Maine Department of Marine Resources

FISHERY MANAGEMENT PLAN FOR ROCKWEED *(Ascophyllum nodosum)*

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Rockweed Fishery Management Plan

Prepared by

Maine Department of Marine Resources &
Rockweed Plan Development Team

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Cover photo by Kathy Tenga-Gonzalez
Note: Cover photo intended to display morphology and holdfast attachment to rock substrate typical of *Ascophyllum nodosum*. Picture is not intended to be representative of legal harvest.

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LIST OF ACRONYMS AND TERMS

Assessed Biomass = Biomass derived from methodology specified in Appendix A
Bladderwrack = *Fucus vesiculosus*
CBRMA = Cobscook Bay Rockweed Management Area as defined in12 MRSA §6803-C
CPUE = Catch per unit effort
Pounds = wet pounds
Rockweed = ‘*Ascophyllum nodosum*’, ‘*A. Nodosum*’, *or* ‘*Ascophyllum*’
Wet ton = raw, unprocessed rockweed. Synonymous with ‘ton’

1. INTRODUCTION

The Maine Department of Marine Resources (Department) submitted two bills during the 1st regular session of the 126th Maine Legislature regarding fisheries management plans (FMPs). LD 811 (P. L. 2013, Ch. 287) provided guidance regarding the purpose and content of FMPs. LD 585 (P. L. 2013, Ch. 169) proposed the development of a statewide approach to seaweed management, and the development of a seaweed FMP. LD 585 was passed in an amended form, and directed the Department to develop a statewide FMP for seaweed for review by the Joint Standing Committee on Marine Resources by January 2014. The initial FMP is focused on rockweed (*Ascophyllum nodosum)*, because rockweed comprises more than 95% of seaweed landings in Maine.

In April 2013, the Commissioner sought nominations for the Rockweed Fishery Management Plan Development Team (PDT) from industry, academia, and environmental organizations to ensure balanced representation from those broad stakeholder groups. The PDT was populated with these nominees shortly thereafter and held their first meeting on June 3, 2013.

The background material and recommendations in this FMP were developed from discussions at 10 meetings (52 hours total) between June 3, 2013 and January 7, 2014. PDT discussions were informed by two field trips to observe harvesting firsthand (rake harvesting in Jonesport, mechanical harvesting in Boothbay), scientific literature, information from Maine Department of Inland Fisheries and Wildlife, and public comment (submitted between and during meetings). The PDT reached consensus on all management recommendations.

It is important to understand that the PDT considers the recommendations in this document to be the starting point for establishing coastwide rockweed management. The recommendations in this FMP were designed to be adaptive as new information becomes available, conflicts arise, and industry grows.

2. PURPOSE OF FMP

This document is intended to summarize background information about rockweed (science, fishing methods, products, etc.) and provide management framework recommendations for the long-term management of the rockweed fishery. Further action by the Department is necessary to implement the management recommendations in this FMP.

3. OWNERSHIP OF INTERTIDAL SEAWEED

Ownership of intertidal seaweed remains unresolved. Clarifying intertidal seaweed ownership is a legal consideration outside the PDT's task as established in LD 585, Sec 2 that "The Commissioner of Marine Resources shall develop a statewide fisheries management plan for seaweed". The PDT acknowledged the ownership question and proceeded to develop this FMP.

4. MANAGED SPECIES

This FMP addresses the rockweed species *Ascophyllum nodosum*, referred to throughout the document as “rockweed”, “*Ascophyllum*”, or “*A. nodosum*”. The common name of rockweed is used in existing statute and rule and is most commonly used by the seaweed industry, the Maine Legislature, Marine Patrol, and others when referring to *A. nodosum* in Maine. The Department acknowledges that the common names Norwegian kelp, knotted kelp, knotted wrack, and egg wrack are also used when referring to *A. nodosum*, and that all species of *Fucus* on the Maine shore are also properly called rockweeds.

5. GOAL AND OBJECTIVES

The goal of this FMP shall be to establish harvest guidelines that support the long-term health and sustainability of *Ascophyllum nodosum* and its associated biota along the Maine coast.

In support of this goal, the management recommendations in this FMP were developed to achieve the following **objectives**:

- Adopt harvesting practices that support species diversity and richness over the long-term, and healthy *A. nodosum* stands.
- Create an adaptive harvest plan that utilizes the best available scientific data.
- Promote continued research to inform management.
- Recognize spatial differences in *A. nodosum* biology and population structures.
- Establish area-based management including closed areas for conservation and research.
- Adopt enforceable regulations that promote self-regulation and include consequences to encourage compliance and licensee accountability.
- Establish harvester training to qualify for a harvesting license or its renewal.
- Establish research and monitoring programs that include representative harvest and control areas for comparative studies.

6. BIOLOGY AND ECOLOGY

i. Distribution

Ascophyllum nodosum (L.) Le Jolis is one of five canopy-forming rockweeds (=fucoid algae) that are abundant presently on the Maine coast (Sears 2002, Johnson et al. 2011). The other species include *Fucus distichus* subsp. e*dentatus* (De La Pylaie) H. T. Powell, *F. distichus* subsp. *evanescens* (C. Agardh) H. T. Powell, *F. spiralis* L., and *F. vesiculosus* L. These rockweeds are all considered to be bioengineers because their canopies reduce the physical stresses (e.g., drying, summer heat, high light, wave exposure) of the intertidal habitat (McCook & Chapman 1991, 1997, Jenkins et al. 1999, Lamote and Johnson 2008, Watt and Scrosati 2013). The relative abundances of these rockweeds on the Maine coast are influenced by wave exposure, salinity, tolerances to drying at low tide, and competition with other algae (including other rockweeds). Most of the biomass of rockweeds on the Maine coast is formed from *Ascophyllum* or *F. vesiculosus* (typically called 'bladderwrack' in Maine).

Both *Ascophyllum* and *F. vesiculosus* have geographic ranges that extend far south and far north of the Maine coast, but by 2200, there may be significant shifts in ranges (Jueterbock et al. 2013). *Ascophyllum* is present from the Delaware/New Jersey shore to southern Greenland in the northwestern Atlantic and from the Iberian Peninsula (Portugal/Spain) to the White Sea (Russia) in the northeastern Atlantic (Schneider and Searles 1991, Sears 2002, www.algaebase.org). In the southern part of its northwestern Atlantic distribution, canopy height of *Ascophyllum* only reaches ca. 0.6 m (~2 ft), and attached plants occasionally occur on the Virginia/North Carolina shore (Schneider and Searles 1991). Sustained water temperatures of about 22-23° C (71-73°F) establish the southern limit for *Ascophyllum* (Baardseth, 1970). Both *Ascophyllum* and *F. vesiculosus* are physiologically competent to grow continuously underwater (e.g., Lubchenco 1980, Peckol et al. 1988, Åberg 1992a), and in the low salinity Baltic Sea, *F. vesiculosus* is the only canopy rockweed underwater for hundreds of kilometers of shore beyond any *Ascophyllum* (Serrão et al., 1996, 1999).

Ascophyllum is a major component of intertidal habitat along Maine's rocky coastlines where it dominates the mid to lower portions of the intertidal zone (Vadas et al. 1976, Keser et al. 1981, Topinka et al. 1981, Vadas and Wright 1986). Patterns of abundance are thought to result from the availability of solid substrata, resistance to grazing, tolerance to temperature and salinity fluctuation, and intolerance to water motion (Baardseth 1970, Vadas et al. 1978, Chock and Mathieson 1979, Stromgren 1983, Vadas et al. 1990). The upper limits of its distribution are controlled by its ability to resist desiccation and high temperatures (Schonbeck and Norton 1978).

Ascophyllum is particularly abundant in estuaries and in sheltered bays of the open coast, where its tallest canopy fronds attain a height in the mid intertidal zone of 1-2 m (3-6 ft) (Sears 2002, Dudgeon et al. 2001). It usually out-competes *F. vesiculosu*s in habitats with low wave exposure. As wave action increases (i.e., open coast), *F. vesiculosus* becomes the most abundant rockweed in the intertidal zone, where some of its canopy fronds attain a height of 0.9 m (2.9 ft) (range: 0.1-0.9 m [0.3-2.9 ft]). *Ascophyllum* is found in more sheltered areas of the coastal *F. vesiculosus* zone, but *Ascophyllum* fronds break easily in such exposed habitats. In general, *F. vesiculosus* has greater physical tolerance than *Ascophyllum* and forms a dense, narrow band above (and sometimes below) the wide *Ascophyllum* band in Maine estuaries. *F. vesiculosus* becomes the dominant rockweed in estuaries where narrow tidal channels increase water flow, and its greater tolerance to low salinity permits it to extend up tidal rivers in Maine beyond areas where *Ascophyllum* can grow (Berndt et al. 2002).

Removal of *Ascophyllum* temporarily allows other fucoids to become established for one or two years (Hawkins and Hartnoll 1985, Keser et al. 1981, Keser and Larsen 1984). *F. vesiculosus* is reproductive throughout most of the year (Speransky et al., 1999, Berndt et al. 2002, Muhlin et al. 2011), unlike *Ascophyllum* which reproduces for a shorter period of time (Bacon and Vadas 1991). Thus *F. vesiculosus* is able to recruit densely and quickly into the cleared space when ice shear and/or storms remove *Ascophyllum* canopy in estuaries and sheltered bays on the Maine coast. Embryos of *F. vesiculosus* appear to grow faster than *Ascophyllum* embryos (Choi and Norton 2005), but embryos of both species are tolerant to physical stresses (Lamote et al. 2007). The rapid replacement of *Ascophyllum* canopy by *F. vesiculosus* canopy following a severe disturbance (natural or experimental) has been demonstrated many times in Maine in estuaries, sheltered bays, and on the open coast, as well as in many other areas of the northern Atlantic in North America and Europe (Keser et al. 1981, Keser and Larson 1984, Thomas 1994, Bertness et al. 2002, Jenkins et al. 2004, Petraitis and Dudgeon 2005).

ii. Morphology

Rockweed attaches to the substratum by a disc-like “holdfast”, and they regenerate fronds from remaining holdfasts after experimental or natural disturbance that removes upright fronds (David 1943, Fritsch 1959, Baardseth 1970, Saga 1978, Fries 1988, McCook and Chapman 1991, 1992). *Ascophyllum* fronds bear air bladders that keep fronds vertically positioned in the water column and that also result in the potential for long-distance dispersal of individuals (including reproductive individuals) when fronds are broken or displaced by storms or ice-shear (Muhlin et al. 2008). *Ascophyllum* moved to new shorelines without extinction in North America during at least the last glacial cycle (ca. 18,000-110,000 years ago), and perhaps during previous glacial cycles, as demonstrated by molecular biogeographic studies (Muhlin and Brawley 2009, Olsen et al. 2010).

The holdfast of *Ascophyllum* typically supports numerous short fronds (suppressed by light limitation) in addition to the tall frond(s). When the taller fronds are broken or removed, regeneration of the canopy usually occurs by growth of these basal shoots and formation of new, lateral branches from the cut fronds (Baardseth, 1955, 1970, Keser et al., 1981) (Fig. 1). Shoot morphology varies greatly between sites and some of this variation can be attributed to environmental gradients (Cousens 1982, Peckol et al. 1988). Shoot length in relation to water movement increases with velocity up to 1 cm/sec (0.4 in/sec) but declines thereafter (Mathieson et al. 1977). Individual plants can reach two meters in length on sheltered shores, but do not attain that size on more exposed shores (MacFarlane 1952, Vadas and Ring 1968, Vadas and Wright 1986).

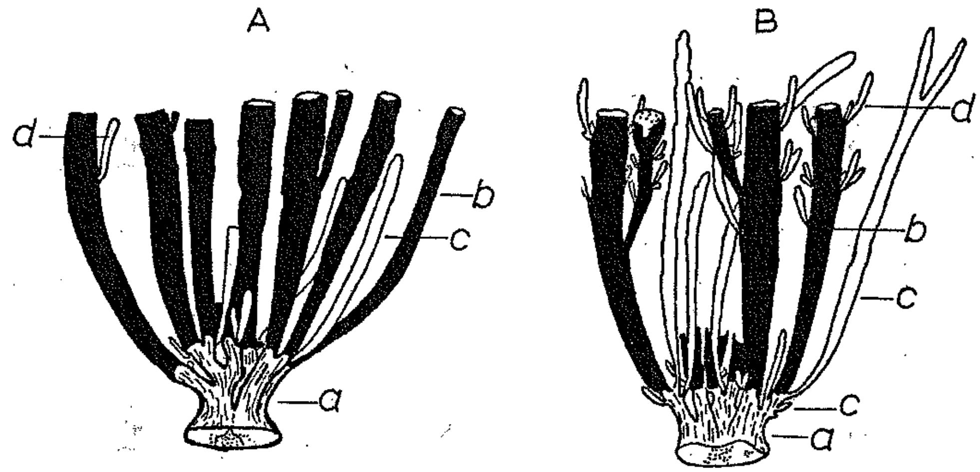

Fig. 8 A: Remnant parts of a plant just after cutting
B: Same, ca. 5 months after the cutting
a = holdfast c = base shoot
b = stump d = stump shoot

Figure 1. Shoot growth in *Ascophyllum* following cutting (from Baardseth 1970, reprinted with permission of the Food and Agriculture Organization of the United Nations).

iii. Reproduction

Ascophyllum is dioecious (male and female reproductive receptacles on separate plants), and the ratio of male plants to female plants was reported as approximately 1:1 (Baarsdeth 1970). Plant sex was determined by coloration of receptacles (male = greenish yellow, female = darker green) (Printz 1956). When mature, male receptacles contain lots of little orange dots (sperm masses) and female receptacles have green dots (egg masses). Receptacles become visible on side branches (laterals) of main fronds in fall, and they grow to large size by late spring when gamete release begins (ca. May-June in Maine, presently); mature receptacles account for about 50% of reproductive frond biomass (Josselyn and Mathieson 1978, 1980). Receptacles are enlarged at sites exposed to wide variations in salinity (Sharp 1987). Reproduction occurs over only about two "spring" tidal cycles (i.e., ~ a 4 week period centered on full and new moons) in late spring/early summer with exact timing of reproductive maturation being dependent upon water temperature (Bacon and Vadas 1991). Juvenile plants are able to persist under canopies and once established, the shoots are long-lived.

There are two ways for *Ascophyllum* (and other rockweeds) to hold space: 1) new recruitment from fertilized eggs, and 2) vegetative regeneration. In some locations (or when experimentally protected from grazers (Bertness et al. 2002, Cervin et al. 2005) *Ascophyllum* juveniles are detected easily. Åberg (1992a) reported 0-41 1-year-old plants/m^2 and Åberg & Pavia (1997) reported a mean of 40 juveniles/m^2, whereas in other studies they were not detected (Vadas et al. 1990). In general, there is agreement among studies across the northern Atlantic that *Ascophyllum* recruits poorly compared to *Fucus* spp., but that *Ascophyllum* is longer lived, with estimates ranging from 20 to 100+ years.

Recruitment from sexual reproduction may have been higher before the invasive common periwinkle (*Littorina littorea*) reached Maine in the late 1800's from the British Isles by way of Canada (Vadas & Elner 1992, Bertness et al. 2002, Brawley et al. 2009). The short period of gamete release and fertilization in *Ascophyllum* coincides with recruitment of juvenile common periwinkles and migration up into the intertidal zone by adults from subtidal areas at the end of winter. Thus, although *Ascophyllum* releases massive quantities of sperm and eggs and fertilization success is high (Lambert and Brawley 1993), most of the young zygotes become food for benthic herbivores, especially food for the invasive periwinkle (Lubchenco 1983). Common periwinkles also feed on zygotes of *Fucus* spp., which are produced over a longer period of the year and may have more opportunities to grow to sizes that escape periwinkle predation than *Ascophyllum* zygotes. In general, zygote settlement in rough surfaced areas (e.g., among barnacles) facilitates fucoid recruitment by protecting juveniles from herbivores (Lubchenco 1983), and when areas under *Ascophyllum* canopy were experimentally caged to eliminate grazing by common periwinkles in the Damariscotta estuary, *Ascophyllum* recruited to > 75% cover at > 25 juveniles/cm^2 within three years (Bertness et al. 2002, see their Fig. 9).

iv. Age, Growth, and Natural Mortality

The real age of an average *Ascophyllum* individual remains unknown due to its regenerative capability (Baardseth 1955, 1970). It is only possible to fix a minimum age to a vertical frond, because of growth inhibition after germination of the fertilized egg into a year 1 frond, but beginning in "year 2", each frond produces an air bladder/vesicle each year at the tip of the main axis. The minimum age of *Ascophyllum* shoots has been determined by the number of vesicles on the longest unbroken shoot, assuming one vesicle is formed annually (Baardseth 1970). In Maine, Keser et al. (1981) reported a maximum age beyond the first vesicle as 16 years, while Fegley (2001) reported 22 years for sheltered locations. Other studies reported 15 years in southwestern Nova Scotia (Sharp, pers. comm.) and 12 years in Wales (David 1943). A growth simulation study in Sweden estimated the maximum lifetime of *Ascophyllum* individuals to be ~50-60 years in areas with ice (Åberg 1992b). Repeated breakage of primary or lateral shoots precludes a meaningful description of age structure of a canopy stand.

Growth occurs at the tips of the branches where new cells are created by cell division (Moss 1970). The major period of growth for *Ascophyllum* in the northern Atlantic is summer (post-gamete release) through early fall (Peckol et al. 1988, Åberg 1992a, Vadas et al. 2004). Average growth rates in this region are approximately 8-11 cm (3-4 in) per year (Vadas et al. 1976, 1978).

Ascophyllum demographers typically divide fronds into size-classes by length or biomass, finding that shorter size classes predominate (Åberg 1992a [see his Fig. 5], Lazo and Chapman 1996 [see their Table 3], Keser et al. 1981 [see their Table 2 for predominance of shorter size classes in Maine]). The distance between air bladders is a general indication of how good the growing conditions were in that year, and can vary dramatically over short geographic distances on the shore as a function of exposure and due to different light levels experienced by different lengths of fronds within the canopy (Vadas et al. 2004). Cousens (1982) found the mean length of the youngest internode varied from 5 to 12.5 cm (2-5 in) of yearly growth on an exposure gradient around a small Nova Scotia island.

The magnitude of natural mortality for *Ascophyllum* varies annually and is affected by tidal level, wave exposure, ice cover (Fig. 2), and water temperature. In more exposed habitats, most fronds have broken at least once, and about 34-50% of *Ascophyllum* biomass is naturally removed on an annual basis on the New England/Canadian Maritime shore (Mathieson et al. 1982, Peckol et al. 1988, Vadas et al. 2004, Ugarte 2011). Vadas et al. (2004) found that 29-71% (mean=54%) of *Ascophyllum* biomass was removed yearly from their five study sites in Cobscook Bay and suggested that biomass turns over every two years in this part of the Maine coast. Removal of plants that included removal of holdfast material by a summer storm in 2004 in southern New Brunswick exceeded removal of harvested plants with some holdfast material (Ugarte 2011, see Fig. 3).

The biomass of unharvested rockweed beds is completely replaced with new growth every three to 11 years (Sharp 1987, Vadas et al. 2010). Holdfasts and short fronds persist and may be very old. Vadas et al. (1976) reported survivorship of shoots in a Maine estuarine site was 75% after one year. Cousens (1981) reported maximum survival for primary shoots beyond the first vesicle was 5 years at exposed sites and 11 years in wave sheltered areas. Demographic studies of *Ascophyllum* populations in Sweden found higher mortality rates and higher probabilities for breakage to smaller sizes in years with ice (Aberg 1992a, Lubchenco 1980).

Grazing by littorinid snails is a major source of mortality for recently settled zygotes and embryos of *Ascophyllum*, but growth of adults is facilitated by these snails. Littorinid browsing removes epiphytes (e.g., diatoms) from rockweed surfaces without damaging adult tissues (Lubchenco 1978 and 1980, Watson and Norton 1985).

Figure 2. Ice damage and recovery by *A. nodosum* and *F. vesiculosus*. Left. Ice damage in Shag Harbour, NS, in 2004. Right. Same area in 2007. Red circles indicate same rock for reference.

v. Growth and Biomass Regeneration Following Harvesting

Ascophyllum has been harvested sustainably for centuries in northern Europe (Baardseth 1970, Guiry and Morrison 2013). The harvest history is well documented from the western Irish coast since the late 1940's, and is about 5,000-6,000 dry wt tons/year presently (wet wt =4x dry wt for *Ascophyllum*), largely from Connemara, County Galway (Guiry and Morrison 2013). Hand-cutting of the canopy to leave intact holdfasts and the basal 25 cm (10 in) lengths of fronds can be repeated every 3-5 years in a particular location (Baardseth 1955, Guiry and Morrison 2013). Before the *Ascophyllum* canopy grows back to its original height, transient recruitment of *F. vesiculosus* occurs (Baardseth 1955). Keser et al. (1981) found less biomass was obtained each year over three successive years (1973-1976) of experimental cutting of *Ascophyllum* canopy to 25 cm (10 in) height in Maine, emphasizing the importance of a fallow period before plants are cut again.

The regrowth of *Ascophyllum* following loss or harvest depends on a number of factors, including the age structure of the population, the extent and pattern of branching, and the presence or absence of grazers such as periwinkles and small crustaceans (Keser et al. 1981, Lazo and Chapman 1996, Fegley 2001, 2006). Regrowth of *Ascophyllum* is reduced if the holdfast is damaged, or where rockweed is completely removed from large areas. The historically-recognized importance of the holdfast by traditional harvesters and the dual importance of sexual reproduction/recruitment and regeneration in *Ascophyllum* population structure were reviewed by Baardseth (1970). Baardseth (1955) documented the regrowth of canopy from stumps (fronds cut to ca. 25 cm [10 in] length by harvesters), including both release of light-suppressed, short shoots existing at the time of the cut and the appearance of new basal and vegetative lateral branches from cut fronds (Fig. 1) and their rapid development and growth in the first year. Growth in fucoids is apical (Fritsch, 1959) and when only the upper part of a plant is broken or harvested, a lateral branch(es) just below the site of the break/cut dominates new growth in length to restore the original canopy height. The recovery of Nova Scotia beds after severe ice scouring (Fig. 2), as well as after harvest, suggests that *Ascophyllum* holdfasts regenerated full canopy, as has been demonstrated elsewhere for rockweeds (McCook and Chapman 1991, Kiirikki and Ruuskanen 1996).

Experimental ecologists have confirmed the importance of leaving the lower sections of *Ascophyllum* intact. When holdfasts are removed by extensive wire brush scraping, lye treatments, formaldehyde treatments and/or burning of the substratum with a propane torch, recovery of the *Ascophyllum* community is very slow, and rarely occurs over typical 3-10 year study periods (Knight and Parke 1950, Keser & Larson 1984, Thomas 1994, Petraitis & Dudgeon 2005, Petraitis et al. 2009), although it can occur over longer periods (e.g., 46% recovery after 12 years in the British Isles, Jenkins et al. 2004).

Fegley (2001) examined three harvesting regimes (cut 18 cm [7 in] from the holdfast, 36 cm [14 in] from the holdfast, and an unharvested control) at Castine, Blue Hill, Lamoine, and Rackliff Island, Maine during 1996-1999. One year after the harvesting event, the growth rate of *Ascophyllum* was highly variable and depended on cut intensity and site. The number of branches at 18 cm [7 in] and the number of apical dichotomies increased in the harvested plots. Two years following the experimental harvest, the biomass values in the three treatments were not statistically different from one another despite the fact that the mean biomass in the 18 cm [7 in] cut plots was only 66% of the mean biomass of the control plots. Plants in control plots were significantly longer than the plants in either of the cut plots, indicating a lack of recovery to pre-existing conditions. Keser et al. (1981) found similar biomass recovery rates: the average biomass recovery in their 15 cm [6 in] cut plots was 62% of the original biomass after three years. Fegley (2001) cautioned that although no statistical difference was detected in the mean biomass values between treatments, the high variability associated with the biomass sampling decreases the power of the statistical analysis making it harder to reject the null hypothesis. Thus caution should be employed in using this information for management.

Lazo and Chapman (1996) reported that *Ascophyllum* growth rates in mechanically cut plots were twice as high as in uncut plots (e.g., winter growth: 4 cm (1.6in)/year +/- mean +/- 11 cm [SD] for a harvested treatment vs. 1.1 cm (0.4 in)/year mean +/- 10.8 cm [SD]) in Lower Woods Harbor, Nova Scotia. They found that growth of *Ascophyllum* fronds is size-dependent with shorter fronds (< 27 cm [10.6 in]) growing faster. Individuals < 27 cm (10.6 in) in the canopy contributed most to recovery because of their higher rate of frond growth when not inhibited by low light and due to their abundance. They recommended a harvesting strategy based on cutting larger fronds. The growth rates in this study were lower than rates reported previously for other southwestern Nova Scotia studies because it included fronds that broke during the course of the study resulting in negative growth for the tallest size class of fronds. Similarly, Ang et al. (1996) found that a bimodal structure (shorter and longer fronds) reappeared about three years after mechanical harvest of *Ascophyllum* in Nova Scotia.

Table 1. Reported growth rates of *Ascophyllum nodosum* from various studies.

Location	Growth Rate	Season	Method	Reference
Great Bay Estuary System, NH	3.6-3.4 cm/mo 2.3 cm/mo 2.2 cm/mo	April & July May October	Tagged plants, measured monthly	Mathieson et al. 1976
Montsweag Bay, ME	10 cm/month	Annual average	Internode measurements	Vadas 1972
Damariscotta River & Montsweag Bay, ME	17.4 +4.7 cm/yr 11.5 + 5.5 cm/yr 12.2 + 5.5 cm/yr	Annual average	Internode measurements	Keser and Larson 1984
Quahog Bay, ME Boothbay Harbor,ME Cobscook Bay, ME	9.35 cm +/- 0.1 SE 7.97 cm +/-0.07 SE 8.61 cm +/- 0.1 SE	Average annual	Internode measurements	Fegley and Vadas 2001
Maine coast	~12 cm/year	1st year following harvest	Internode measurements	Fegley 2001
Nova Scotia	0.33-1.2 cm/month 9 cm avg. (4-15 cm/yr range)	Annual	Internode measurements	MacFarlane 1932
Nova Scotia	5-12.5 cm/year	Average annual	Internode measurements	Cousens 1982
Southwestern Nova Scotia	1.5-8.9 cm/yr	Average annual	Tagged fronds	Lazo and Chapman 1996

The overall impacts of cutter rake harvests on intertidal habitat in a Nova Scotia study were of short duration (Ugarte et al. 2006). Biomass recovered after a year of the experimental harvest, and the rapid recovery was attributed to a stimulation of growth and branching of the suppressed shoots of the clumps (a clump is the collection of shoots from a contiguous holdfast). Biomass recovery in harvested clumps was 85% after a year in one plot, total in another, and a 52% increase in a third plot. Two years after harvest, there was total recovery in the first plot, a 22% increase in biomass in the second, and the biomass in the third plot was down but still maintained a 23% increase over the original biomass. The distribution of biomass within a clump changes from being proportionately higher closer to the bottom of clumps at lengths less than 90 cm (35 in) to over 50% in the upper one third of the clump in the 130 cm (51 in) long clump class. Length was significantly reduced by harvest in clumps >70 cm (27.5 in), and clumps >90 cm (35 in) and >130 cm (51 in) lost 35% and 45% of their original length. The mean clump length in harvested plots increased through the first year after harvest to total recovery in one plot and only 95% and 92% in the other two plots; there was a small but significant increase in mean clump length in the control plots.

The incidence of holdfast material in two studies of rockweed harvested by cutter rakes ranged from 6.6 to 7.78% (Ugarte et al. 2009, Ugarte 2011). Ugarte (2011) found that when a rake strips a clump, it only detaches 17.4% of the holdfast surface, leaving 36.8% of the plant biomass and 80.3% of the shoot density intact. An analysis of storm-cast material from the same study area showed a similar effect in the clump structure, although the holdfast incidence could be as high as 30%. Due to the high biomass detached each year by coastal storms in New Brunswick, storm impact on the *A. nodosum* resource is 21 times higher than the annual harvest (Ugarte 2011). Holdfast incidence in harvested material can be the result of a friable substrate holding the rockweed clumps, a naturally damaged clump, or poor condition of the harvesting tool.

vi. Ecology

Rockweeds, collectively, provide a number of ecological functions including nutrient cycling, providing food for grazers and detritus feeders, helping maintain water quality, and providing habitat for numerous species (Wippelhauser 1996). Seaweed canopies have long been identified as playing important community structuring roles by modifying the physical and biological conditions in the habitats where they dominate (Dayton 1975, Menge 1978, Eckman et al. 1989, Bertness et al. 1999, Fegley 2001). The structural complexity alters the physical environment, thereby influencing the abundance and distribution of associated species (Bertness 1999).

Fucoid biomass, especially that of *Ascophyllum* and *F. vesiculosus*, contributes to several detrital/consumer pathways. An excess of sperm is produced during rockweed reproduction, and these gametes contribute to the planktonic food web (Berndt et al. 2002, Maximova and Sazhin 2010, Muhlin et al. 2011). Following gamete release, receptacles begin to decompose. They detach from adults and contribute to the estuarine and marine detrital pools (e.g., 445 g dry wt/m^2/yr within the Great Bay Estuary System of New Hampshire-Maine, Josselyn and Mathieson 1978). Decomposition is relatively slow; about 50% of the ash-free dry weight of receptacles is lost within 50 days (Josselyn and Mathieson 1978). Broken fronds of adults also enter detrital pathways, and can drift long distances in floating mats when removed by ice shear or storms (Ingólfsson 1998, Vadas et al. 2004). Drifting mats of buoyant *Ascophyllum* and *F. vesiculosus* also contain many invertebrates such as amphipods, isopods, and several phyla of “worms” including nematodes, as well as non-intertidal species (Ingólfsson et al. 1998, Clarkin et al. 2012). These mats of drifting rockweeds can be carried to shore where they supply food to a variety of invertebrates (e.g., amphipods, insects) as the wrack decomposes at the high tide line (MacMillan and Quijon 2012, Gómez et al. 2013).

Many algal epiphytes (e.g., a variety of filamentous brown algae) and invertebrates (e.g., amphipods, isopods) are found in common between co-occurring *F. vesiculosus* and *Ascophyllum* (Rindi and Guiry 2004, Longtin et al. 2009, Watt and Scrosati 2013), but *Ascophyllum* is commonly colonized by the filamentous red alga *Vertebrata lanosa* (= *Polysiphonia lanosa*), which is rare on *F. vesiculosus* (Sears 2002). Rockweed zygotes/embryos attached to the substratum and rockweed epiphytes (e.g., diatoms, filamentous algae) provide food for a variety of small invertebrates (Lubchenco 1983, Golléty et al. 2010), but the adult algae are rarely eaten because they store chemicals (tannins=phenolics) that make them unpalatable. If eutrophication increases filamentous algal biomass on the fucoid canopy, associated isopod/amphipod grazers grow to reach large size and densities, which leads to destruction of rockweed canopy after the grazers consume their preferred epiphytic foods (Kangas et al. 1982). Davies et al. (2007) observed a loss of canopy cover of *Ascophyllum* with increases in limpet population density following a series of mild winters in Northern Ireland.

The most commonly associated invertebrate of *Ascophyllum*-dominated, sheltered sites on the open coast of Maine is a barnacle (*Semibalanus balanoides*), but numerous other invertebrates are found such as amphipods, periwinkle snails, mussels, isopods, nematodes, and oligochaetes (Schmidt et al. 2011, Larsen 2012). Fucoid canopies protect young stages of marine organisms from many physical stresses (e.g., drying, heat), but can inhibit larval settlement (e.g., of barnacles), remove juvenile benthic species as fronds sweep the substratum, and can shelter predators such as the invasive green crab (*Carcinus maenas*) that eats mollusks (Leonard et al. 1998, Bertness et al. 2002, Menge 1976, Brawley and Johnson 1991, Bertness et al. 1999, Jenkins et al. 1999, Dijkstra et al. 2012).

At high tide, fish such as rock gunnels and juvenile pollock enter rockweed canopies to feed on the associated small invertebrates (Rangeley and Kramer 1995, Rangeley and Davies 2000). A study of the possible impact of removal of *Ascophyllum* on intertidal abundance of fishes and their gut contents found no significant differences in number and weight of fish between cleared (cut to the level of the holdfast) and intact areas during June to October, and only cunner (*Tautogolabrus adspersus*) had more food in their stomachs when leaving the intact areas than when leaving clear areas (Black and Miller 1991). Numbers of fish in the intertidal were significantly lower than in the shallow subtidal. The study provided no evidence for adverse effects of the removal of patches of *Ascophyllum* on fishes. Schmidt et al. (2011) examined ecosystem structure and services in eelgrass (*Zostera marina*) and rockweed (*Ascophyllum nodosum*) and overall, found the abundance of adult and juvenile fishes and decapods in transects and quadrats were low and variable. They documented the occurrence of American eel (*Anguilla rostrata*), threespine stickleback (*Gasterosteus aculeatus*), rock gunnel (*Pholis gunnellus*), and Atlantic mackerel (*Scomber scombrus*) within rockweed at high tide; and cod (*Gadus morhua*), tomcod (*Microgadus tomcod*), Atlantic mackerel, northern pipefish (*Syngnathus fuscus*), tautog (*Tautogalabrus adspersus*), and winter flounder (*Pseudopleuronectes americanus*) along the edge of rockweed at high tide. More recently, Van Guelpen and Pohle (2013) looked at short and long-term impact of rockweed harvesting on the intertidal fish community in southwest New Brunswick and found a large magnitude of environmental variability but no statistical differences in pre- and post- harvest ichthyoplankton community structure in 2011 and 2012. Results of 2011 gillnet sampling indicated no differences in fish community structure between the first harvest and control sites.

Common Eider ducklings and associated females in the Bay of Fundy feed extensively on invertebrates found in association with rockweed (Hamilton 2001). Blinn et al (2008) examined factors, including harvested and non-harvested rockweed beds, affecting selection of brood-rearing habitat by common eiders in the Bay of Fundy, New

Brunswick. Overall, abundance of *Ascophyllum nodosum* did not appear to be an important selection criterion for Common Eider brood-rearing sites. Habitat slope was much more important and sites with a gradual slope, which offered more surface feeding area, supported 43-85% more ducklings than sites with a steep slope. Results provided limited evidence of an adverse effect of rockweed harvesting on ducklings, specifically on Grand Manan, where the combined effect of a steep slope and harvest may have reduced food availability.

There is no documentation that rockweed beds serve as primary habitat for the American lobster (*Homarus americanus*). Lobster primarily occurs subtidally throughout its range, but juveniles can be found in the lowest intertidal, primarily underneath small rocks or cobble, near or below the lower distributional fringe of *Ascophyllum* (MacKay 1926, Cowan 1999, Ellis and Cowan 2001, Schmidt et al. 2011). During two census periods in July 2006 at Appledore Island, ME, Jones and Shulman (2008) reported the average densities and size of lobsters (2.2 lobsters/20 m^2, average carapace length =59 mm) moving from the adjacent subtidal zone in the day to forage on nocturnal high tides in rocky intertidal ledge habitat covered in the algae *Chondrus crispus* and *Mastocarpus stellatus*. This habitat is below the *Ascophyllum* zone. Seeley et al. (2013) observed more lobsters at night and more in the high subtidal (*Corallina*), than *Chondrus* or rockweed edge in August 2013 at Appledore Island.

Fucoid communities are well studied; however, most studies of the impacts of harvesting or losses due to natural causes of *Ascophyllum* and the communities it supports have been short term. Rockweed harvesting removes physical habitat, causing a temporary decrease in the number of species utilizing cut areas (Sharp and Pringle. 1990, Fegley 2001). Few effects persist beyond one year, and many important members of the intertidal community appear unaffected by one-time harvest at a moderate intensity. Fegley (2001) examined the ecological implications of harvesting *Ascophyllum* on the associated community. Short term effects (< 1 year) of three harvest treatments (unharvest/control and harvested at 18 cm (7 in) and 36 cm (14 in) from holdfast) on the associated macroscopic floral and faunal (non-fish) assemblages were evaluated to assess possible changes in community structure at four intertidal sites in mid-coast Maine using a single harvest event. Ten of the most common species were significantly affected by the harvesting of rockweed. While abundances of many organisms remained stable following the harvest, the intensity of the disturbance was an important factor in the recovery rate of those species that were affected. The study concluded that both the target species and the associated community are resilient to single perturbations at a moderate (36 cm cut [14 in]) harvesting intensity.

Trott and Larsen (2009) evaluated short-term changes in rockweed and associated epifaunal communities following cutter rake harvesting at a site in Cobscook Bay in 2008. Conclusions of this study were that cutting rockweed results in increased biomass, species assemblages were not distinctly different before and after harvesting, and there was no significant impact of harvesting on abundance of epifauna on either substrate or rockweed thalli, on the species richness of epifauna, or on the abundance of the three species of periwinkle snails during the two-month duration of the study. Beal et al.

(2012) found no statistical difference in algal biomass 40 days after cutting between control and harvested plots and no significant impacts on periwinkle biomass. Preliminary results of a study to assess the impacts of rockweed harvesting on intertidal fauna at Sears Island in Penobscot Bay found that harvested plots have more periwinkles, fewer green crabs, and no difference in the various species of meiofauna/infauna or sediment characteristics as compared to unharvested sites (Phillippi 2013).

A preliminary study was conducted to monitor periwinkle bycatch and the incidence of holdfasts in hand harvested rockweed in Cobscook Bay (Ugarte et al. 2010). The commercially harvested common periwinkle (*L. littorea*) was the least abundant periwinkle species (0.175 mt) while the smooth periwinkle (*L. obtusata*) dominated the bycatch with an estimated 0.86 mt removed during the entire harvest season, followed by the rough periwinkle (*L. saxatilis*) (0.29 mt). Average common periwinkle densities in the canopy at Shackford Head in Cobscook Bay in 2008 were 45/m^2 (Trott and Larsen 2009). If similar densities exist along all rockweed beds in Cobscook Bay, the total biomass of common periwinkles would be around 2,327 mt and approximately 0.008% of the commercial periwinkle harvest would have been taken in the rockweed harvest in 2009. Using Trott and Larsen's (2009) density estimations for the other periwinkle species, approximately 0.044% of the total snail population found on rockweed beds was removed during the 2009 harvest.

7. CONDITION OF THE RESOURCE

i. History of Biomass Assessments in Maine

Numerous studies have estimated biomass of *Ascophyllum nodosum* along the Maine coast (Table 2). Estimates of standing crop and productivity are highly variable, based on method of estimation, and temporal and spatial variability. Vadas et al. (2004) estimated biomass and productivity of rockweed in Cobscook Bay, an area unique in New England for its high tidal amplitude, wide intertidal expanse, diverse flora and fauna, and presumed high intertidal productivity. Their highest estimates were comparable to estimates for southwestern Nova Scotia [~32 kg/m^2 (MacFarlane 1952, Sharp 1987)], Norway (Baardseth 1970), and Spain (Soneira and Niell 1975). Turnover rates of *Ascophyllum* ranged from 29 to 71% (mean over all sites = 54 %) indicating that biomass of this alga turns over approximately every two years.

Assessments of *Ascophyllum* were conducted for the Department in 2000 in Quahog Bay, the Boothbay/Sheepscot River region, and Cobscook Bay (Fegley and Vadas 2001); Quahog Bay and the Boothbay region in 2002 (Fegley 2003); and Quahog Bay, Taunton Bay, and Frenchman's Bay in 2005 (Fegley 2006) (Table 2). In addition to biomass estimates, individual plants at each site were measured for growth and population characteristics. Total biomass was estimated for Quahog Bay in 2005 because of the geographic discreteness of the Bay and the fact that a single company has sustainably harvested in this Bay over a number of years.

Table 2. Biomass estimates (wet weight) for *Ascophyllum nodosum*.

Location	**Year**	**Biomass** (wet weight)	**Study**
Southwestern Nova Scotia	1948-1950	9-26 kg/.8361 m^2	MacFarlane 1952
Cobscook Bay	1995-1996	8.5-28.9 kg/m^2	Vadas et al. 2004
Cobscook Bay	2000	8.7-23.2 kg/m^2 14.6 kg/m^2	Fegley and Vadas 2001
Frenchman's Bay/Taunton Bay	2005	6.3-15.4 kg/m^2 avg. 8.8 kg m^2	Fegley 2006
Lamoine, Blue Hill Bay, Castine	1996	7 +/-4 kg/m^2	Fegley 2001
Lamoine, Blue Hill Bay, Castine, Rackliff Is.	1999	17 +/-3 kg/m^2	Fegley 2001
Damariscotta River/Pemaquid Point	1974-1976	5.0 +/-3.6 kg/m^2 - 17.5 +/-6.9 kg/m^2	Keser et al. 1981
Sheepscot River/Damariscotta River	1978	17 kg/m2 (all fucoids)	Topinka et al. 1978
Boothbay/Sheepscot River region	2000	6.4-19.6 kg/m^2 avg. 15.3 kg/m^2	Fegley and Vadas 2001
Boothbay/Sheepscot River region	2002	5.8-19.3 kg/m^2 avg. 10.7 kg/m^2	Fegley 2003
Quahog Bay	2000	7.6-18.1 kg/m^2 avg. 12.4 kg/m^2	Fegley and Vadas 2001
Quahog Bay	2002	6.7-22.6 kg/m^2 avg. 14.8 kg/m^2	Fegley 2003
Quahog Bay	2005	8.5-35.4 kg/m^2	Fegley 2006

Overall most biomass values for Quahog Bay were not statistically different in 2005 from previous years. There were a few cases where biomass values were substantially higher than in 2002, with a reduction at only one area. Examination of individual plants from Quahog Bay revealed that most of the plant biomass is found higher than the minimum cutting height of 40.5 cm (16 in). It was estimated that 13,280 metric tons (14,758 short tons) of rockweed is contained in Quahog Bay. The overall biomass in the Boothbay Harbor Region decreased from 2000 to 2002. The substantial ice rafting in the bay over the interceding winters could have caused a reduction in the overall *Ascophyllum* biomass.

ii. Cobscook Bay Management Area Assessments

Recent assessments of rockweed have been conducted in Cobscook Bay as required by Maine statute, 12 M.R.S.A. , Ch. 623, §6803-C. Cobscook Bay Rockweed Management Area (CBRMA). Cobscook Bay is divided into 36 management sectors that are allocated to harvesters or their representatives (Fig. 3). In order to harvest from a sector, total rockweed biomass contained in the sector must be provided to the Department, based on a survey conducted within the previous three years. Biomass assessments for all sectors were conducted by Acadian Seaplants Limited (ASL) in 2008, and selected sectors by ASL and other harvesters in 2011 and 2012.

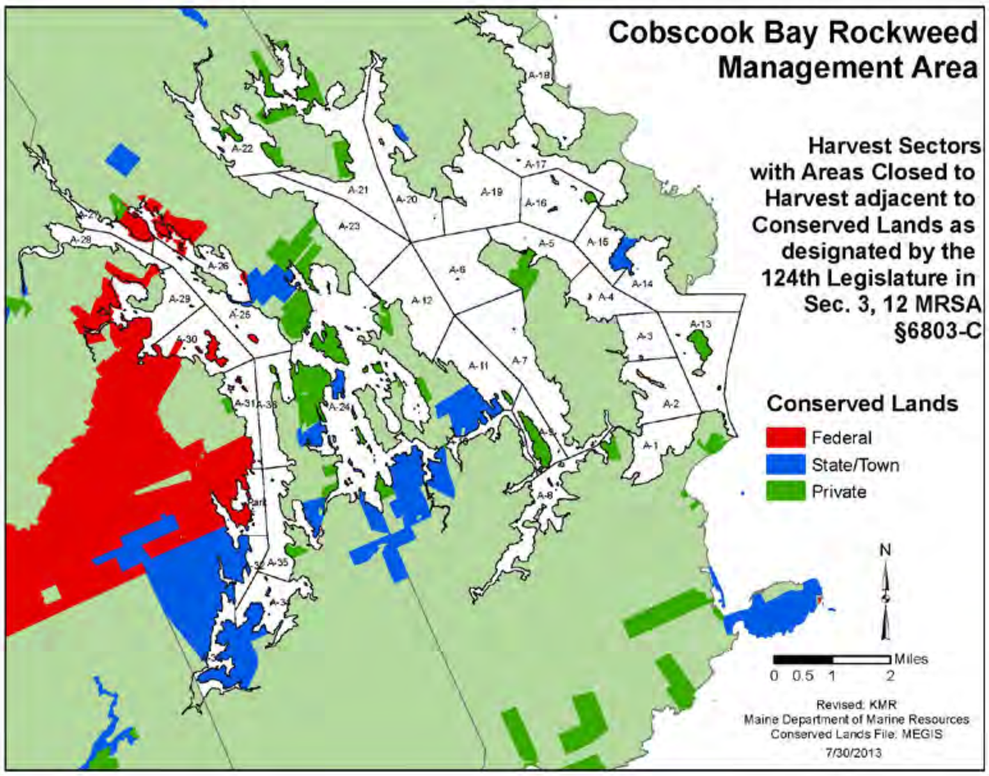

Figure 3. 2013 Cobscook Bay Rockweed Management Area sectors.

To determine the biomass of rockweed in Cobscook Bay and other locations in Washington Co., ASL used a biomass assessment program that integrated aerial photography analysis and ground truthing (Ugarte, pers. commun.). This methodology has been adopted and used by other harvesters or their representatives in Cobscook Bay. Color aerial photographs of the Maine shoreline from the Department were used to identify and estimate the area covered by the resource. These photographs were taken in 1993 and no evidence of changes in the perimeter of the beds measured with the old photos was detected during ground truthing. The first step was a visual examination of the shoreline on the aerial photographs to identify the *Ascophyllum* beds. A bed is defined as a homogenous and continuous geographical unit containing *Ascophyllum*. Usually its borders are defined by a geographical disruption (e.g., a sandy beach, a rock formation, etc.), or any other physical feature that resulted in a drastic change in cover. All the selected aerial photos containing *Ascophyllum* beds were scanned into a computer and properly identified according to harvesting sectors. Subsequently, the area of the beds was measured using an image analysis program (Image J). Calibration of the photographs was made with navigation charts and field measurement. A total of 1,186 beds were identified and measured in Cobscook Bay.

Ground truthing was carried out in 120 locations previously selected in the aerial photographs and spread along the Bay. Although a random stratified sampling design has been suggested for the biomass assessment of *Ascophyllum*, experience indicates that the rockweed biomass is quite homogenous in 90% of the bed width (between its high and low borders). Thus, transects were set horizontally in the mid portion of the bed from which at least ten random samples were taken.

The sampling unit used during the assessment is a 0.25 m^2 (50 x 50 cm) size. This quadrat has been demonstrated to represent a good compromise between statistical and practical requirements. Besides biomass density, general information on the transect location included substrate type, wave exposure, slope, and any other particular details of the bed. Bare patches are considered a natural property of the zone and all zero values (quadrats without clumps) were recorded and counted. The width of the bed at the transect point was also recorded and used to calibrate area measurement from aerial photos.

After the ground truthing data were obtained and the computer analysis of the area was completed for the aerial photographs, an integration of information was carried out. A computer file was created for each individual sector with all the biological and physical information of each individual bed. For beds smaller than 80 m long where no transect was used, an extrapolation of the average biomass from the neighboring, larger beds was made.

8. ROCKWEED FISHERY

i. History of the Fishery

In early American and colonial times, rockweed was utilized by Native Americans, and later, by New England colonists for agriculture, food, and animal feed.

Prior to the 1970's, industries were well established in Canada, the British Isles, France, Iceland, and Norway. In Maine, rockweed was traditionally harvested for fertilizer and seafood packing material.

Commercial scale operations began in Maine in the 1970's. North American Kelp was established in 1971 in Boothbay, harvesting from the Sheepscot River to the Damariscotta River. Their processing facility was relocated to Waldoboro in 1973. Source Maine began operations in Georgetown in 1981 and moved to Brunswick in 1986, harvesting mainly in the Casco Bay region. Ocean Organics, a producer of primarily extracts, was started in Waldoboro in 1991. Acadian Seaplants, a Nova Scotia-based company, began harvesting rockweed in Cobscook Bay in 1999 for processing in

Pennfield, New Brunswick. Their harvesting operations were subsequently expanded in 2004 to include the Jonesport/Beals region.

In the 1980's, Maine statutes that established harvesting permits, fees, violation fines, and a dedicated management fund were enacted.

In 1993, the Maine Seaweed Council was founded to protect and promote the sustainable use of Maine's seaweeds and address regulatory, legislative and public concerns about the resource. Its members include harvesters, processors, scientists, and other interested parties.

In 2000, the Department implemented regulations for a minimum rockweed cutting height and mandatory landings reporting. The regulation requires that rockweed must be harvested such that the lowest lateral branches remain attached to the main stalk, and a minimum of 16" of the plant remain above the holdfast.

In 2009, the Cobscook Bay Rockweed Management Area was established by statute.

ii. Canadian Fishery

The majority (ca. 90%) of the *Ascophyllum* currently harvested in the Canadian Maritimes is cut on leases held by Acadian Seaplants, Ltd. in Nova Scotia and licenses in New Brunswick. Harvest in New Brunswick is by cutter rake at 17% of biomass/yr. The harvest in 2010 reached 40,100 wet tons of an estimated total biomass of 352,723 wet tons on the New Brunswick and Nova Scotia shore (Ugarte and Sharp 2012). Harvests before 1997 by several companies in Nova Scotia were done with mechanical harvesters of a very different design than those being used today in Maine. In the last ten years, there was a transition from machine to manual methods of harvest and today there are no mechanical harvesters active in the Maritimes (Ugarte and Sharp 2012).

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iii. Maine Fishery

Over the last five years, between 44 and 61 people harvested rockweed in Maine (Table 3).

Table 3. Number of rockweed harvesters from 2003 – 2012. Source. DMR Landings Program.

Year	Number of Rockweed Harvesters
2003	33
2004	29
2005	37
2006	32
2007	51
2008	61
2009	49
2010	44
2011	54
2012	59

Rockweed has comprised over 95% of Maine's seaweed landings by weight over the past five years and landings have increased gradually over the same time period (Table 4, Figure 4). The majority of harvest is made by hand raking (58% in 2012) and mechanical cutters (40% in 2012) (Fig. 5, Table 5).

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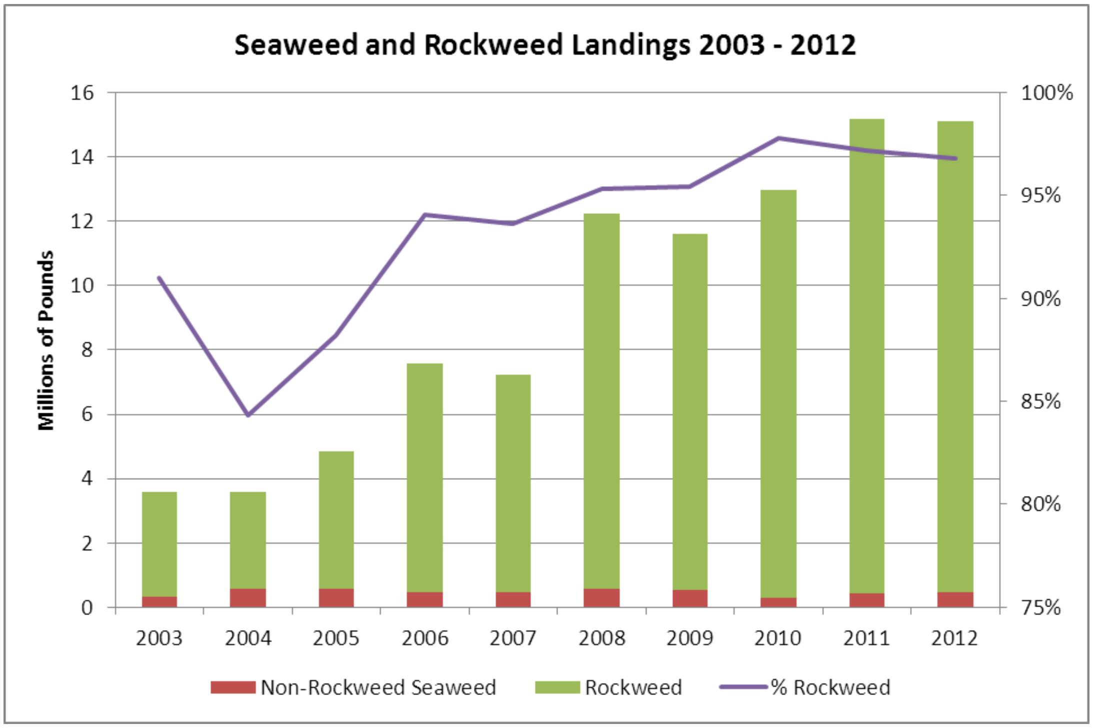

Figure 4. Non-rockweed seaweed and rockweed landings 2003 – 2012 in pounds (wet weight). 2012 landings are preliminary and subject to change. Source. DMR Landings Program.

Table 4. Non-rockweed and rockweed landings 2003 – 2012 in pounds. 2012 landings are preliminary and subject to change. Source. DMR Landings Program.

Year	Non-Rockweed Seaweed	Rockweed	% Rockweed
2003	324,140	3,276,511	91.0%
2004	565,020	3,032,871	84.3%
2005	573,113	4,280,734	88.2%
2006	451,279	7,124,677	94.0%
2007	462,964	6,775,612	93.6%
2008	570,110	11,654,227	95.3%
2009	530,821	11,090,274	95.4%
2010	287,644	12,676,252	97.8%
2011	427,413	14,735,164	97.2%
2012	483,802	14,625,667	96.8%

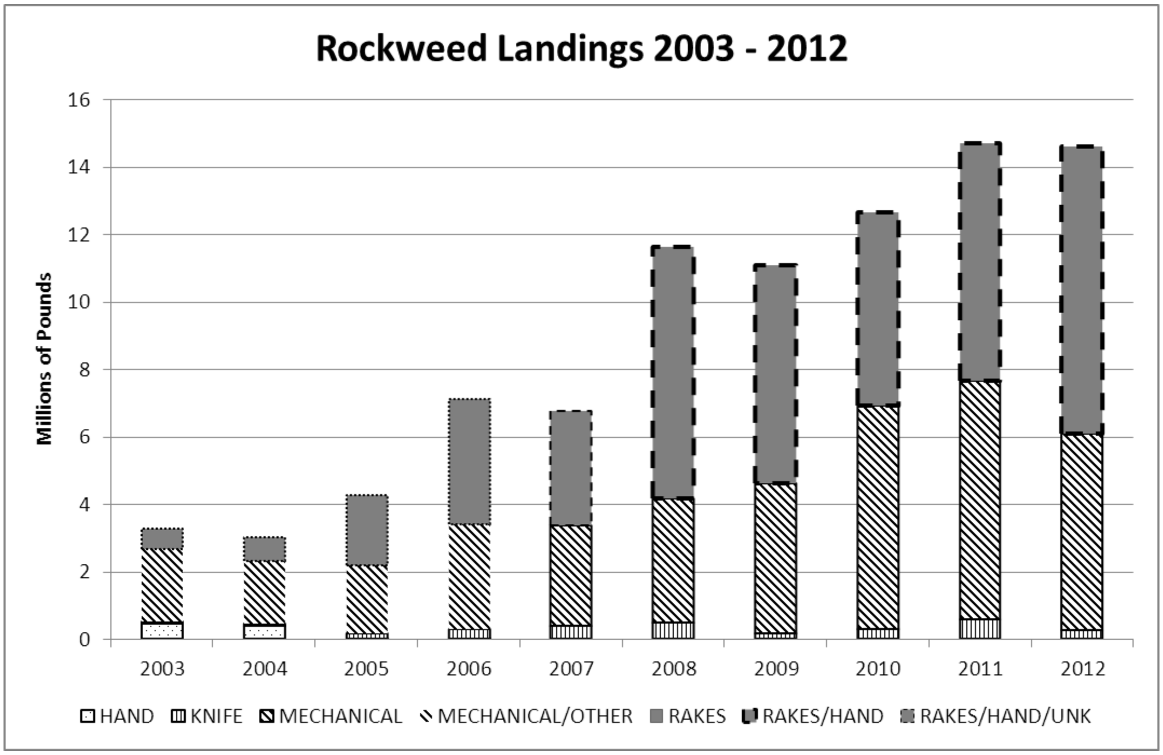

Figure 5. Rockweed landings 2003 – 2012 by gear type. 'Mechanical' and 'other' from 2003-2006, 'rakes' and 'hand' in 2007, and 'rakes' 'hand' and 'unknown' from 2008 - 2012 were combined to protect confidential data. 2012 landings are preliminary and subject to change. Source. DMR Landings Program.

Table 5. Rockweed landings 2003 – 2012 by gear type in pounds. 'Mechanical' and 'other' from 2003-2006, 'rakes' 'hand' and 'unknown' in 2007, and 'rakes' and 'hand' from 2008 - 2012 were combined to protect confidential data. 2012 landings are preliminary and subject to change. Source. DMR Landings Program.

Year	HAND	KNIFE	MECHANICAL	MECHANICAL/ OTHER	RAKES	RAKES/ HAND	RAKES/ HAND/ UNK	Total
2003	478,216	72,021		2,135,125	591,149			3,276,511
2004	397,809	74,660		1,855,746	704,656			3,032,871
2005	99,857	90,246		2,020,098	2,070,534			4,280,734
2006	72,252	250,073		3,105,644	3,696,709			7,124,677
2007		406,722	2,992,610				3,376,280	6,775,612
2008		507,935	3,694,857			7,451,435		11,654,227
2009		179,198	4,443,063			6,468,013		11,090,274
2010		320,930	6,605,964			5,749,358		12,676,252
2011		594,430	7,068,069			7,072,665		14,735,164
2012		270,650	5,829,950			8,525,067		14,625,667

9. HARVEST METHODS

In Maine, rockweed is harvested by hand or with a mechanical harvesting boat. Hand-harvest is typically done with either a cutting rake or knife. A cutting rake resembles a landscape rake that has been modified with an extended handle that is fluted at the end for grip, tines rotated 90 degrees towards the handle, a horizontal blade below the tines, and D-shaped guards on the sides to hold the blade off the bottom (Fig. 6).

i. Rakes

Cutting rakes are used from boats during mid-flood to mid-ebb tide, when rockweed beds are accessible by boat and the plants are floating upright. Vessel operators allow their boats to drift and do not use anchors when harvesting. To collect rockweed, harvesters plunge the rake into the water keeping one hand on the end of the handle, pull towards the boat to cut the rockweed (which droops across the top of the rake), and flip the rockweed into the boat (Fig. 6). The rake displaces water which pushes the plant sideways preventing harvest of the lowest portion of the plant. Cutting with a sharp rake increases efficiency and harvesters tend to keep their rakes sharp to maximize their catch per unit effort (CPUE). A crane is used to offload rake-harvested rockweed from harvest boats into tractor trailers that transport the rockweed to processing plants.

Harvesting rockweed with a cutting rake is relatively inefficient and labor intensive, causing hand harvesters to focus on dense beds to maximize their CPUE. As rockweed is harvested from an area, CPUE decreases and harvesters move on to denser beds that maximize their effort. This practice leaves a significant part of harvested areas uncut creating a non-uniform cutting pattern. Currents, tides, and wind impart further randomness into the harvest. These factors combine to make it highly impractical and nearly impossible to produce a uniform 16” cut.

Figure 6. Left. Harvest of rockweed with a hand rake from a 4-5 ton boat in Jonesport, July 2013. Right. Sharpening the blade of an upside down hand rake in Jonesport, July 2013.

ii. Knife

Knife harvest involves hand-selecting plants and cutting them with a knife or machete (Fig. 7). This approach is the most precise way to leave the appropriate height of plant growth, but the most time consuming, and is not usually used where larger volumes are harvested. Knife harvest can be done "on foot" or from a boat floating in shallow water. The hand cut plants are carried or floated to the pickup area where they are loaded into a truck for transportation to the processing plant.

Figure 7. Example of knife used to harvest rockweed. Picture taken in Waldoboro, 2013.

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iii. Mechanical

Mechanical harvester vessels are approximately20 foot long, flat-bottomed boats that have been modified with specialized equipment to suction, cut, and collect rockweed. Propulsion and suction are generated from water-jet hydraulic thrusters and the term "jet-propelled" is often used to describe mechanical harvesters. However, mechanical harvesters are by no means the speedy, sleek, jet boats as the term "jet-propelled rockweed harvester" might suggest (Fig. 8).

Figure 8. Mechanical harvesting vessels. Top. Boothbay Harbor, August 2013. Bottom left. Cundy's Harbor, July 2011. Bottom right. Quahog Bay, July 2010.

Mechanical harvesters are outfitted with a horizontally-aligned cutting head attached at the bow of the vessel. The head can be raised or lowered via a hydraulic boom. Spinning cutting blades are recessed inside the head. Once cut, the rockweed travels through a large-diameter hose attached to the back of the head, where it collects in removable net bags (Fig. 9). Operators often float full bags at the surface for collection later. Mesh bags are offloaded with boom cranes onto trucks that transport the rockweed to processing plants (Fig. 10).

Figure 9. Left. Mechanical harvesting vessel boom cutter. Right. Mesh bag full of mechanically harvested rockweed. Boothbay Harbor, July 2013.

The design, position, and operation of the cutting head of mechanical harvesters combine to achieve a non-uniform, greater than 16" cutting height. The horizontal position of the cutting head and setback of the blades are nearly sufficient to leave a 16" cut. Additionally, the cutting head must be held far enough off the bottom to avoid sucking up rocks or debris that will dull the cutting blades and clog hoses. Similar to harvesting with a cutting rake, randomness occurs with mechanical harvesters because operators focus on areas that maximize catch per unit effort and currents, wind, and changing tide further increase the variability of cutting height.

iv. Transport

Regardless of the harvesting method, offloading and transport of harvested rockweed is similar for large-volume harvesting operations. A boom crane is used to offload rockweed from the harvest boats into trucks that transport the rockweed to processing facilities (Fig. 10). Access to a dock with a boom crane in close proximity to harvest areas is necessary for a high-volume operation to turn a profit. The shift to non-working waterfront uses in some Maine harbors could prevent large expansions of rockweed harvesting in some areas if harvesters are unable to unload their rockweed efficiently.

Figure 10. Workboats offloading rockweed in Cundy's Harbor, July 2011.

10. MAINE'S ROCKWEED PRODUCTS

The landed value of rockweed, or price paid at the dock, is relatively low, but only a fraction of the harvest is sold fresh or raw. The majority is processed into wholesale and retail products creating additional jobs and resulting in a much greater value to the industry and state (e.g., operators, research and development, harvesters, processing facility employees, marine equipment retailers).

While the uses vary, two facts are generally true for all rockweed derived products: 1) they are highly specialized, value-added products developed from years of research and development, and 2) the benefits stem from unlocking rockweed's micronutrients and natural plant growth stimulants. The majority of rockweed harvested in Maine is processed into two general product categories—nutritional supplements (nutraceuticals) and concentrated fertilizers.

Granular and liquid fertilizer applications provide increased plant growth and fruiting, improved stress tolerance (high temperatures, drought, high salinity conditions, and disease), delayed plant decline, improved plant health and vigor, increased cell wall strength, increased root mass, increased chlorophyll content, improved photosynthetic efficiency, increases to antioxidant levels, and stimulation of microorganisms for improved production and soil quality (Rayirath et al. 2009, Craigie 2010, Jayaraman et al. 2010, Fan et al. 2011,). A secondary, environmental benefit from many of these products is reduced dependency on chemical fertilizers and pesticides, and lower water use due to greater root mass (Craigie 2010).

Nutraceutical applications include supplements for animals and people. They provide a broad spectrum of minerals, amino acids and vitamins that are often lacking in land grown crops, as well as additional beneficial micronutrients whose effects are not yet fully understood (Craigie 2010).

Ascophyllum products are used widely throughout the US in agriculture and related applications (e.g., Maine potatoes, California wine grapes, Washington state apples, North Carolina soybeans, Florida oranges, and Kentucky race horses). The value-added products include those used for golf courses, vegetable farms, orchards, home gardens, livestock feed, pet foods and supplements and specialty nutraceutical products for people. Maine's rockweed products are also shipped internationally and include destinations in Asia, Europe, the Middle East, South America, and New Zealand.

11. MANAGEMENT BACKGROUND

i. Current Management Measures in Maine

Rockweed is managed through a combination of statutes and regulations (Table 6 & 7). The following section is a general summary and the full suite of applicable laws and regulations can be found at http://www.maine.gov/dmr/lawsandregs/regs/29.pdf http://www.maine.gov/dmr/lawsandregs/regs/08.pdf and http://www.maine.gov/dmr/lawsandregs/lawbook10-09-13.pdf

Harvester permits, buyer's licenses, and their associated fees are defined by statute (12 M.R.S.A. Chapt. 623, §6803 Seaweed Permit, §6803-A. Seaweed Buyer's License, and §6803-B. Seaweed Buyer's Surcharge). As prescribed by these laws, commercial seaweed harvesters are required to obtain a resident seaweed permit for $58.00 or nonresident seaweed permit for $200.00. The law also established a less expensive supplemental seaweed permit for an employee or immediate relation of a seaweed permit holder that costs $29.00 and $58.00 for residents and non-residents, respectively. A seaweed buyer's license is required for a person who purchases seaweed directly from harvesters, and costs $200.00 and $500.00 for residents and nonresidents, respectively. The seaweed buyer's surcharge gives the Commissioner the ability to establish a buyer's surcharge up to $5.00 per wet ton.

Department of Marine Resources Regulations Chapter 8.10(C)5 requires persons who purchase more than 10 wet tons annually to pay a buyers' surcharge of $1.50 per wet ton. Chapter 8.20(C) requires harvesters to record daily harvest (area, method, species, weight, etc.) and submit these records to the Department monthly. Chapter 29.05(A) specifies that harvesters of *Ascophyllum* shall leave a minimum of 16" of rockweed above the holdfast with the lowest lateral branches undisturbed.

In addition to the permits, licenses, reporting, and cutting height measures described above, bay-specific sector management measures for Cobscook Bay are prescribed by Chapt. 623, 12 MRSA §6803-C. Cobscook Bay Rockweed Management Area. The CBRMA law establishes designation of closed areas and sectors. Harvesters must submit harvest annual plans that include a biomass assessment (conducted within the previous 3 years) to receive a sector allocation. Harvesters fishing under an approved harvest plan may remove a maximum of 17% of the annual harvestable biomass, must make a reasonable effort to minimize bycatch mortality, and cannot harvest in designated closed areas.

The Commissioner has the authority to adopt rules that limit taking of marine organisms (including seaweed) by time, method, number, weight, length, and/or location under 12

M.R.S.A. Chapt. 607, §6171. A seaweed-specific law, 12 M.R.S.A. Chapt. 607, §6807 Seaweed harvesting rules, allows the Commissioner to adopt rules that limit the number of licenses, designate seasons, limit the quantity that may be harvested in a season, establish areas that are open or closed to harvest, designate sectors, establish limitations on harvest by sector, allocate sectors, and regulate gear and techniques that may be used in harvesting. Legislation to amend Maine law is required for the Commissioner to implement management measures other than those listed in this paragraph.

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Table 6. Laws and regulations pertaining to rockweed harvest for the entire Maine coast.

Law or Regulation	Area	Requirement	Fee	Exceptions	Violation Amount
§6803(1) Seaweed Permit	Coastwide	Resident or nonresident seaweed permit required to harvest, possess, ship, transport, or sell seaweed	$58 resident; $200 nonresident	Person harvesting 50 pounds or less for noncommercial purposes; charitable or municipal org. for noncommercial use; for seaweed that detached naturally and is dead.	Civil violation; between $100 - $500
§6803(1-A) Supplemental Permit	Coastwide	Supplemental permit allows employee or immediate relation of a seaweed permit holder to harvest, possess, or transport seaweed for commercial purposes	$29 resident; $58 nonresident	Person harvesting 50 pounds or less for noncommercial purposes; charitable or municipal org. for noncommercial use; for seaweed that detached naturally and is dead.	Civil violation; between $100 - $500
§6803-A Seaweed buyer's license	Coastwide	Required to buy, possess, ship, transport, or sell seaweed	$200 resident; $500 nonresident	none	Civil violation; between $100 - $500
DMR Chapter 8.10 (C)(5) Seaweed Primary Buyer Permit Reporting	Coastwide	Buyers who purchase more than 10 wet tons annually required to pay $1.50 surcharge per wet ton	not applicable	none	Civil violation; minimum $100 fine
DMR Chapter 8.20 (C) Seaweed Harvester Reporting	Coastwide	Seaweed harvester must report harvesting activity for all seaweed species. Record must be kept daily and reported monthly.	not applicable	none	Civil violation; minimum $100 fine
DMR Chapter 29.05 (A)(1) Harvesting Restrictions for Rockweed	Coastwide	*A. nodosum* must be harvested so that the lowest branches remain undisturbed and attached to the main stalk of the rockweed that is attached to the substrate	not applicable	none	Civil violation; minimum $100 fine
DMR Chapter 29.05 (A)(2) Harvesting Restrictions for Rockweed	Coastwide	*A. nodosum* must be harvested so that a minimum of 16 inches of the rockweed shall remain above the holdfast	not applicable	none	Civil violation; minimum $100 fine

Table 7. Cobscook Bay specific laws pertaining to rockweed harvest. These are in addition to those listed in Table 6.

Law or Regulation	Area	Requirement	Fee	Exceptions	Violation Amount
§6803-C(2) Designation of areas closed to harvesting	Cobscook Bay	Commissioner shall identify areas that are closed to commercial harvest. Up to 30 acres for research.	not applicable	none	Person who violates this section commits a Class E crime for which a fine of not less than $1,000 must be adjudged.
§6803-C(3) Harvest management sectors	Cobscook Bay	Commissioner shall divide the CBRMA into at least 14 harvest management sectors.	not applicable	none	
§6803-C(4)-(8)	Cobscook Bay	Commercial harvesters shall submit annual harvest plan with: sector area requested; total rockweed biomass in area based on survey; proposed biomass amount; description of harvest method; description of how marine organisms harvested with the rockweed will be managed; and description of harvester training.	not applicable	none	
§6803-C(9) Biomass harvest limit	Cobscook Bay	Harvest in sector may not exceed 17% of the harvestable biomass that is eligible to be harvested annually.	not applicable	none	

ii. Seaweed Management in Eastern Canada

Rockweed harvesting in Nova Scotia began in the late 1950's when it was used as raw material for sodium alginate and "kelp" meal (Ugarte and Sharp 2001). It began as an open fishery with no limit on the number of harvesters, their area of operation, or levels of exploitation, but after 1959, a few exclusive-purchasing licenses were issued by the provincial government in southwestern Nova Scotia. The majority of the resource was totally open to harvest and the level of exploitation was generally low. Mechanical cutters of a different design than those currently employed by Maine harvesters were used beginning in the early 1970's along with hand harvesting techniques. By the 1980's a rake with a cutter blade was the preferred manual harvesting gear, and mechanical harvesting ended in the 1990's.

Area-based sub-sector management was introduced in the 1970's on an *ad hoc* basis with no biomass targets except for mechanically harvested areas that had 40-60% exploitation rates, required a 2-3 year fallow period. The demand for rockweed increased after 1985 and more of the coastline was placed under exclusive license. Resource assessments were conducted by government research groups along with informal "non-scientific" company surveys. Quotas were established using exploitation rates below 25% of harvestable standing stocks. The management system that resulted was uneven with a mix of open areas with no limitations, exclusive licensed areas with true area-based management, and other areas with an un-monitored *ad hoc* management plan.

A new approach to seaweed management that recognized the habitat role of rockweed, was implemented in Atlantic Canada in 1995(Ugarte and Sharp 2001). New Brunswick did not have a legislative structure for marine plant management, so a Memorandum of Understanding was developed between the Federal Department of Fisheries and Oceans and the provincial Department of Fisheries and Aquaculture with five goals: 1) To maximize the number of continuing full-time employment opportunities for New Brunswick residents; 2) To ensure a sustainable harvest; 3) To promote the development of a commercial viable industry founded on sound business principles; 4) To integrate the rockweed industry with other users of marine resources; and 5) To ensure rockweed harvesting and processing are undertaken in an environmentally acceptable manner. A four year precautionary pilot plan was jointly implemented by the federal and provincial governments to monitor and manage the expansion of the harvest from Nova Scotia to New Brunswick. The plan included a maximum exploitation rate, cutting height, gear restrictions, and protected areas, along with a research and monitoring program involving the industry, universities, and the provincial and federal government to evaluate the effect of the harvest on the resource and associated species and to provide information to improve the management of rockweed. A scientific peer review was carried out in 1998 and 1999, and the consensus was that the harvest impact on the habitat architecture was minimal and of short duration, and to continue the harvest but maintain a precautionary approach.

12. MANAGEMENT RECOMMENDATIONS

The following management recommendations combine to provide a holistic approach to coastwide rockweed harvest and were designed to preserve the ecological functions and stature of rockweed beds, while allowing for sustainable commercial harvest; and for collection of data to monitor the fishery and the ecological impacts of harvest. None of these measures would be sufficient to achieve the goal and objectives of the FMP on its own.

i. Recommendation: Maintain the 16" minimum cutting height; remove the requirement to cut above the first lateral branches for rockweed harvest

Legislative or Department Action Required: Department rulemaking

Description/Rationale: At 16", sufficient biomass remains to preserve the stature and ecosystem function of rockweed stands: biomass regeneration in a few years; sufficient canopy to prevent desiccation and regulate temperature of organisms inhabiting rockweed beds at low tide; and provide refuge from predators for organisms inhabiting beds at high tide. As described in the current harvest methods section of this FMP (begins on page 21), current harvest methods produce random, non-uniform cuts and there are no cutting methods in Maine that could produce a large-scale "mowed lawn effect" at this time.

The lateral branch requirement should be removed from Department regulations because a typical rockweed clump will have one or more lateral branches below 16" and new lateral branches will form in response to cutting. This requirement is impractical for harvesters and difficult to enforce. Rockweed morphology and growth rates are explained in detail in the Biology and Ecology section of this FMP (begins on page 3).

Additional Considerations: Current harvest methods, both hand and mechanical, are relatively inefficient. The eventual decrease in catch per unit effort during harvest in an area will cause harvesters to move to denser areas, leaving patches unharvested (or unevenly harvested at a height greater than 16") and prevent a "mowed lawn effect". Currents, wind, and tides add further randomness that make cutting at a uniform 16" height nearly impossible.

The PDT discussed a request to increase the cutting height to greater than 16" and concluded that it would likely have the unintended consequence of causing an expansion of harvest area to collect the same amount of rockweed, resulting in a larger portion of the coast being harvested—without decreasing (and potentially increasing) the regeneration time. Rockweed growth rates are highly variable and increase as light and nutrients become more available. Additionally, the mode of regeneration is different depending upon where a plant is broken or cut (i.e., from vertical growth and branching of suppressed short shoots near the base of the frond or by formation of a new leading frond from an existing lateral if cut or broken near the frond's maximum height). As the upper, taller portions of a plant are removed during harvest, the lower branches and suppressed shoots receive more sunlight and nutrients (increased water circulation, decreased competition for nutrients). The amount of time for regeneration to pre-cut heights is unlikely to vary greatly between a plant that has been cut to 16" and one that is cut at a height greater than 16" (for example, at 32") given the physiological characteristics of rockweed and varying modes of regeneration. A plant cut at 32" will grow slower than one cut at 16" but does not have to grow as much to return to pre-cut levels.

ii. Recommendation: Implement Coastwide Sector Management

Legislative or Department Action Required: Department rulemaking

Description/Rationale: The PDT recommends coastwide sector management to promote accountability, incentivize responsible harvest, simplify enforcement, and collect long-term harvest data to inform future management decisions. The recommended approach would allocate a sector to one entity only for up to six years and renewal will be granted only if harvest in that sector has been compliant with statute and rule. The entity that is granted the sector bears full responsibility for harvest activities in their sector. Non-compliance results in revocation or non-renewal of a sector—providing a strong incentive to harvest responsibly. Monitoring and enforcement are simplified if only one entity holds responsibility for harvest in a sector.

Sectors boundaries are not pre-determined, but will be allocated as areas are applied for and assigned as sectors. This ground up approach is simple and establishes sectors based on current needs, rather than relying on outdated or arbitrary boundaries. Maps would be populated with sectors as they are assigned.

Additional Considerations: The PDT faced a significant challenge to develop a management system that creates accountability while meeting the needs of both large- and small-scale harvesters. The proposed sector management system should accomplish both of those goals because it does not restrict sector size and an individual may apply for and receive as small or large of an area as meets their needs.

Sector Management Recommendations Part I: General

- Sectors are assigned to one entity only (individual, company, corporation, etc.) that bears full responsibility for compliant harvest in their sector.
- Sectors boundaries are not pre-determined, but will be allocated as areas are applied for and designated as sectors.
    - Sectors shall be assigned for a maximum of six years.
    - Commissioner shall renew a sector unless:
        - Significant non-compliance.
        - No significant harvest in a calendar year without reasonable explanation (e.g., periodic non-harvest is part of harvest plan, equipment failure, personnel issues).
    - The Commissioner may revoke a sector at any time for:
        - Significant non-compliance.

- No significant harvest in a calendar year without reasonable explanation (e.g., periodic non-harvest is part of harvest plan, equipment failure, personnel issues).

Sector Management Recommendations Part II: Required Sector Request Information

- Contact information.
- Boundaries of requested sector harvest area with GPS coordinates. Landmark descriptions are helpful but may not replace GPS coordinates.
- Harvesting methods.
- Preliminary estimate of biomass to be removed.
- Location where rockweed will be landed and processed.
- Digital photos taken at low tide that are representative of rockweed stands in the proposed sector.
- Description of harvester training.
- Preliminary list of harvesters.
- Previous experience harvesting rockweed including any history harvesting in the requested sector area.

Description/Rationale: This information would allow the Department to fully evaluate a sector application.

Sector Management Recommendations Part III: Allocation

- The Commissioner may grant or deny a sector application based on the information collected in *Part II: Required Sector Request Information*.
- The Commissioner may allocate a sector for up to six years.
- Harvest is prohibited in an assigned sector until biomass has been assessed; and the Department has reviewed and accepted the assessment results (see *Requirements Prior to Harvesting* below for specifics).

Description/Rationale: The PDT recommends giving the Department authority to grant or deny sector applications for up to six years based on the information collected in *Required Sector Request Information*. Harvest is prohibited until all requirements in *Part IV: Requirements Prior to Harvesting* have been fulfilled to the Department's satisfaction.

Sector Management Recommendations Part IV: Requirements Prior to Harvesting

- A biomass estimate following the methodology specified in *Appendix A: Biomass Assessment Methodology* is required prior to harvesting.
- Biomass assessments are valid for up to three years.
- The Department may allow a maximum harvest of 17% per year of assessed biomass. "Assessed biomass" is defined as a biomass estimate derived from the methodology specified in *Appendix A: Biomass Assessment Methodology*
    - The Department may reduce this amount, establish other conditions on harvest in a sector, and/or prohibit harvest if significant biomass of rockweed is removed through natural ecological processes (e.g., ice scour,

natural loss) and harvest of the remaining rockweed threatens long-term sustainability and ecosystem function of the remaining stands in an area.

- The Department may allow removal of up to 30% of "assessed biomass" once every three years with an approved research proposal designed to study the impacts of 30% removal in a year.
  - The Department may reduce this amount, establish other conditions on harvest in a sector, and/or prohibit harvest if significant biomass of rockweed is removed through natural ecological processes (e.g., ice scour, natural loss) and harvest of the remaining rockweed threatens long-term sustainability and ecosystem function of the remaining stands in an area.
- Harvesters who land less than or equal to 10 metric tons in a year may forego a formal biomass assessment and apply for a sector using the biomass per area estimate of (10 kilograms / meters^2 x 6).
  - Minimum sector area (meters^2) = 600 x number of metric tons requested.
- Sector holders are required to submit a current list of harvesters to the Department prior to harvest.
  - Required to notify the Department of any changes to the harvester list within 48 hours prior to any new harvesters collecting rockweed.
- Sector holders must submit an annual harvest report for each sector that includes the following information:
  - Amount removed the previous year (in addition to required landings).
  - Noteworthy information relevant to stature, long-term sustainability, and ecosystem function of rockweed stands in the sector (e.g., ice scour or natural loss).
  - General description of where harvesting occurred in the previous year.
- The Department will coordinate third party biomass assessment results as resources allow.

Description/Rationale: After a sector is assigned, the receiving entity must conduct a biomass assessment following the systematic, replicable, survey method specified in Appendix A and defined as "assessed biomass". Standardizing the assessment methodology will allow the Department to collect and monitor long term abundance data and verify assessment results. The PDT recommends allowing a maximum harvest of 17% of "assessed biomass" per year.

Additionally, the PDT recommends allowing harvest of 30% of "assessed biomass" once every three years (must sit fallow for two years), contingent upon the sector holder conducting a study on the impacts of 30% removal in one year. While the rotational strategy would reduce total biomass harvest by 21% over the three-year period compared to annual removal of 17% (17% x 3 = 51%), some PDT members were concerned about the impact to the structural integrity of the rockweed beds in a sector if 30% is removed in a year. Studying the practice will allow the Department to monitor and better-understand the impacts of 30% annual harvest and adjust management measures as the research results become available.

The Department may reduce the initial harvest removal amount to less than 17% after considering environmental factors and the long-term health and ecosystem function of rockweed in a sector; or reduce the originally approved harvest amount at any time to preserve the viability and ecosystem function of rockweed stands in a sector.

The calculation for minimum sector size will allow smaller operations, who may not have the expertise or resources to conduct biomass assessments, access to the rockweed resource. ASL's biomass assessments conducted over the past nine years in Maine have found biomass values of 12 – 18 kilogram/meter^2 in typical commercially viable beds (Ugarte, pers. comm.). The PDT recommends 10 kilogram/meter^2 as an easy to calculate, conservative estimate of total biomass in an area. Dividing total biomass by 6 prevents removal of more than 17% per year (100% biomass / 6 = 16.6%). Using this equation, a harvester can calculate their sector area (meter^2) by multiplying the requested number of metric tons by 600. For example, a harvester who wishes to remove 10 metric tons would need a sector that is at least 6,000 meter^2.

Original equation:
Area of sector (m^2) = #metric tons requested * 1,000 kg/metric ton * m^2/10 kg * 6
Simplified equation:
Area of sector (m^2) = #metric tons requested * 600

The requirement for sector holders to submit a list of harvesters to the Department prior to harvest, and provide notice if there is a change to the list will aid Marine Patrol when enforcing regulations. Annual harvest reports will help the Department monitor rockweed harvest and relevant environmental changes in a sector, and provide useful harvest/yield over-time trends.

iii. Recommendation: Designation of no-harvest areas

Legislative or Department Action Required: Department rulemaking

Description/Rationale: The PDT recommends that the Department implement no-harvest areas that consider the impact of rockweed harvest, if any, on sensitive wildlife areas (e.g., shorebird habitat, seal haul out, previously mapped critical areas) and conserved lands. Additionally, the PDT recommends that the Department implement reference sites along the coast and control plots in and/or around sectors. Establishing these no-harvest research areas will allow for comparisons between harvested and natural areas to evaluate the long-term impacts of harvesting on rockweed beds.

Additional Considerations: All PDT members agreed that the best approach for no-harvest recommendations given their timeline and the scope of this FMP is to provide general recommendations for further development. It is important to note that PDT endorsement of this approach is dependent on the future process and actual designation of closed areas. The PDT recommends that the Department convene a working group in 2014 to develop no-harvest areas.

iv. **Recommendation: Status quo for Cobscook Bay Rockweed Management Area until coastwide management (including no-harvest areas) is established**

Legislative or Department Action Required: None

Description/Rationale: The PDT recommends maintaining 12 M.R.S.A. , Ch. 623, §6803-C. Cobscook Bay Rockweed Management Area until coastwide management measures (including no-harvest areas) have been implemented. In the future, the Legislature should consider repealing the CBRMA law to establish consistent coastwide rockweed management measures based on the recommendations in this FMP.

v. **Recommendation: Implement harvester training**

Legislative or Department Action Required: DMR Rulemaking

Description/Rationale: The PDT recommends implementation of a mandatory harvester training program to promote compliant harvest. Realizing that available resources will dictate the rigor of the mandatory harvester training, the PDT did not develop specific details of the required training, but suggested that the Department work to include the following:

- Training class or written exam similar to the Department's non-commercial lobster/crab license exam.
- Training/exam should cover
    - Overview of applicable rule and statute.
    - Best harvest practices, such as tool use and tool maintenance.
    - Basic *Ascophyllum* biology and ecology
    - Harvester/landowner relations

vi. **Recommendation: Five-year FMP review**

Legislative or Department Action Required: None

Description/Rationale: The PDT recommends a five-year Department review of the implementation and performance of the recommended management measures contained in this plan. As noted throughout this document, the PDT considers this FMP to be the first phase of comprehensive coastwide rockweed management, and developed these recommendations to be adaptive.

13. RESEARCH NEEDS

In February 2010, the Department, Maine Seaweed Council, and University of Maine Sea Grant Program organized a rockweed research symposium. The two goals of the symposium were to summarize what is known about the rockweed resource and identify and prioritize research needs. Minutes of the symposium can be downloaded at http://www.maine.gov/dmr/rm/rockweed/symposium2010/minutes.pdf

The PDT discussed research needs developed at the 2010 Rockweed Research Symposium and recommended that a number of questions continue to be a high priority. The PDT agreed that the highest priority need is for a multi-year examination of the impact of natural removal compared with harvest removals at the recommended 17% harvest rate and a 30% or greater rotational harvest rate against control no-harvest areas. This would include long term studies of habitat recovery, canopy architecture, and changes in biota.

The following specific research needs from the 2010 symposium remain a high priority:

i. Biomass Assessment

- Evaluation of long term effects of harvesting techniques as permitted by the Department and in use in Maine on defined areas at commercial scale; especially, how canopy structure (height) is affected.
- Periodic re-evaluation of natural mortality vs. harvest mortality, especially if hurricane incidence increases or other effects of warming water and invasives are deemed potentially serious.

ii. Ecology and Habitat

- How does structural change from harvest benefit/detract from habitat?
- How does architecture of rockweed affect associated species?
- How much loss/change is too much?

iii. Effects of Harvesting

- Assess the long-term effects of harvesting on a large spatial scale.
- What is the difference between the 17% harvest rate and natural mortality in a given year in different areas of the coast?
- Will cumulative effects of successive harvest restructure habitat and/or ecosystems?

14. REFERENCES

Aberg, P. 1992a. A demographic study of two populations of the seaweed *Ascophyllum nodosum*. Ecol. 73(4): 1473-1487.

Aberg, P. 1992b. Size-based demography of the seaweed *Ascophyllum nodosum* in stochastic environments. Ecol. 73(4): 1488-1501.

Åberg, P and H. Pavia. 1997. Temporal and multiple scale variation in juvenile and adult abundance of the brown alga *Ascophyllum nodosum*. Mar. Ecol. Prog. Ser. 158: 111-119.

Ang, P. O., Sharp, G. J. & R. E. Semple. 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. Inst. for Industrial Research and Standards, Dublin. (available as pdf at www.algaebase.com)

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

Bacon, L. C. and R. L. Vadas. 1991. A model for gamete release in *Ascophyllum nodosum* (Phaeophyta). J. Phycol 27: 166-173.

Beal, B., R. A. Ugarte, and S. Stoddard. Short-term effects of commercial seaweed harvesting on algal biomass and selected rocky intertidal organisms. Presented at the 51st Northeast Algal Symposium, April 2012, Winter Harbor, ME.

Berndt, M. L., J. A. Callow, and S. H. Brawley. 2002. Gamete concentrations and timing and success of fertilization in a rocky shore seaweed. Mar. Ecol. Prog. Ser. 226, 273-285.

Bertness, M. D. 1999. The Ecology of Atlantic Shorelines. Sinauer Assoc. Inc., Sunderland, MA.

Bertness, M. D., P. O. Yund, and A. F. Brown. 1983. Snail grazing and the abundance of algal crusts on a sheltered New England rocky beach. J. Exp. Mar. Biol. Ecol. 71: 147-164.

Bertness, M. D., Leonard, G. H., Levine, J. M., Schmidt, P. R. & A. O. Ingraham. 1999. Testing the relative contribution of positive and negative interactions in rocky intertidal communities. Ecology 80, 2711-2726.

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

Black, R. and R. J. Miler. 1991. Use of the intertidal zone by fish in Nova Scotia. Env. Biol. Fishes 31: 109-121.

Blinn, B. M., A. W. Diamond, and D. J. Hamilton. 2008. Factors affecting selection of brood-rearing habitat by common eiders (*Somateria molissima*) in the Bay of Fundy, New Brunswick, Canada. Waterbirds 31(4): 520-529.

Brawley, S. H., J. A. Coyer, A. M. H. Blakeslee, G. Hoarau, L. E. Johnson, J. E. Byer, W. T. Stam and J. L. Olsen. 2009. Historical invasions of the intertidal zone of Atlantic North America associated with distinctive patterns of trade and emigration. Proc. Natl. Acad. Sci., U.S.A. 106: 8239-8244.

Brawley, S. H. & L. E. Johnson. 1991. Survival of fucoid embryos in the intertidal zone depends upon developmental stage and microhabitat. J. Phycol. 27, 179-186.

Cervin, G., Åberg, P. & S. R. Jenkins. 2005. Small-scale disturbance in a stable canopy dominated community: implications for macroalgal recruitment and growth. Mar. Ecol. Prog. Ser. 305: 31-40.

Chock, J. S. and A. C. Mathieson. 1979. Physiological ecology of *Ascophyllum nodosum* (L.) Le Jolis and its detached ecad *Scorpiodes* (Hornemann) Hauck (Fucales, Phaeophyta). Bot. Mar. 22: 21-26.

Choi, H. G. & T. A. Norton. 2005. Competition and facilitation between germlings of *Ascophyllum nodosum* and *Fucus vesiculosus*. Mar. Biol. 147, 525-532.

Clarkin, E., Maggs, C. A., Allcock, A. L. & M. P. Johnson. 2012. Environment, not characteristics of individual algal rafts, affects composition of rafting invertebrate assemblages in Irish coastal waters. Mar. Ecol. Prog. Ser. 470: 31-40.

Cousens, R. 1981. Variation in the annual production by *Ascophyllum nodosum* with degree of exposure to wave action. Proc. Int. Seaweed Symp. 2: 253-258.

Cousens, R. 1982. The effect of exposure to wave action on the morphology and pigmentation of *Ascophyllum nodosum* (L.) Le Jolis in southeastern Canada. Bot. Mar. 25: 191-195.

Cowan, D. F. 1999. Method for assessing relative abundance, size distribution, and growth of recently settled and early juvenile lobsters (*Homarus americanus*) in the lower intertidal zone. J. Crustac. Biol. 19: 738-751.

Craigie, J. S., 2010. Seaweed extract stimuli in plant science and agriculture. J. Appl. Phycol. 23 (3): 371-393

David, H. M. 1943. Studies in the autoecology of *Ascophyllum nodosum* Le Jol. J. Ecol. 31: 178-198.

Davies, A. J., Johnson, M. P., & C. A. Maggs. 2007. Limpet grazing and loss of *Ascophyllum nodosum* canopies on decadal time scales. Mar. Ecol. Prog. Ser. 339, 131-141.

Dayton, P.K. 1975. Experimental evaluation of ecological dominance in a rocky intertidal community. Eco. Monogr. 454: 99-118.

Dijkstra, J. A., J. Boudreau, and M. Dionne. 2012. Species-specific mediation of temperature and community interactions by multiple foundation species. Oikos 121(5): 641–800.

Dudgeon, S, J. E. Kubler, W. A. Wright, R. L. Vadas, Sr., and P. S. Petraitis. 2001. Natural variability in zygote dispersal of *Ascophyllum nodosum* at small spatial scales. Functional Ecol. 15, 595-604.

Duggins, D. O., J. E. Eckman, and A. T. Sewall. 1990. Ecology of understory kelp environments. II. Effects of kelps in recruitment of benthic invertebrates. J. Exp. Mar. Biol. Ecol. 143: 27-45.

Eckman, J. E., D. O. Duggins, and A. T. Sewall. 1989. Ecology of understory kelp environments. I. Effects of kelps on flow and particle transport near the bottom. J. Exp. Mar. Biol. Ecol. 129: 173-187.

Ellis, S. L. and D. F. Cowan. 2001. Volunteer-based monitoring of juvenile American lobster, *Homarus americanus*, Mar. Fresh. Res. 52: 1095-1102.

Fan D., D. M. Hodges, J. Zhang, C. W. Kirby, X. Ji, S. J. Locke, A. T. Critchley, and B. Prtihiviraj. 2011. Commercial extract of the brown seaweed *Ascophyllum nodosum* enhances phenolic antioxidant content of spinach (*Spinicia oleracea L.*) which protects *Caenorhabditis elegens* against oxidative and thermal stress. Food Chemistry. 124: 195-202.

Fegley, J. C. 2001. Ecological implications of rockweed *Ascophyllum nodosum* (L.) harvesting. Ph.D. Thesis, University of Maine, Orono, ME.

Fegley, J. C. 2003. Rockweed (*Ascophyllum nodosum*) biomass reassessment at selected sites along the coast of Maine. Final Report to the Maine Department of Marine Resources.

Fegley, J. C. 2006. Morphological, population and biomass studies of rockweed in Quahog Bay and Taunton Bay. Final Report to the Maine Department of Marine Resources. Augusta, ME.

Fegley, J. C. and R. L. Vadas. 2001. A quantitative assessment of the rockweed (*Ascophyllum nodosum*) resource at selected sites along the coast of Maine. Final Report to the Maine Department of Marine Resources.

Fries, L. 1988. *Ascophyllum nodosum* (Phaeophyta) in axenic culture and its response to the endophytic fungus *Mycosphaerella ascophylli* and epiphytic bacteria. J. Phycol. 24, 333-337.

Fritsch, F.E. 1959. The Structure and Reproduction of the Algae II. Foreward, Phaeophyceae, Rhodophyceae, Myxophyceae. Cambridge: Cambridge University Press.

Golléty, C., Riera, P. & D. Davoult. 2010. Complexity of the food web structure of the *Ascophyllum nodosum* zone evidenced by a ∂13C and ∂15N study. J. Sea Res. 64: 304-312.

Gómez, M., Barreiro, F., López, J, Lastra, M. & R. de la Huz. 2013. Deposition patterns of algal wrack species on estuarine beaches. Aquat. Bot. 105: 25-33.

Guiry, M. D. and L. Morrison. 2013. The sustainable harvesting of *Ascophyllum nodosum* (Fucaceae, Phaeophyceae) in Ireland, with notes on the collection and use of some other brown algae. J. Appl. Phycol. DOI 10.1007/s10811-013-0027-2.

Hamilton, D. J. 2001. Feeding behavior of common eider ducklings in relation to availability of rockweed habitat and duckling age. Waterbirds 24 (2): 233-241.

Hawkins, S. J. and R. G. Hartnoll. 1985. Factors determining the upper limits of intertidal canopy-forming algae. Mar. Ecol. Prog. Ser. 20: 265-271.

Ingólfsson, A. 1998. Dynamics of macrofaunal communities of floating seaweed clumps off western Iceland: a study of patches on the surface of the sea. J. Exp. Mar. Biol. Ecol. 231: 119-137.

Ingólfsson, A. 1998. Dynamics of macrofaunal communities of floating seaweed clumps off western Iceland: a study of patches on the surface of the sea. J. Exp. Mar. Biol. Ecol. 231: 119-137.

Jayaraman, J., J. Norrie, Z. K. Punja. 2010. Commercial extract from the brown seaweed *Ascophyllum nodosum* reduces fungal diseases in greenhouse cucumber. J. Appl. Phycol. 23 (3): 353-361

Jenkins, S. R., Norton, T. A. and S. J. Hawkins. 1999. Settlement and post-settlement interactions between *Semibalanus balanoides* (L.) (Crustacea: Cirripedia) and three species of fucoid canopy algae. J. Expt. Mar. Biol. Ecol. 236: 49-67.

Jenkins, S. R., Norton, T. and S. J. Hawkins. 2004. Long term effects of *Ascophyllum nodosum* canopy removal on mid shore community structure. J. Mar. Biol. Ass. UK 84: 327-329.

Johnson, L. A., Brawley, S. H. and W. H. Adey. 2011. Factors explaining the continued spread of *Fucus serratus* in the Canadian Maritimes. Biological Invasions DOI: 10.1007/s10530-01109976-z.

Jones, P. L. and M. J. Shulman. 2008. Subtidal-intertidal trophic links: American lobsters [*Homarus americanus* (milne-Edwards)] forage in the intertidal zone on nocturnal high tides. J. Exp. Mar. Biol. Ecol. 361: 98-103.

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

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

Kangas, P. , Autio, H., Hallfors, G., Luther, H., Niemi, A., and H. Salemaa. 1982. A general model of the decline of *Fucus vesiculosus* at Tvarminne, south coast of Finland in 1977-81. Acta Botanica Fennica 118: 1-27.

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

Keser, M., and B. R. Larsen. 1984. Colonization and growth of *Ascophyllum nodosum* (Phaeophyta) in Maine. J. of Phycol. 20:83-87.

Kiirkki, M. and A. Ruuskanen. 1996. How does *Fucus vesiculosus* survive ice scraping? Bot. Mar. 39: 133-139.

Knight, M. and M. Parke. 1950. A biological study of *Fucus vesiculosus* L. and *F. serratus* L. J. Mar. Biol. Assoc. UK 29. 439-515.

Lambert, A. J. and S. H. Brawley. 1993. Fertilization success and polyspermy in estuarine *Ascophyllum nodosum* Northeast Algal Symp. Woods Hole. p. 15.

Lamote, M., Johnson, L. E. and Y Lemoine. 2007. Interspecific differences in the response of juvenile stages to physical stress: Fluorometric responses of fucoid embryos to variation in meteorological conditions. J. Phycol. 43: 1164-1176.

Lamote, M. and L. E. Johnson. 2008. Temporal and spatial variation in the early recruitment of fucoid algae: the role of microhabitats and temporal scales. Mar. Ecol. Prog. Ser. 368: 93-102.

Larsen, P. F. 2012. The macroinvertebrate fauna of rockweed (*Ascophyllum nodosum*)-dominated low-energy rocky shores of the northern Gulf of Maine. J. Coast. Res. 28: 36-42.

Lazo, L. and A. R. O. Chapman. 1996. Effects of harvesting on *Ascophyllum nodosum* (L.) Le Jol. (Fucales, Paheophyta): a demographic approach. J. Appl. Phycol. 8: 87-103.

Leonard, G. H., Levine, J. M., Schmidt, P. R. and M. D. Bertness. 1998. Flow-driven variation in intertidal community structure in a Maine estuary. Ecology 79: 1395-1411.

Longtin, C. M., Scrosati, R. A., Whalen, G. B. and D. J. Garbary. 2009. Distribution of algal epiphytes across environmental gradients at different scales: Intertidal elevation, host canopies, and host fronds. J. Phycol. 45: 820-827.

Lubchenco, J. 1978. Plant species diversity in a marine intertidal community: importance of herbivore food preference and algal competitive abilities. Amer. Nat. 112(983): 23-39.

Lubchenco, J. 1980. Algal zonation in the New England rocky intertidal community: An experimental analysis. Ecol. 61: 333-344.

Lubchenco, J. 1983. *Littorina* and *Fucus*: Effects of herbivores, substratum heterogeneity, and plant escapes during succession. Ecol. 64: 1116-1123.

McCook, L. J. and A.R.O. Chapman. 1991. Community succession following massive ice-scour on an exposed rocky shore: effects of *Fucus* canopy algae and of mussels during late succession. J. Exp. Mar. Biol. Ecol. 154: 137-169.

MacFarlane, C. 1952. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. Can. J. Bot. 30: 78-97.

MacKay, D. A. 1926. Post-larval lobsters. Science 64: 530.

MacMillan, M. R. and P. A. Quijon. 2012. Wrack patches and their influence on upper-shore macrofaunal abundance in an Atlantic Canada sandy beach system. J. Sea Res. 72: 28-37.

Mathieson, A. C. 1989. Phenological patterns of northern New England seaweeds. Bot. Mar. 32: 419-438.

Matthieson, A. C., E. Tveter, M. Daly, and J. Howard. 1977. Marine algal ecology in a New Hampshire tidal rapid. Bot. Mar. 20: 277-290.

Mathieson, A. C., Penniman, C. A., Busse, P. K., and E. Tveter-Gallagher. 1982. Effects of ice on *Ascophyllum nodosum* within the Great Bay estuary system of New Hampshire-Maine. J. Phycol. 18: 331-336.

Maximova , O. V. and A. F. Sazhin. 2010. The role of gametes of the macroalgae *Ascophyllum nodosum* (L.) Le Jolis and *Fucus vesiculosus* L. (Fucales, Phaeophyceae) in summer nanoplankton of the White Sea coastal waters. Oceanology 50: 198-208.

McCook, L. J. and A. R. O. Chapman. 1991. Community succession following massive ice scour on an exposed rocky shore: effects of *Fucus* canopy algae and of mussels during late succession. J. Exp. Mar. Biol. Ecol. 154: 137-169.

McCook, L. J. and A. R. O. Chapman. 1992. Vegetative regeneration of *Fucus* rockweed canopy as a mechanism of secondary succession on an exposed rocky shore. Bot. Mar. 35: 35-46.

McCook, L. J. and A. R. O. Chapman. 1997. Patterns and variations in natural succession following massive ice-scour of a rocky intertidal seashore. J. Exp. Mar. Biol. Ecol. 214: 121-147.

Menge, B. A. 1976. Organization of the New England rocky intertidal community: role of predation, competition and environmental heterogeneity. Ecol. Monogr. 46: 355-393.

Menge, B. A. 1978. Predation intensity in a rocky intertidal community. I. Relation between predator foraging activity and environmental harshness. II. Effect of wave action and desiccation on predator feeding rates. Oecologia 34: 1-35.

Muhlin, J. F., C. R. Engel, R. Stessel, R. A. Weatherbee and S. H. Brawley. 2008. The influence of coastal topography, circulation patterns and rafting in structuring populations of an intertidal alga. Molec. Ecol. 17: 1198-1210.

Moss, B. 1970. Meristems and growth control in *Ascophyllum nodosum*. New Phytol. 69: 253-260.

Muhlin, J. and S. H. Brawley. 2009. Recent versus relic: Discerning the genetic signature of *Fucus vesiculosus* (Heterokontophyta; Phaeophyceae) in the northwestern Atlantic. J. Phycol. 45: 828-837.

Muhlin, J. F., Coleman, M. A., Rees, T. A. V. and S. H. Brawley. 2011. Modeling of reproduction in the intertidal macrophyte *Fucus vesiculosus* L. and implications for spatial subsidies in the nearshore environment. Mar. Ecol. Prog. Ser. 440: 79-94.

Olsen, J. L., Zechman, F. W., Hoarau, G., Coyer, J. A., Stam, W. T., Valero, M. and P. Aberg. 2010. The phylogeographic architecture of the fucoid seaweed *Ascophyllum nodosum*: an intertidal 'marine tree' and survivor of more than one glacial-interglacial cycle. J. Biogeogr. 37: 842-856.

Peckol, P., M. M. Harlin, and P. Krumscheid. 1988. Physiological and population ecology of intertidal and subtidal *Ascophyllum nodosum* (Phaeophyta). J. Phycol. 24: 192-198.

Petraitis, P. S. and S. R. Dudgeon. 2005. Divergent succession and implications for alternative states on rocky shores. J. Ecol. Mar. Biol. Ecol. 326: 14-26.

Petraitis, P. S., Methratta, E. T., Rhile, E. C., Vidargas, N. A. and S. R. Dudgeon. 2009. Experimental confirmation of multiple community states in a marine ecosystem. Oecologia 161: 139-148.

Phillippi A, A. Perna, and K. Tran. 2013. Impacts of rockweed harvesting on intertidal fauna. Presented at the 42nd Annual Benthic Ecology Meeting, March 20-24, 2013. Savannah, GA.

Printz, H. 1956. Recuperation and recolonization in *Ascophyllum*. Proc. Int. Seaweed Symp. 2: 194-197.

Rangeley, R. W. and D. L. Kramer. 1995. Use of rocky intertidal habitats by juvenile Pollock *Pollachius virens*. Mar. Ecol. Prog. Ser. 126: 9-17.

Rangeley, R. W., and J. Davies, editors. 2000. Gulf of Maine Rockweed: Management in the face of scientific uncertainty, proceedings of the GPAC workshop, 5-7 December 1999, St. Andrews, New Brunswick. Huntsman Marine Science Centre Occasional Report No. 00/1.

Rayirath, P., B. Benkel, D. M. Hodges, P. Allan-Wojtas, S. MacKinnon, A. T. Critchley, and B. Prithiviraj. 2009. Lipophilic components of the brown seaweed, *Ascophyllum nodosum,* enhance freezing tolerance in *Arabidopsis thaliana.* Planta. 230(1):135-47

Rindi, F. and M. Guiry. 2004. Composition and spatio-temporal variability of the epiphytic macroalgal assemblage of *Fucus vesiculosus* Linnaeus at Clare Island, Mayo, western Ireland. J. Exp. Mar. Biol. Ecol. 311: 233-252.

Saga, N. 1978. Notes on Fucales 8. Regeneration from rhizoid piece of *Pelvetia wrightii* germling to complete thallus. Jap. J. Phycol. 26: 1-4.

Schmidt, A. L., M. Coll, T. N. Romanuk, and H. K. Lotze. 2011. Ecosystem structure and services in eelgrass *Zostera marina* and rockweed *Ascophyllum nodosum* habitats. Mar. Eco. Prog. Ser. 437: 51-68 + Supp.

Schonbeck, M. W. and T. A. Norton. 1978. Factors controlling the upper limits of fucoid algae on the shore. J. Exp. Mar. Biol. Ecol. 31: 303-313.

Sears, J. (ed). 2002. NEAS KEYS to Benthic Marine Algae of the Northeastern Coast of North America from Long Island Sound to the Strait of Belle Isle (2nd ed). North Dartmouth: Northeast Algal Society, 161 pp

Sebens, K. P. 1991. Habitat structure and community dynamics in marine benthic systems. In: Bell, S.S., McCoy, E.d., Muchincky, H.R. (Eds.), Habitat Structure: the Physical Arrangement of Objects in Space. Chapman and Hall, NY, pp. 211-234.

Seeley, R. H., M. Leone, and D. O. Brown. 2013. Lobsters use rockweed habitat in the intertidal zone at night. Poster presented at the Regional Association for Research on the Gulf of Maine 2013 Annual Science Meeting: The 2012 Gulf of Maine heat wave: anomalous year or the new normal?, October 8, 2013, Portsmouth, NH.

Serrão, E. A., G. Pearson, L. Kautsky and S. H. Brawley. 1996. Successful external fertilization in turbulent environments. Proc. Natl. Acad. Sci. U.S.A. 93: 5286-90.

Serrão, E., S. H. Brawley, J. Hedman, L. Kautsky and G. Samuelsson. 1999. Reproductive success in *Fucus vesiculosus* (Phaeophyceae) in the Baltic Sea. J. Phycol. 35: 254-269.

Sharp, G. J. 1987. *Ascophyllum nodosum* and its harvesting in eastern Canada, pp. 3-46 in Case Studies of Seven Commercial Seaweed Resources, FAO Fisheries Technical Paper 281. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/X5819E/x5819e00.htm

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

Soneira, A. and X. Niell. 1975. Sobre la biologia de *Ascophyllum nodosum* (L.) Le Jolis en Galicia I. Distribucion y abundancia en la Ria de Vigo. Investagacion Pesquera 39: 43-59.

Speransky, V. S. Speransky, and S. H. Brawley. 1999. Cryoanalytical studies of freezing damage and recovery in *Fucus vesiculosus* (Phaeophyceae). J. Phycol. 35: 1264-1275.

Stromgren, T. 1983. Temperature-length growth strategies in the littoral alga *Ascophyllum nodosum* (L.). Limnol Oceanogr. 28: 516-521.

Terry, L. A. and B. L. Moss. 1980. The effect of photoperiod on receptacle initiation in *Ascophyllum nodosum*. Br. Phycol. J. 15: 291-301.

Thomas, M. L. H. 1994. Littoral communities and zonation on rocky shores in the Bay of Fundy, Canada: an area of high tidal range. Biol. J. Linn. Soc. 51: 149-168.

Topinka, J., L. Tucker, and W. Korgeff. 1981. The distribution of fucoid macroalgal biomass along central coastal Maine. Bot. Mar. 24: 311-319.

Trott, T. J. and P. F. Larsen. 2009. Evaluation of short-term changes in rockweed (*Ascophyllum nodosum*) and associated epifaunal communities following cutter rake harvesting in Maine. Report to the Maine Department of Marine Resources. 31 pp.

Ugarte, R. A. 2011. An evaluation of the mortality of the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. produced by cutter rake harvests in southern New Brunswick, Canada. J. Appl. Phycol. 23: 401-407.

Ugarte, R. A., C. Bartlett, and L. Perry. 2010. A preliminary study to monitor periwinkle by-catch and incidence of holdfasts in harvested rockweed, *Ascophyllum nodosum*, from Cobscook Bay, Maine. Report To the Maine Department of Marine Resources. 13 pp.

Ugarte, R. A. and G. Sharp. 2001. A new approach to seaweed management in eastern Canada: the case of *Ascophyllum nodosum*. Can. Biol. Mar. 42: 63-70.

Ugarte, R. A. and G. Sharp. 2012. Management and production of the brown algae *Ascophyllum nodosum* in the Canadian Maritimes. J. Appl. Phycol. 24: 409-416.

Ugarte, R., G. Sharp, and B. Moore. 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. J. Appl. Phycol. 18: 351-359.

Vadas, R. L. and P. D. Ring. 1968. An evaluation of the seaweed resources of Maine. Res. Life Sci., winter Issue, pp. 16-22.

Vadas, R. L., M. Keser, P. C. Rusanowski. 1976. Influence of thermal loading on the ecology of intertidal algae. In: G.W. Esch and R.W. MacFarlane (Eds.), Thermal Ecology 11. ERDA Symposium Series (CONF-750425), Augusta, GA, pp. 202-212.

Vadas, R. L., M. Keser, and B. Larson. 1978. Effects of reduced temperatures on previously stressed populations of intertidal algae. In: J.H. Thorp and J. W. Gibbons (Eds.), Energy and environmental stress in aquatic systems. DOE Symposium Series, NTIS, Springfield, VA, pp. 434-451.

Vadas, R. L., and W. A. Wright. 1986. Recruitment, growth and management of *Ascophyllum nodosum*. Actas II Congreso Algas Marinas Chilenas: 101-113.

Vadas, R. L., W. A. Wright, and S. L. Miller. 1990. Recruitment of *Ascophyllum nodosum*: wave action as a source of mortality. Mar. Ecol. Prog. Ser. 18: 81-144.

Vadas, R. L. & R. W. Elner. 1992. Plant-animal interactions in the north-west Atlantic. In: Plant-Animal Interactions in the Marine Benthos (eds. D. M. John, S. J. Hawkins, J. H. Price). Oxford: Oxford Univ. Press. pp.87-100.

Vadas, R. L., W. A. Wright, and B. F. Beal. 2004. Biomass and productivity of intertidal rockweeds in Cobscook Bay. Northeastern Naturalist 11(special issue 2):123-142.

Vadas, R. L., B. Beal, S. H. Brawley, N. A. Blouin, and W. A. Wright. 2010. Rockweed harvesting: a recipe for sustainability. Bangor Daily News,

Van Guelen, L. and G. Pohle. 2013. Short- and long-term impact of rockweed harvesting on the intertidal fish community in southwest New Brunswick. Fin. Rep. to the New Brunswick Wildlife Trust Fund. Proj. F302-058. Abstract.

Watson, D.C. and T. A. Norton. 1985. Dietary preferences of the common periwinkle, *Littorina littorea* (L.). J. Exp. Mar. Biol. Ecol. 88: 193-211.

Watt, C. A. and R. A. Scrosati. 2013. Bioengineer effects on understory species richness, diversity, and composition change along an environmental stress gradient: Experimental and mensurative evidence. Estuarine, Coastal and Shelf Science 123: 10-18.

Wippelhauser, G. S. 1996. Ecology and management of Maine's eelgrass, rockweeds, and kelps. Maine Natural Areas Program, Dept. Cons., Augusta, ME. 73 p.

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Appendix A: Biomass Assessment Methodology

General

The entity (individual, business, etc.) that has been allocated a sector by the DMR will be responsible for conducting biomass assessments within its sector or having assessments conducted by a third party, to be identified by the DMR. The methodology outlined below shall be followed when conducting biomass assessments. The Department may divide a sector into subsectors, depending on the size and variability of rockweed stands in the requested sector, and biomass assessments shall be conducted in each subsector where rockweed harvest is proposed. Assessments for each area proposed for harvest will be conducted prior to harvest and at least every three years.

Biomass assessments shall be conducted after the reproductive season (generally May-June in Maine) until the end of September.

Methodology

Area measurement
Aerial photography, available web mapping services, or actual area measurements shall be used to identify and estimate the area covered by the resource. The most recent aerial photography taken near low water is available through web mapping services. Photography for the entire Maine coast is available from the Maine Office of GIS at http://www.maine.gov/megis/maps/. A visual examination of the shoreline shall be made to verify the location of *Ascophyllum* beds. A bed is defined as a homogenous and continuous geographical unit containing *Ascophyllum*. The borders are typically defined by a geographical disruption (e.g., a sandy beach, a rock formation), or any other physical feature that changed its cover drastically.

Ground truthing
Ground truthing shall be carried out by setting out 30-meter transects at a predetermined number of locations selected from the aerial photographs/maps and distributed along the proposed harvesting sector. The number of transects for a sector will depend on the size of the area and the complexity of the shoreline within the area. Prior assessment experience indicates that the rockweed biomass is generally quite homogenous in 90% of the bed width (between its high and low water level). Therefore, one to three transects per bed should be sufficient, depending on the homogeneity of the area, to adequately assess a sector. Ten quadrats should be sampled along each 30-meter transect.

The sampling unit used for the assessment shall be a 0.25 m^2 (50 x 50 cm) quadrat. This quadrat has been demonstrated to represent a good compromise between statistical and practical requirements. *Ascophyllum* shall be assessed at a cutting height of 12 inches. A clump of *Ascophyllum* within each quadrat should be selected randomly for measurement of individual fronds.

The following data should be recorded and submitted to the Department in an Excel spreadsheet:

- Sector identification
- Transect number
- GPS latitude
- GPS longitude
- Date
- Time
- Low water time
- Exposure
- Substrate
- Transect length
- Quadrat number
- *Ascophyllum* weight (kg/.25 m^2)
- *Fucus* weight (kg/.25 m^2)
- Individual *Ascophyllum* length measurements (cm)
- *Ascophyllum* Bed width (m)
- Epiphytes
- Other algal species
- Faunal species
- Notes (other pertinent information)
- Name of surveyor(s)

Besides biomass density, general information on the transect location, substrate type, wave exposure, slope and any other particular details of the bed shall be recorded. Bare patches are considered a natural property of the zone and all zero values (quadrats without clumps) shall be recorded and counted. The width of the bed at the transect point shall also be recorded and used to calibrate area measurement from aerial photos/maps.

Data integration
Sector holders shall submit to the Department an Excel computer file (with paper back-up) that includes all above information for each individual sector or subsector. Biomass will be calculated as follows: Total biomass = Total Area x Average Biomass/Sector (Sample Area).

DMR will hold periodic training workshops to train sector holders in biomass assessment methodology.

<u>Audits</u>

Independent/third party audits will be conducted on a random subset of the sectors or subsectors held by each entity to validate the results of each entity's assessments. Audits may be conducted in conjunction with the sector-holder's assessment. The latter option is preferred as it would eliminate discrepancies in assessment results. Audits should be conducted prior to the start of harvesting.