wave exposures and four seasons. Journal of Experimental Marine Biology and Ecology, 272: 71-101.

Pringle, J. 1979. Aspects of the ecological impact of *Chondrus crispus* (Florideophyceae) harvesting in eastern Canada. Proceedings of the International Seaweed Symposium, 9: 225-232.

Pringle, J. 1986. Structure of certain North American government fishery agencies and effective resource management. Ocean Management, 10: 11-20.

Pringle, J., and Mathieson, A. 1987. *Chondrus crispus* Stackhouse. *In* Case studies of seven commercial seaweed resources. Edited by M. Doty, J. Caddy, and B. Santelices. FAO Fisheries Technical Paper 281. pp. 49-122.

Pringle, J., and Semple, R. 1978. The incidental harvest of immature *Chondrus crispus* (Irish moss) and its possible effects on commercial yield. Fisheries and Marine Service Technical Report 806. 12 p.

Pringle, J., and Semple, R. 1980. The benthic algal biomass, commercial harvesting, and *Chondrus* growth and colonization off southwestern Nova Scotia. *In* Proceedings of the workshop on the relationship between sea urchin grazing and commercial plant / animal harvesting. Edited by J. Pringle, G. Sharp, and J. Caddy. Canadian Technical Report of Fisheries and Aquatic Sciences 954. pp. 144-169.

Pringle, J., and Sharp, G. 1980. Multispecies resource management of economically important marine plant communities of eastern Canada. Helgolander Meeresunters, 33: 711-720.

Pringle, J., and Sharp, G. 1986. Rational for the path chosen in bringing assessment science to the eastern Canadian Irish moss (*Chondrus crispus*) fishery. Actas Segundo Congreso Nacional sobre Algas Marinas Chilenas. pp. 75-90.

Pringle, J., Ugarte, R., and Semple, R. 1990. Annual net primary production calculated from eastern Canadian Irish moss fishery data. Hydrobiologia, 204/205: 317-323.

Printz, H. 1955. Recuperation and recolonization in *Ascophyllum*. Proceedings of the International Seaweed Symposium, 2: 194-197.

Printz, H. 1959. Investigations in *Ascophyllum* areas. Skrifter det Norske Videnskaps-Akademi, I. Mat.-Naturv. Klasse, 3: 1-15.

Rangeley, R. 1994a. Habitat selection in juvenile pollock, *Pollachius virens*: Behavioural responses to changing habitat availability. Ph.D. Thesis, McGill University, Montreal, Quebec. 216 p.

Rangeley, R. 1994b. The effects of seaweed harvesting on fishes: A critique. Environmental Biology of Fishes, 39: 319-323.

Rangeley, R., and Davies, J. 2000. Gulf of Maine rockweed: Management in the face of scientific uncertainty. Huntsman Marine Science Center Occasional Report, 00/1.

Rangeley, R., and Kramer, D. 1995. Use of rocky intertidal habitats by juvenile pollock *Pollachius virens*. Marine Ecology Progress Series, 126: 9-17.

Rangeley, R., and Kramer, D. 1998. Density-dependent antipredator tactics and habitat selection in juvenile pollock. Ecology, 79: 943-952.

Saier, B., and Chapman, A. 2004. Crusts of the alien bryozoan *Membranipora membranacea* can negatively impact spore output from native kelps (*Laminaria longicruris*). Botanica Marina, 47: 265-271.

Saunders, M., and Metaxas, A. 2008. High recruitment of the introduced bryozoan *Membranipora membranacea* is associated with kelp bed defoliation in Nova Scotia, Canada. Marine Ecology Progress Series, 369: 139-151.

Scheibling, R., and Anthony, S. 2001. Feeding, growth and reproduction of sea urchins (*Strongylocentrotus droebachiensis*) on single and mixed diets of kelp (*Laminaria* spp.) and the invasive alga *Codium fragile* ssp. *tomentosoides.* Marine Biology, 139: 139-146.

Scheibling, R., and Gagnon, P. 2006. Competitive interactions between the invasive green alga *Codium fragile* ssp *tomentosoides* and native canopy-forming seaweeds in Nova Scotia (Canada). Marine Ecology Progress Series, 325: 1-14.

Scheibling, R., and Raymond, B. 1990. Community dynamics on a subtidal cobble bed following mass mortalities of sea urchins. Marine Ecology Progress Series, 63: 127-145.

Scheibling, R., Hennigar, A., and Balch, T. 1999. Destructive grazing, epiphytism, and disease: The dynamics of sea urchin - kelp interactions in Nova Scotia. Canadian Journal of Fisheries and Aquatic Sciences, 56: 2300-2314.

Schmidt, A., and Scheibling, R. 2007. Effects of native and invasive macroalgal canopies on composition and abundance of mobile benthic macrofauna and turf-forming algae. Journal of Experimental Marine Biology and Ecology, 341: 110-130.

Schmidt, A., Coll, M., Romanuk, T., and Lotze, H. 2011. Ecosystem structure and services in eelgrass *Zostera marina* and rockweed *Ascophyllum nodosum* habitats. Marine Ecology Progress Series, 437: 51-68.

Scrosati, R., Garbary, D., and McLachlan, J. 1994. Reproductive ecology of *Chondrus crispus* (Rhodophyta Gigartinales) from Nova Scotia, Canada. Botanica Marina, 37: 293-300.

Seeley, R., and Schlesinger, W. 2012. Sustainable seaweed cutting? The rockweed (*Ascophyllum nodosum*) industry of Maine and the Maritime Provinces. Annals of the New York Academy of Sciences, 1249: 84-103.

Sharp, G. 1980. History of kelp harvesting in southwestern Nova Scotia. *In* Proceedings of the workshop on the relationship between sea urchin grazing and commercial plant / animal harvesting. Edited by J. Pringle, G. Sharp, and J. Cadd. Canadian Technical Report of Fisheries and Aquatic Sciences 954. pp. 170-179.

Sharp, G. 1981. An assessment of *Ascophyllum nodosum* harvesting methods in southwestern Nova Scotia. Canadian Technical Report of Fisheries and Aquatic Sciences 1012, 36 p.

Sharp, G. 1987a. *Ascophyllum nodosum* and its harvesting in eastern Canada. *In* Case studies of seven commercial seaweed resources. Edited by M. Doty, J. Caddy, and B. Santelices. FAO Fisheries Technical Paper 281. pp. 3-48.

Sharp, G. 1987b. Growth and production in wild and cultured stocks of *Chondrus crispus*. Hydrobiologia, 151/152: 349-354.

Sharp, G., and Carter, J. 1986. Biomass and population structure of kelp (*Laminaria* species) in southwestern Nova Scotia. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1907. 47 p.

Sharp, G., and Pringle, J. 1990. Ecological impact of marine plant harvesting in the northwest Atlantic: a review. Hydrobiologia, 204/205: 17-24.

Sharp, G., and Roddick, D. 1980. The impact of *Chondrus* dragraking on substrate stability in southwestern Nova Scotia. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1593. 21 p.

Sharp, G., and Roddick, D. 1982. Catch and effort trends of the Irish moss (*Chondrus crispus* Stackhouse) fishery in southwestern Nova Scotia, 1978 to 1980. Canadian Technical Report of Fisheries and Aquatic Sciences 1118. 43 p.

Sharp, G., and Semple, R. 1991. An assessment of *Ascophyllum nodosum* resources in Scotia / Fundy 1990. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document, 91/52.

Sharp, G., and Semple, R. 1992. Data base for management strategies *Ascophyllum nodosum* (rockweed) resources southern New Brunswick. Canadian Atlantic Fisheries Scientific Advisory Committee, Working Paper, 92/218.

Sharp, G., and Semple, R. 1997. Rockweed (*Ascophyllum nodosum*). Fisheries and Oceans Canada. Canadian Stock Assessment Secretariat Research Document, 97/31.

Sharp, G., and Tremblay, D. 1989. An assessment of *Ascophyllum nodosum* resources in Scotia / Fundy. Canadian Atlantic Fisheries Scientific Advisory Committee, Research Document, 89/1.

Sharp, G., Tremblay, D., and Roddick, D. 1986. Vulnerability of the southwestern Nova Scotia *Chondrus crispus* resource to handraking. Botanica Marina, 29: 449-453.

Sharp, G., Ang, P.J., and MacKinnon, D. 1995. Rockweed (*Ascophyllum nodosum* (L.) Le Jolis) harvesting in Nova Scotia, Canada: Its socioeconomic and biological implications for coastal zone management. *In* Proceedings of Coastal Zone Canada, Dartmouth, Nova Scotia. Edited by P.G. Wells and P.J. Ricketts. pp. 1632-1644.

Sharp, G., Semple, R., and MacEachreon, T. 1998. Rockweed and periwinkle harvests conflict or complement? *In* Coastal monitoring and the Bay of Fundy. Proceedings of the Maritime Atlantic Ecozone Science Workshop, St. Andrews, New Brunswick, November 11-15, 1997. Edited by M. Burt, and P. Wells. pp. 113-117.

Sharp, G., Ugarte, R., and Semple, R. 2006. The ecological impact of marine plant harvesting in the Canadian Maritimes, implications for Coastal Zone Management. Science Asia, 32: 77-86.

Sharp, G., Semple, R., Wilson, M., Vandermeulen, H., and Rowland, B. 2008. A survey of the distribution and abundance of Irish moss (*Chondrus crispus*) on the south shore of Nova Scotia. Port Medway, Shelburne co. to Pennant Point, Halifax Co. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2856. 34 p.

Sjotun, K., and Lein, T. 1993. Experimental oil exposure of *Ascophyllum nodosum* (L.) Le Jolis. Journal of Experimental Marine Biology and Ecology, 170: 197-212.

Smith, B. 1986. Implications of population dynamics and interspecific competition for harvest management of the seaweed *Laminaria.* Marine Ecology Progress Series, 33: 7-18.

Steneck, R., Graham, M., Bourque, B., Corbett, D., Erlandson, J., Estes, J., and Tegner, M. 2002. Kelp forest ecosystems: Biodiversity, stability, resilience and future. Environmental Conservation, 29: 436-459.

Stromgren, T. 1977. Short term effects of temperature upon the growth of intertidal fucales. Journal of Experimental Marine Biology and Ecology, 29: 181-195.

Stromgren, T. 1986. Comparative growth ecology of *Ascophyllum nodosum* from Norway (LAT. 63N) and Wales (Lat. 53N). Aquatic Botany, 24: 311-319.

Stuart, V., Lucas, M., and Newell, R. 1981. Heterotrophic utilisation of particulate matter from the kelp *Laminaria pallida.* Marine Ecology Progress Series, 4: 377-348.

Stuart, V., Newell, R., and Lucas, M. 1982. Conversation of kelp debris and faecal material from the mussel *Aulacomya ater* by marine micro- organisms. Marine Ecology Progress Series, 7: 47-57.

Sumi, C., and Scheibling, R. 2005. Role of grazing by sea urchins *Strongylocentrotus droebachiensis* in regulating the invasive alga *Codium fragile* ssp. *tomentosoides* in Nova Scotia. Marine Ecology Progress Series, 292: 203-212.

Taylor, A., Chen, L., Smith, B., and Staples, L. 1981. *Chondrus* holdfasts in natural populations and in culture. Proceedings of the International Seaweed Symposium, 8: 140-145.

Thomas, M. 1978. Comparison of oiled and unoiled intertidal communities in Chedabucto Bay, Nova Scotia. Journal of the Fisheries Research Board of Canada, 35: 707-716.

Thomas, M. 1994. Littoral communities and zonation on rocky shores in the Bay of Fundy, Canada: An area of high tidal range. Biological Journal of the Linnean Society, 51: 149-168.

Thompson, R., Crowe, T., and Hawkins, S. 2002. Rocky intertidal communities: Past environmental changes, present status and predictions for the next 25 years. Environmental Conservation, 29: 168-191.

Thorne, S. 1974. Evaluation of a new Irish moss (*Chondrus crispus*) harvesting method and survey of potential harvesting sites. Nova Scotia Research Foundation Project #9025/9026. 79 p.

Toth, G., and Pavia, H. 2006. Artificial wounding decreases plant biomass and shoot strength of the brown seaweed *Ascophyllum nodosum* (Fucales, Phaeophyceae). Marine Biology, 148: 1193-1199.

Tveter, E., and Mathieson, A. 1976. Sporeling coalescence in *Chondrus crispus* (Rhodophyceae). Journal of Phycology, 12: 110-118.

Ugarte, R., and Sharp, G. 2001. A new approach to seaweed management in Eastern Canada: The case of *Ascophyllum nodosum*. Cahiers de Biologie Marine, 42: 63-70.

Ugarte, R., and Sharp, G. 2012. Management and production of the brown algae *Ascophyllum nodosum* in the Canadian maritimes. Journal of Applied Phycology, 24: 409-416.

Ugarte, R., Sharp, G., and Moore, B. 2006. Changes in the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. Plant morphology and biomass produced by cutter rake harvests in southern New Brunswick, Canada. Journal of Applied Phycology, 18: 351-359.

Ugarte, R., Critchley, A., Serdynska, A., and Deveau, J. 2009. Changes in composition of rockweed (*Ascophyllum nodosum*) beds due to possible recent increase in sea temperature in Eastern Canada. Journal of Applied Phycology, 21: 591-598.

Ugarte, R., Craigie, J., and Critchley, A. 2010. Fucoid flora of the rocky intertidal of the Canadian maritimes: implications for the future with rapid climate change. *In* Seaweeds and their role in globally changing environments. Edited by A. Israel, R. Einav, and J. Seckbach. Springer, Dordrecht, The Netherlands. pp. 73-90.

Vadas, R., Wright, W., and Beal, B. 2004. Biomass and productivity of intertidal rockweeds (*Ascophyllum nodosum* LeJolis) in Cobscook Bay. Northeastern Naturalist, 11: 123-142.

Vadas, R., Wright, W., and Miller, S. 1990. Recruitment of *Ascophyllum nodosum*: Wave action as a source of mortality. Marine Ecology Progress Series, 61: 263--272.

Vandermeulen, H. 2005. Assessing marine habitat sensitivity: A case study with eelgrass (*Zostera marina* L.) and kelps (*Laminaria, Macrocystis*). Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Research Document, 2005/032.

Vandermeulen, H., Surette, J., and Skinner, M. 2012. Responses of eelgrass (*Zostera marina* L.) to stress. Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Research Document, 2011/095.

Vea, J., and Ask, E. 2011. Creating a sustainable commercial harvest of *Laminaria hyperborea*, in Norway. Journal of Applied Phycology, 23: 489-494.

Viejo, R., and Aberg, P. 2003. Temporal and spatial variation in the density of mobile epifauna and grazing damage on the seaweed *Ascophyllum nodosum*. Marine Biology, 142: 1229-1241.

Watson, D., and Norton, T. 1985. Dietary preferences of the common periwinkle*, Littorina, littor*ea (L.). Journal of Experimental Marine Biology and Ecology, 88: 193-211.

FIGURES

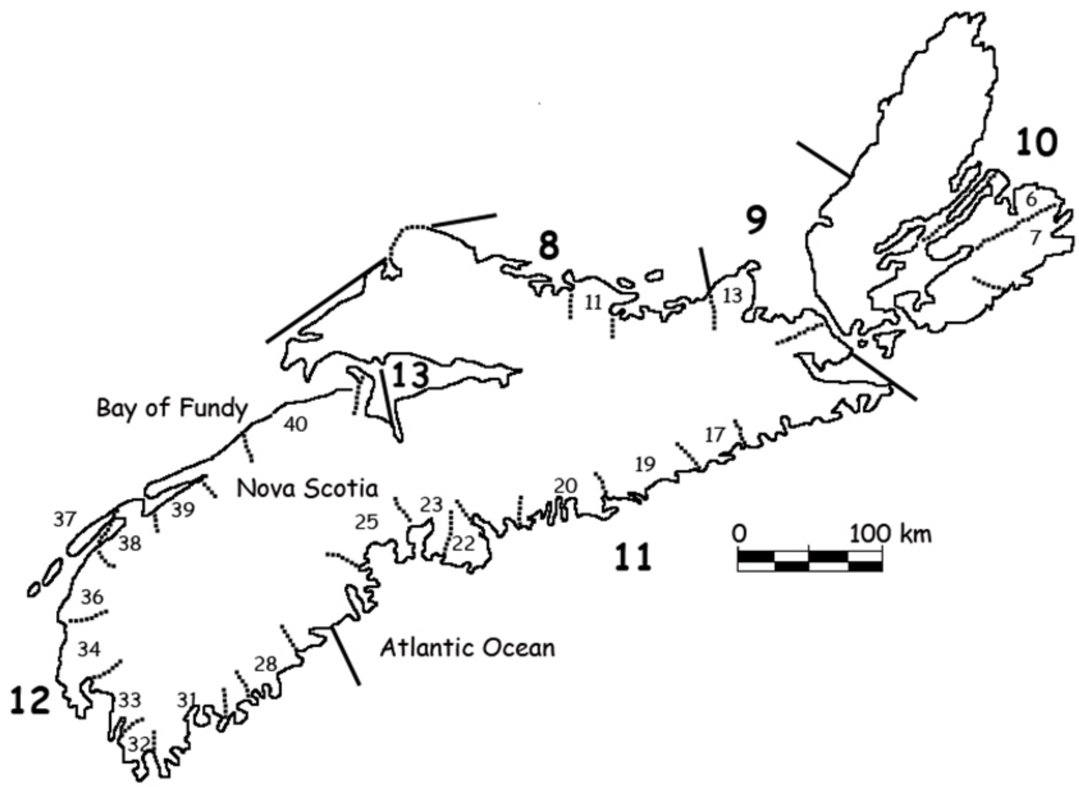

Figure 1. Map of Nova Scotia Marine Plant Harvesting Districts (large numbers) and some Fisheries Statistical Districts (small numbers) - (modified from Sharp and Roddick 1982, used with permission).

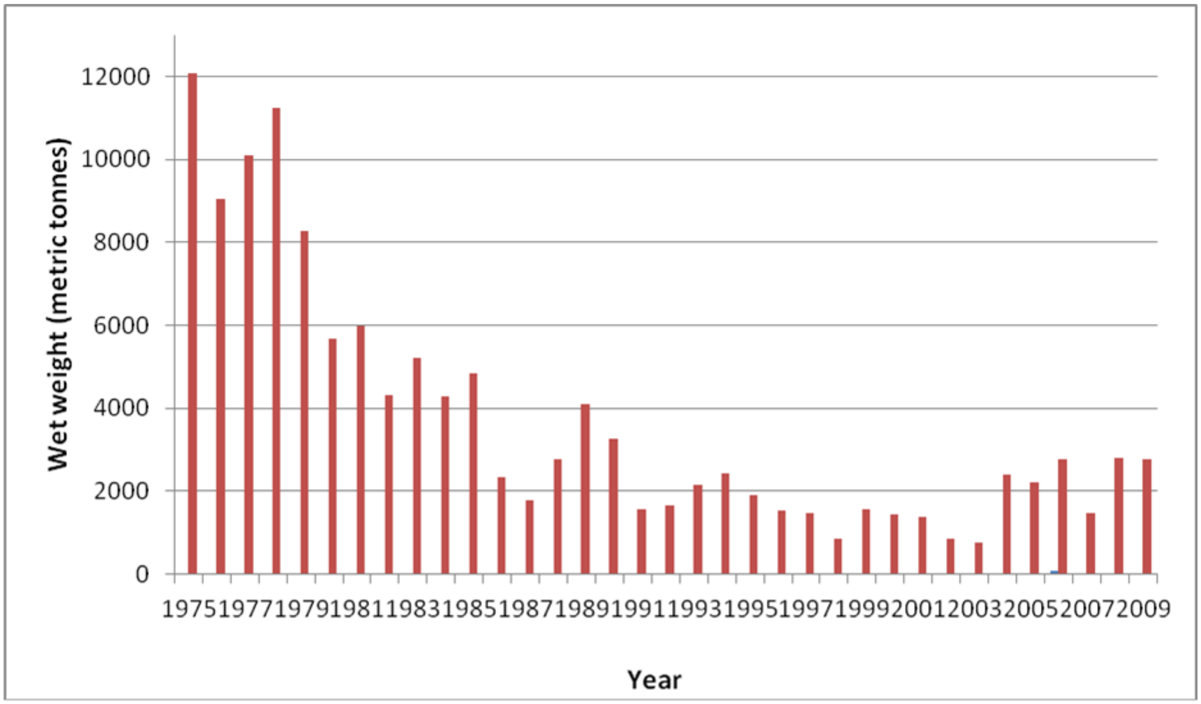

Figure 2. Nova Scotia Chondrus landings (wet weight, metric tonnes) from D12, years 1975-2009.

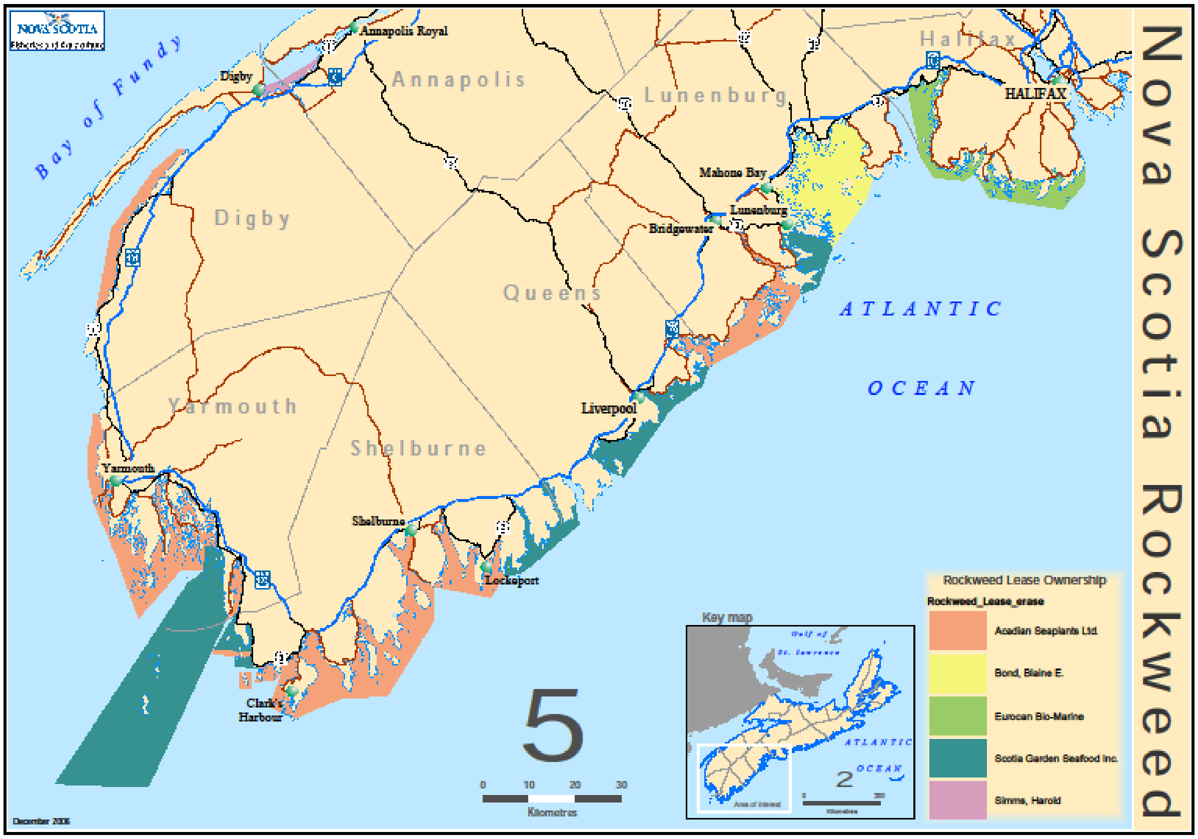

Figure 3. Map of Nova Scotia provincial lease areas for Ascophyllum.

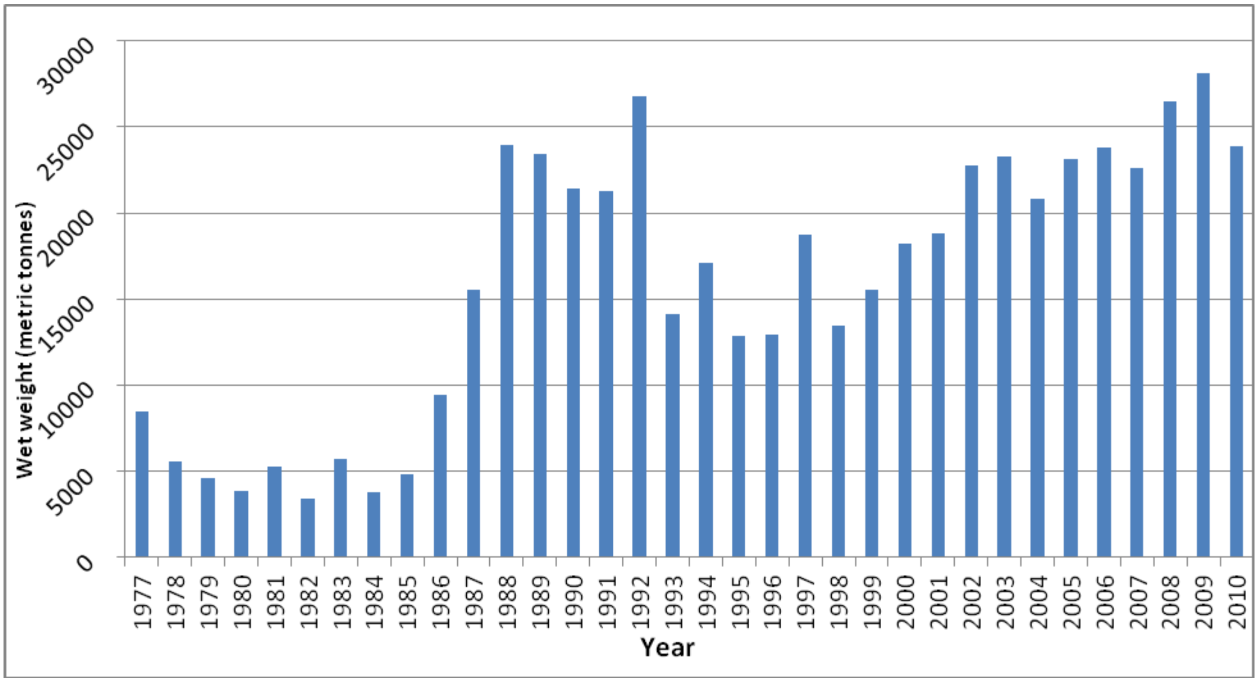

Figure 4. Nova Scotia Ascophyllum landings(wet weight, metric tonnes) from D12, years 1977-2010.

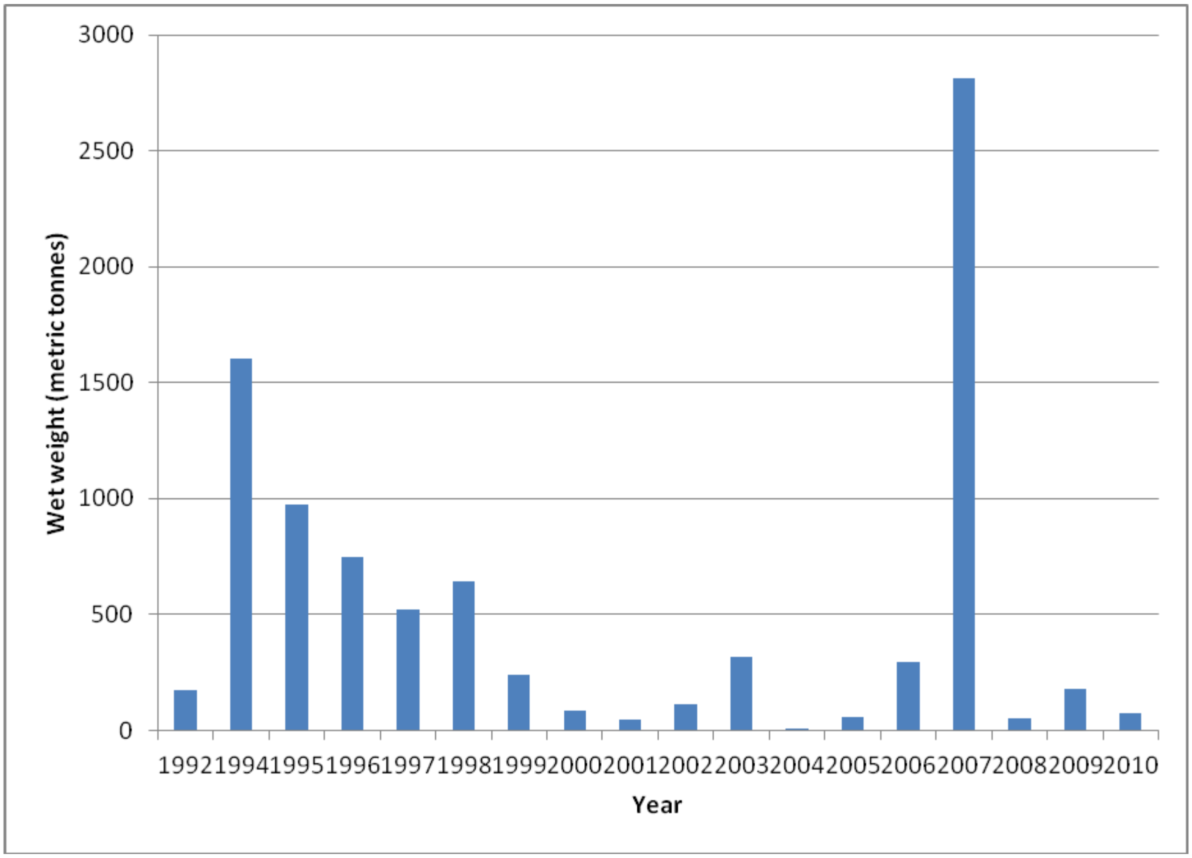

Figure 5. Nova Scotia Ascophyllum landings(wet weight, metric tonnes) from D11, years 1992-2010.