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Maine's Potential to Be a Global Leader in Sustainable Seaweed Harvesting and Management

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Cover Page Footnote

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ABSTRACT

Sustainable harvest of seaweed species is both economically and ecologically important in Maine. Management of these resources in Maine targets the intertidal foundation species, rockweed (*Ascophyllum nodosum*). Delayed adoption of the rockweed fisheries management plan, drafted in 2014, presents an opportunity to re-examine the plan from an ecosystem-based management perspective. Our comparison of such strategies to the drafted plan reveals that many of the critical elements are included. With additional management strategies, Maine could set a standard of ecosystem-based management for a foundation species and can position itself as a global leader in management of wild, and farmed, seaweed harvesting.

INTRODUCTION

With an annual global wild harvest of 2.5 million tons, seaweeds play an integral role in the *blue economy* (BBC Research 2021) and provide a multitude of ecosystem services (Cotas et al. 2023). Maine's approximately 3,500 miles of convoluted coastline along the Gulf of Maine is characterized primarily by rocky intertidal shores and hard-substrate subtidal environments dominated by fucoid, or brown, seaweeds and kelp species (Trott 2022). In Maine, many seaweed species are harvested or cultivated commercially, including bladderwrack, rockweed, sugar kelp, winged kelp, sea lettuce, Irish moss, and dulse. During 2020, 8,165 tons of seaweed, both wild and farmed, with a landed value of approximately $1.6 million USD was harvested, and over the last 5 years (2017–2022), approximately 125 harvesting permits have been issued per year.[1] Seaweeds are also harvested for sustenance and cultural purposes. Although Maine currently represents a fraction of the total global harvest, the state's clean water and lengthy coastline, combined with the world's increasing demand for seaweed products, will place pressure to increase harvests.

By weight, 95 percent of Maine's seaweed landings are wild-harvested *Ascophyllum nodosum* (hereafter called rockweed). Rockweed is one of the dominant seaweeds in the rocky intertidal zone throughout its North Atlantic range (Sears 2002) and has been primarily harvested for decades throughout the range for agricultural and nutraceutical applications (Mac Monagail et al. 2017). Rockweed extracts, when used in plant agriculture, have been identified as a critical antidote for reducing use of chemical fertilizers, reducing water usage, and protecting crops from pest and abiotic stresses associated with climate change (Kumari et al. 2023). Although the landed value of rockweed is relatively low, the contribution of value-added products increases the realized value by at least 20 times (Thayer and Schmitt 2013).

Unlike other harvested marine organisms, rockweed is a habitat-forming species and controls many ecological processes by modifying the physical (Johnson 2001), biological (Schmidt et al. 2011), and chemical (Hay 2009) environment. Rockweed significantly structures intertidal and marine communities, providing habitat to diverse assemblages of fish, invertebrates, micro- and macroalgae, and migratory birds (Larsen 2012). Additionally, this foundation species is an important primary producer in nearshore ecosystems, and is part of Maine's blue carbon potential (CMWG 2020). It is crucial that harvesting activities are managed to ensure not only a sustainable fishery but also to maintain the ecosystem functions and services of rockweed.

ECOSYSTEM-BASED MANAGEMENT

Marine ecosystem-based management is an approach to resource use with goals to sustain healthy, productive and diverse marine ecosystems (McLeod and Leslie 2009). Reducing risks of ecosystem degradation, avoiding permanent changes to ecosystem structure and function,

and selectively harvesting biota facilitate a blue economy that is socially equitable, environmentally sustainable, and economically viable. In 2014, initiated by Maine's seaweed industry leaders and implemented through the Maine State Legislature (LD 585), Maine drafted a rockweed fishery management plan (Maine DMR-RPDT 2014). The work built on long-term, traditional practices of Maine's rockweed harvesters, plus current Department of Marine Resource (DMR) management tools of harvester and processor licensing, minimum cutting heights, landing reports by specified areas (called sectors), and penalties. In recognition of some unsustainable harvest practices in other bioregions (e.g., DFO 1998), the management plan was initiated in proactive awareness of increasing rockweed harvest in the state.

The legality of the rockweed ownership is disputed, and there are a number of emerging lawsuits and legislative initiatives that seek to resolve the 2019 Maine Superior Court ruling (*Kenneth W. Ross et al. v. Acadian Seaplants, Ltd.*) that rockweed located within the intertidal zone is the private property of the adjacent upland property owner. It is, however, still the obligation of DMR to manage these marine organisms as part of its mandate to conserve and develop marine and estuarine resources. Due to litigation regarding ownership of rockweed (see Totten 2019 for timeline), the management proposal has yet to be adopted.

The delay in adoption and heightened public awareness of the importance of rockweed is an opportunity to re-examine the fisheries management plan from an ecosystem-based management perspective. For that purpose, we compare such strategies to the existing rockweed fisheries management plan and identify areas of synergy as well as gaps in the management and harvesting activities. Based on our analysis, we propose Maine adopt an ecosystem-based approach and strategies for wild as well as farmed seaweeds, starting with rockweed. We draw from strategies synthesized in Lotze et al. (2019) (Figure 1), which focused specifically on wild harvested seaweeds and include the following:

1. Bycatch limits, for holdfasts and vulnerable species
2. Spatial management, including area limits, rotations, and harvest exclusion zones
3. Harvest limits or quotas
4. Seasonal closures—for seaweed reproduction and for associated species breeding and nursery seasons
5. Gear restrictions
6. Regulation of cutting methods/height
7. Reporting and enforcement
8. Research and monitoring
9. Co-management in areas with multiple species harvest

Bycatch Limits

The rockweed fisheries management plan only suggests that bycatch "be minimized." Bycatch in wild seaweed harvest may refer to removal of holdfasts (the part of the seaweed that attaches to rock or another hard surface) or of nontarget species associated with seaweed (e.g., for rockweed: *Littorina littorea,* periwinkles). Intact holdfasts, which house their own rich assemblages of species (Phillippi et al. 2014), allow for regrowth of the seaweed fronds and maintenance of a seaweed stand.

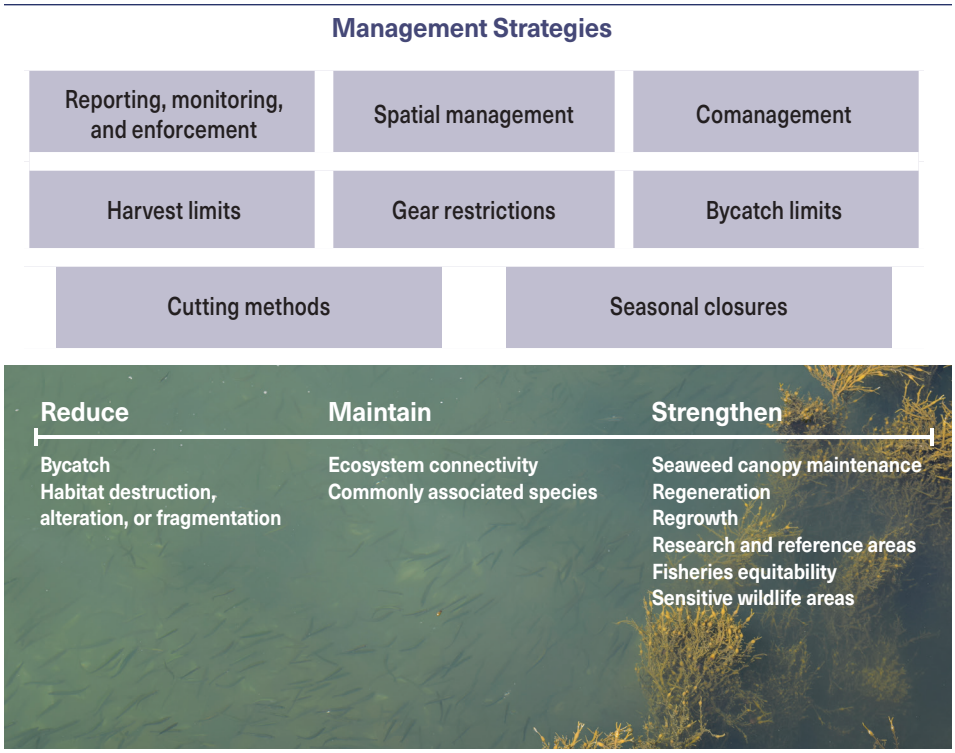
Bycatch could be limited by adopting comprehensive harvester training, gear restrictions, monitoring and reporting standards, and enforcement for noncompliance. For example, in Nova Scotia, holdfasts must represent no more than 15 percent of harvest sample by weight (N.S. Reg. 239/2016), requiring both a random sampling regime (by regulators, industry, or a neutral third party) and a reporting obligation. Programs, such as NOAA's National Bycatch Reduction (NOAA 2016), could also be established to monitor rockweed beds for holdfast removal and nontarget species bycatch.

Spatial Management

The rockweed fisheries management plan recommends statewide adoption of area-based management, which would allow for area-specific quotas and increased accountability for and among rockweed harvesters. We believe that area-based management is key for ecosystem-based management. The coast of Maine is variable in terms of biophysical characteristics and some regions (i.e., southwestern coastlines) may be less resilient to changing climate (Bricknell et al. 2021) and coastal development. Within each area the management plan proposes an annual removal quota of no more than 17 percent of the available biomass. However, spatial rotation within areas is missing from the plan—currently harvesters can return to the same rockweed beds within an area year after year. Requiring within-area bed rotation could reduce environmental and ecological impacts of harvest and maximize regrowth potential.

The rockweed fisheries management plan requires no-harvest or closed areas in and around rockweed harvesting areas. For ecosystem-based management, these closed areas

FIGURE 1: **Summary of Ecosystem-based Management Strategies and Ecosystem Responses**



should include (a) sensitive wildlife areas (e.g., shorebird habitat, seal haul-out, previously mapped critical areas), (b) research areas to understand the effects of harvesting, and (c) reference areas to track background ecosystem change—all of which are outlined in the management plan. Identifying a portion of harvest-quality rockweed beds as no-harvest areas allows for research and monitoring. However, because closing areas increases pressure on the reduced number of harvestable beds, there must be a maximum of closed acreage per management area.

Another major concern in spatial management is the equitable allocation of harvest areas. Embracing a justice, equity, diversity, and inclusion framework for area allocation has been demonstrated to have a multitude of environmental, economic, and societal benefits (Cisneros-Montemayo et al. 2021). Area equitability would allow tribal and smaller-scale harvesters access to the resource as well as larger-scale operations.

The rockweed management plan area management recommendations include specific area allocations (called sectors throughout the plan) to single entities. However, releasing harvest statistics with each area allocated to a single entity, runs afoul of the rule of three ("Data, statistics, or information in aggregate or summary form means the combined data of three or more submitters" [Maine DMR 2021: 3]). The rule of three makes independent verification of 17 percent removal limits difficult, if not impossible. Transparent and near real-time updating of landings data is necessary to allow harvesters and resources managers to know when removal limits are reached and will help ensure equitable allocation of the resource.

Harvest Limits or Quotas

The rockweed fisheries management plan has a 17 percent assessed biomass per area per annum quota, requires a rockweed harvester to submit a harvesting plan that includes a preharvest biomass assessment, and directs DMR to coordinate third-party biomass assessments. Setting harvest quotas on foundation species such as rockweed allows for maintenance of ecosystem function and connectivity and, in conjunction with leaving holdfasts (or the areas of tissue regeneration), allows for the regrowth of seaweed biomass after harvest. Biomass assessment research currently underway includes developing spectral libraries and biomass remote-sensing capabilities (Seatone 2023). Additionally, ground-truthing efforts (including the citizen science effort Project ASCO)[2] are in progress. When these efforts are fully available, we propose that DMR take charge of, and budget for, seaweed stock assessment, as they do with other fisheries. The combined approach of area allocation, biomass quotas, rotational harvests, cutting height regulations, and routine stock assessment will reduce the risk of overharvest.

Seasonal Closures

There is currently no seasonal closure recommendation in the rockweed fisheries management plan. Restricting

TABLE 1: **Rockweed Harvest Cutting Heights**

Location	Cutting height	Regulatory or advised	Source
Maine	16 in. (41 cm)	Regulatory	Maine DMR-RPDT 2014
Atlantic Canada	5 in. (13 cm)	Regulatory	https://novascotia.ca/just/regulations/regs/fcrweed.htm/; Vandermeulen 2013
Finistère, France	9 in. (20 cm)	Regulatory	Mesnildrey et al. 2012
Côte d'Armor, Morbihan, Ille-et- Vilaine, France	12 in. (30 cm)	Regulatory	Mesnildrey et al. 2012
Wales and England	4-9 in. (10–20 cm)	Advised	NRW 2018; Bailey and Owen 2014
Ireland	10 in. (25 cm)	Advised	Bruton et al. 2009
Scotland	12 in. (30 cm)	Advised	Marine Scotland 2016

harvesting to certain seasons can accommodate seaweed reproduction and growth in addition to protecting critical periods during the life cycles of rockweed-associated species. Rockweed individuals release eggs and sperm in the spring when water temperatures reach 6°C (Bacon and Vadas 1991). The peak breeding or nursery season of commonly associated species, e.g., common eider, *Somateria mollissima* (Blinn et al. 2008) and pollock, *Pollachius virens* (Rangeley and Kramer 1995), occurs in the spring to early summer. A seasonal closure that encompasses the rockweed reproductive season and minimizes impact to breeding and nursery seasons of associated species should be incorporated into the rockweed plan.

Gear Restrictions

The rockweed fisheries management plan has no gear restrictions. There are currently three methods for cutting rockweed in Maine: hand harvest with cutter rake, hand harvest with knife, and mechanical harvest. Although knife cutting is limited, it is conducted at low tide and has the greatest potential for small-scale habitat destruction (Maine DMR-RPDT 2014). Cutter raking and mechanical harvesting are conducted at high tide (Johnston et al. 2023). Cutter rakes have a 16-inch guard that restricts the depth to which a rake can be placed; however, unsharpened cutter rake blades and friable substrate can lead to considerable damage to the ecosystem (Vandermeulen 2013). While mechanical cutting methods have evolved to control cutting height and limit bycatch, they can remove biomass rapidly over large swathes potentially impacting the intertidal ecosystem more broadly.

The rockweed management plan needs to include a gear restriction that supports the regulatory 16-inch cutting height—mandating at least a 16-inch guard on cutter rakes and at least a 16-inch inset on the mechanical harvesters. While hand harvesting with a knife at low tide is a small-scale means of harvesting, those harvesters should seek allocation of smaller areas, or an agreed-upon subarea, and the practice should have clear enforceable guidelines to reduce destructive practices.

Regulations on Cutting

Maine DMR regulations Chapter 29.05(A), in place since 2000, sets the cutting height at 16 inches as a way to minimize impact to the seaweed canopy and encourage rapid regrowth (Maine DMR-RPDT 2014). Individual rockweeds can reach over 6 feet in length on sheltered shores (MacFarlane 1952). In comparison to other countries where rockweed is harvested, a 16-inch cutting height is one of the most conservative, regulated, or advised (Table 1) and is compatible with ecosystem-based management.

Reporting and Enforcement

The rockweed fisheries management plan requires both rockweed purchasers and harvesters to report only on biomass removed per area per month. Reporting should also include specific area-based bycatch and catch-per-unit-effort (as an indirect measure of abundance). Without reporting and enforcement, it is difficult to know whether regulations are followed or to fully assess the health of the resource and the environment. Other fisheries use GPS devices to track where and when harvesting occurs. GPS tracking of rockweed mechanical harvesting operations has shown

considerable success in quota-based area management in Nova Scotia (Sharp and Sharp 2023). A GPS-based reporting tool may allow for more automated, more rapid, and easier reporting for harvesters and should be developed in collaboration with harvesters. It could also facilitate more frequent reporting, giving regulators more current data on a sector's 17 percent harvest limit.

Research and Monitoring

The rockweed fisheries management plan identifies ecology and habitat, biomass and height recovery, and large-scale effects of harvesting as important research needs. As mentioned earlier, research is currently underway to develop remote sensing for biomass (Seatone 2023), and ground truthing efforts, including the citizen science Project ASCO. There are variable estimates for the standing stock of rockweed in Maine as a whole (see Maine DMR-RPDT 2014), but better estimates for areas with long-term harvesting (Cobscook and Quahog Bays). Preliminary remote-sensing analysis indicates that intertidal seaweed biomass is estimated at 1.4 million metric tons for the coast of Maine (Claesson 2023).

For ecosystem-based management, research and monitoring needs to expand beyond biomass assessment, and this, too, is happening. Johnston et al. (2023) found that one-year post-harvest, harvested rockweed beds regained biomass. There has been additional research on rockweed's importance to coastal bird guilds (Johnston et al. 2019), the effect of harvest on the invertebrate community (Mittelstaedt, unpublished), and the effect of rockweed architecture on the invertebrate community (Webber, unpublished). Despite the growing depth of knowledge about macroalgae habitat, questions and data gaps remain, particularly around the long-term effects of harvesting on rockweed canopies and associated communities, the ecological effects of different harvest histories, and the effects of harvest on carbon cycling.

Comanagement

While the rockweed fisheries management plan was created collaboratively with harvesters and other stakeholders, it did not recommend a form of governance that incorporates tribal harvesters, local or regional operators, or other interest holders (such as those who collect rockweed for packing material to ship bait worms and lobsters). However in 2019, the DMR commissioner established the Seaweed Fisheries Advisory Council (SFAC), composed of diverse seaweed interests to advise on "the health of the seaweed resource, its ecosystem and the industry it supports" (Title 12, Part 9, Chapter 605, §6087). But at this time, the SFAC does not interact with the commissioner's five other fishery advisory groups, focusing only on seaweed matters. Because rockweed is a foundation species and harvesting overlaps with other fisheries (e.g., periwinkles, urchins, clamming, worming, lobstering) we propose the development of a DMR-appointed multifisheries interest group (regulators, managers, tribal representatives, coastal land owners, harvesters, processors, researchers) to manage the interplay between different and overlapping nearshore fisheries and other resource uses, as well as support DMR with management decisions for seaweed and other fisheries.

Ecosystem-based management will require better integration of data sharing and regulatory communication between DMR (marine resources), Department of Inland Fisheries and Wildlife (stewardship of Maine's wildlife, including seabirds and waterfowl such as common eider, *Somateria mollissima*), and Department of Agriculture,

SUMMARY OF RECOMMENDATIONS

- Adopt training, gear restrictions, monitoring and reporting standards, and enforcement policies
- Monitor rockweed beds for holdfast removal and nontarget species bycatch
- Require within-area bed rotation
- Require near real-time updating of landings data
- Undertake seaweed stock assessment
- Adopt a seasonal closure that encompasses the rockweed reproductive season
- Include gear restrictions that support 16-in. cutting height
- Develop GPS-based reporting tool in collaboration with harvesters
- Invest in research on long-term effects of harvesting
- Appoint a multifisheries interest group
- Expand research to include additional harvested seaweed species

Conservation and Forestry (administration of publicly owned submerged lands).

STRATEGIES THAT STRENGTHEN MANAGEMENT

The rockweed fisheries management plan proposed additional strategies that strengthen the management approach.

Training

The plan recommends a training program. We propose that the state promote nonprofit or industry organizations (such as the Maine Seaweed Council) to provide standardized, updated harvester and processor training on the basic biology and ecology of rockweed and other commercial species and their associated ecosystems, regulations, and gear maintenance.

Five-Year Review

The plan also describes a five-year review process. A five-year review allows for management modification based on research findings, monitoring outcomes, emerging interests (e.g., blue carbon), or changes to the larger social-ecological system, and creates an opportunity to set a new research agenda.

ECOSYSTEM-BASED MANAGEMENT FOR OTHER HARVESTED SEAWEED SPECIES

Ecosystem-based management relies on strong knowledge of the ecosystem and the role of the harvestable species within that system. We know enough of the basics about rockweed (e.g., biology and ecology) to advance ecosystem-based management for the species. Growth rates, both pre- and postharvest (regeneration) are well reported in the literature (from MacFarlane [1933] through Lauzon-Guay et al. [2021]), as is its reproduction (e.g., Dudgeon and Petraitis 2005). The associated rockweed community is well-covered (e.g., Larsen 2012). Additionally, well known harvest practices, including removal of only part of the individual, differentiates harvesting of rockweed from harvesting other marine organisms. For a sound ecosystem-based management for additional harvested seaweed species (e.g., dulse [*Palmaria palmata*], sea lettuce [*Ulva* spp.], truffleweed [*Vertebrata lanosa*]), there needs to be a similar level of diverse research and documentation of harvest practices, as exists for rockweed.

TABLE 2: **Summary of Ecosystem-based Management Strategies and the Rockweed Fisheries Management Plan**

Strategy	Status in the plan
Spatial management	Present
Harvest limits	Present
Cutting height limits	Present
Reporting requirements	Present
Research and monitoring	Present
Training	Present
Five-year review	Present
Bycatch limits	Not present
Seasonal closures	Not present
Gear restrictions	Not present
Comanagement/interest holder-engaged governance	Not present

SUMMARY

The rockweed fisheries management plan has many of the critical elements of ecosystem-based management: spatial management, harvest limits, cutting height limits, and reporting requirements. Yet, the plan can move closer to ecosystem-based management with additional management strategies around bycatch limits, seasonal closures, gear restrictions, enhanced reporting and communication, and interest holder-engaged governance (Table 2). This work may be undertaken incrementally or as a whole for rockweed management. If Maine moves forward with refining and adopting the rockweed fisheries management plan it will set a standard of ecosystem-based management for a foundation species such as rockweed, be positioned to address ecosystem-based management for other wild harvest seaweed species, and will be a global leader in management of wild and farmed seaweed harvesting. The global demand for seaweed products will only grow; that demand has to be balanced with our need to maintain functional ecosystems, our obligations to protect biodiversity, and our need to maintain blue carbon storage ecosystems. It is with a sense of urgency that DMR, policymakers, coastal stakeholders, and Maine's existing seaweed industry complete the work of the rockweed fisheries management plan.

NOTES

1 Data provided by Maine DMR (https://www.maine.gov/dmr/fisheries/commercial/licenses).

2 https://schoodicinstitute.org/science/marine-ecology-research/latest-projects/project-asco-assessing-seaweed-via-community-observations/

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