Social Acceptance of a Reduced-Footprint Synthetic Mooring System for Floating Offshore Wind Turbines in the Gulf of Maine

Rebecca Green, Suzanne MacDonald, Rebecca Fuchs, and Matthew Hall

National Renewable Energy Laboratory

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List of Acronyms

BOEM	Bureau of Ocean Energy Management
DOE	U.S. Department of Energy
ft	feet
LMA	lobster management area
nmi	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
RFI	Request for Interest
SAR	search and rescue
UMaine	University of Maine

Executive Summary

For generations, the Gulf of Maine has been an area of active marine uses, including commercial and recreational fishing across a multitude of species and gear types, representing businesses from the three coastal states in the region, Maine, Massachusetts, and New Hampshire. In 2022, the Bureau of Ocean Energy Management began a process to facilitate the development of offshore wind energy in the Gulf of Maine, which will require the use of floating offshore wind turbine technology, given the region's significant water depths. A floating offshore wind farm comprises an array of floating offshore wind turbines, each anchored to the ocean floor with a mooring system (typically three lines) featuring chain and/or rope mooring lines.

Engineers are looking to reduce the size of floating offshore wind mooring footprints to minimize conflict with other ocean users. To this end, the University of Maine received funding from the U.S. Department of Energy to design, demonstrate, and validate a novel, reduced-footprint, synthetic mooring system for floating offshore wind turbines that reduces impacts to fisheries and the levelized cost of energy. The study presented in this report was conducted by the National Renewable Energy Laboratory and sought to independently gather fishing industry and other marine user feedback on the potential interactions of their activities with a conventional, chain-based, catenary mooring system as compared to a rope-chain hybrid mooring system that has a reduced footprint on the ocean floor. These "catenary" chain and "semitaut" hybrid mooring systems were designed by the University of Maine and then adjusted and evaluated independently by the National Renewable Energy Laboratory.

NREL held 10 discussions with marine users including commercial fisheries, fishing organizations, and state and federal regulatory agencies. Feedback on fishing gear interactions broadly represented both the fixed and mobile gear types and fishing practices in the region, including those associated with lobster traps, groundfish and squid trawling, scallop dredging, and tuna harpooning. A primary safety consideration identified by the discussion participants was the potential to snag fishing gear either on the floating offshore wind turbine mooring line resting on the seabed or the portion hanging in the water column. In addition to the horizontal footprint of the mooring system, multiple other characteristics of the mooring lines were of interest to participants including the curvature of the lines, the touchdown point of the lines, natural burial of the lines on the seabed, anchoring characteristics, and considerations for marking.

Study results indicate a modest increase in accessibility and acceptance for a single wind turbine using the rope-chain hybrid mooring system design. Across all rankings, the hybrid design was most often identified as being somewhat more accessible and acceptable than the conventional design based on the smaller footprint and the potential to leave more space open for fishing activities. The rankings were significantly caveated with respondents largely not able to separate the footprint of a single turbine's mooring lines from array considerations related to turbine spacing. Generally, study participants felt that if the hybrid design with the smaller footprint maintained an adequate corridor between wind turbines for fishing activities, then the reduced horizontal footprint presented advantages. However, not all respondents felt this way, with some concerned with the length of mooring line in the water column (in addition to the amount of line on the seabed) and others having concerns about the use of synthetic rope in the hybrid design (e.g., durability).

Respondents noted several additional considerations related to mooring configurations and interactions with fishing and other ocean-use activities. For example, they conveyed siting as a top priority and asked that regulators and developers avoid siting projects in areas that are considered of high value to fisheries and that have sensitive benthic (i.e., seafloor) habitat. Numerous respondents felt that mooring footprint and wind turbine spacing considerations could not be separated. They conveyed that as mooring footprints decrease, regulators and developers should avoid reducing spacing between turbines so as not to further restrict the area available for fishing activities. In response to spacing considerations, we note that a smaller mooring footprint would typically not be expected to affect wind turbine spacing, which is mainly driven by energy yield considerations based on wind resource and wake effects, as well as safety considerations for the fishing industry and other ocean users, and additional regulatory inputs. All respondents identified marking as a priority for understanding the location of mooring lines underwater, which could include marking anchors with lit buoys, additions to nautical charts, and/or marking mooring lines with a transponder to avoid gear interactions. Commercial fishing participants conveyed that they would avoid fishing within proximity to the mooring lines and likely focus their efforts elsewhere. Some suggested that as knowledge of potential interactions with floating offshore wind turbines and mooring lines increase, they might consider fishing in greater proximity particularly if they are in a financially lucrative area. Based on feedback, future research could consider potential interactions with arrays of floating offshore wind turbines and the floating balance of system (including both mooring lines and power cables), as well as expand on the types of media (e.g., video, virtual reality) available to support marine users to better understand floating offshore wind turbine technology and minimize potential interactions with their activities.

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1 Introduction

Engineers are looking to reduce the size of floating offshore wind mooring footprints to minimize conflict with other ocean users. To this end, the University of Maine (UMaine) received funding from the U.S. Department of Energy (DOE) to design, demonstrate, and validate a novel, reduced-footprint, synthetic mooring system for floating offshore wind turbines that reduces impacts to fisheries and the levelized cost of energy. UMaine designed two mooring systems for the New England Aqua Ventus I demonstration project to quantify the technical, economic, and social impacts of a reduced-footprint hybrid mooring system. New England Aqua Ventus I is a pilot project offshore Monhegan Island in Maine that will mount a wind turbine on a floating semisubmersible concrete hull, with the turbine held in position by three marine mooring lines anchored to the seabed and connected by subsea cable to the Maine power grid. Specifically, UMaine designed a traditional catenary chain mooring system and a novel, semitaut, polyester rope-chain hybrid system for this assessment.

For this work, the National Renewable Energy Laboratory (NREL) was funded by DOE to help independently quantify the social and techno-economic impacts of the rope-chain hybrid mooring system designed by UMaine. This report focuses on NREL's assessment of the social acceptance by competing users of the reduced-footprint rope-chain hybrid mooring system and the conventional all-chain mooring system in the Gulf of Maine. In April 2022, the Bureau of Ocean Energy Management (BOEM) released the Gulf of Maine Planning Area for potential federal offshore wind energy leasing, which covers waters off of Maine, New Hampshire, and Massachusetts (Figure 1). In August 2022, BOEM published a Request for Interest (RFI) for the Gulf of Maine in the Federal Register. The study area for the assessment in this project is based on this RFI area, which included a smaller region within the planning area identifying the offshore locations that appear most suitable for development. The RFI map accounts for potential impacts to resources and ocean users, including Stellwagen Bank National Marine Sanctuary and traffic separation schemes (Figure 2). A draft Call for Information and Nominations Area for the Gulf of Maine was released by BOEM in January 2023, following the activities performed for this report.

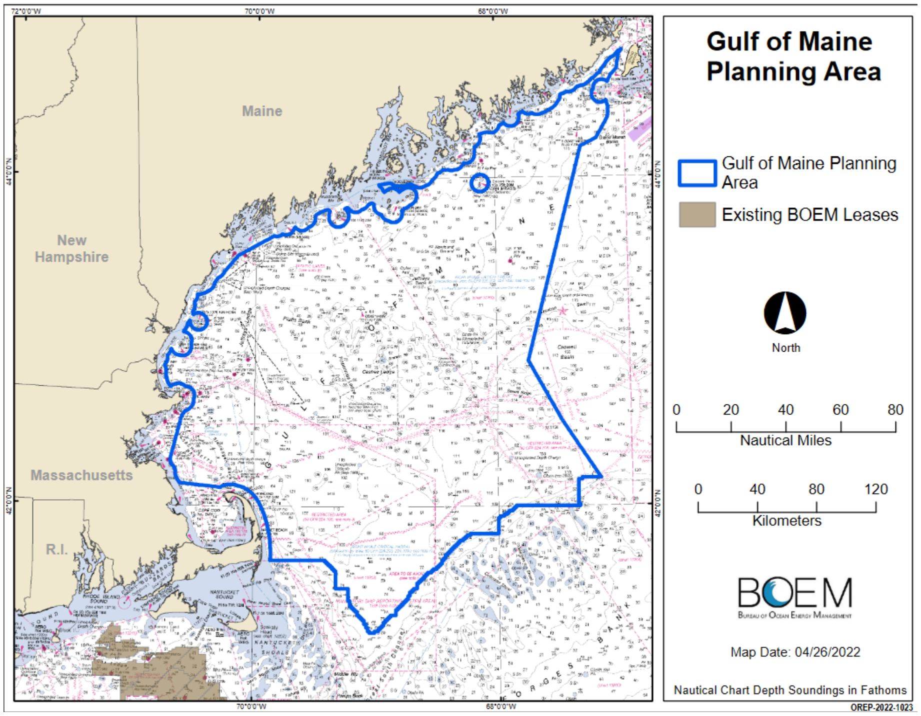

Figure 1. Gulf of Maine Planning Area. ***Image from BOEM***

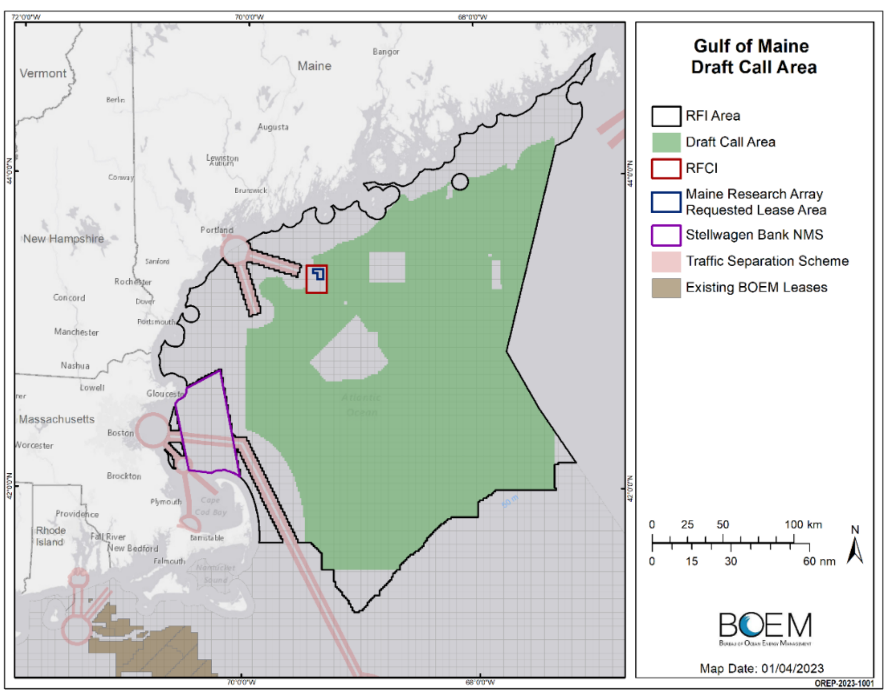

Figure 2. Gulf of Maine RFI Area embedded in the Draft Call Area map. ***Image from BOEM***

2 Stakeholder Characterization

The first task in the project involved stakeholder characterization to identify primary fishery participants and other ocean users in the Gulf of Maine, including those from Maine, Massachusetts, and New Hampshire. In particular, the team identified stakeholders whose activities could have potential interactions with the mooring lines of the floating offshore wind turbine designs being considered. The following sections provide an overview of fishing and other ocean use considerations in the region, including a discussion of regional fishing activities and representatives and regional fisheries regulators, managers, and additional ocean users.

2.1 Background

The fishing community in the Gulf of Maine has raised concerns that floating offshore wind plants may exclude fishing activities within a project's boundaries and disrupt where and how they fish. As a result, fishermen are concerned about the potential impact of offshore wind development on their livelihoods, particularly as the issue is compounded with new regulations to protect the North Atlantic right whale, high and volatile fuel prices, fluctuating demand for their product, and shifts and uncertainty due to warming waters and climate change. In response to objections from Maine fishermen, Maine Governor Janet Mills signed legislation into law in July 2021 that created a moratorium on all new offshore wind energy development in state waters for 10 years, with an exemption for the New England Aqua Ventus I research project on the edge of state waters off Monhegan Island. According to the Mills administration, 75% of Maine's commercial lobster harvesting takes place within state waters (State of Maine 2021).

In July 2021, the Maine Governor's Energy Office formally launched the Maine Offshore Wind Roadmap effort, a federally funded initiative to identify how to support an offshore wind energy economy in Maine that considers the impacts on current marine users, wildlife, and the diversity of marine resources valued by Maine residents.[1] As part of the road map process, the Governor's Energy Office is working to minimize impacts on fisheries and other ocean users, and established a related working group. In the subsequent months, the Fisheries Working Group met to develop recommendations on ways to avoid, minimize, and better understand potential impacts on fisheries, aquaculture, and marine resources from future wind energy development in the Gulf of Maine, as well as opportunities to improve communication and engagement (State of Maine 2022). The Fisheries Working Group includes diverse representation, including harvesters, distributors, processors, industry representatives and associations for the commercial and recreational fisheries sectors (State of Maine 2022). Draft recommendations from the group were refined throughout 2022, with a final road map released in February 2023.

For more than a decade, fisheries stakeholders in Massachusetts have also been advising on the offshore wind energy development process, through the Massachusetts Fisheries Working Group on Offshore Wind Energy (Commonwealth of Massachusetts 2022). Established in 2011, the working group is facilitated by the Massachusetts Executive Office of Energy and Environmental Affairs and the Massachusetts Clean Energy Center and designed to supplement the efforts of the

[1] More information on the Maine Offshore Wind Roadmap is available at https://www.maine.gov/energy/initiatives/offshorewind/roadmap and https://www.maineoffshorewind.org/road-map/

BOEM/Commonwealth of Massachusetts Intergovernmental Renewable Energy Task Force by creating a forum for discussion with key fisheries stakeholders. According to the commonwealth, "input from the working groups has directly resulted in accommodations to avoid important marine habitat, fishing grounds, and marine commerce routes in the designation of the wind energy lease areas" (Commonwealth of Massachusetts 2022). The working group comprises voluntary members from commercial and recreational fisheries, research organizations, and state and federal agencies. Like the Maine road map process, the efforts of the Massachusetts Fisheries Working Group also intersect with the Massachusetts Habitat Working Group, a related effort to engage key environment and wildlife stakeholders alongside the BOEM process.

These two state-focused working groups have made significant contributions to the understanding of stakeholder activities in the Gulf of Maine RFI area, as have related state-led efforts, such as the State of Maine's siting efforts for the Gulf of Maine Floating Offshore Wind Research Array. Research awards made by the Northeast Sea Grant Consortium, in partnership with DOE and the National Oceanic and Atmospheric Administration (NOAA), in 2022 are also expanding the understanding of Gulf of Maine stakeholders. Specifically, institutions hope to identify and engage stakeholders regarding the coexistence of offshore wind energy with Northeast fishing and coastal communities (Sea Grant MIT 2022).

2.2 Regional Fishing Activities and Representatives

As part of this study, we characterized the primary marine users with an interest in offshore wind energy development in BOEM's Gulf of Maine RFI area. The reduced-footprint, rope-chain hybrid mooring system was specifically designed with fishing requirements in mind. Thus, a primary focal group for this study was the commercial and recreational fishing industries.

While the Gulf of Maine is home to a wide range of marine-based activities and stakeholders, it is perhaps most distinguished by its commercial fishing activities and its deep connection to the economy and culture of the coastal communities that line its shores. In Maine alone, more than 211 million pounds (lb) of seafood were landed (i.e., brought to shore) from a host of different fisheries in 2021 (Maine Department of Marine Resources 2022a), with a value of more than $890,668 million (Figure 3) (Maine Department of Marine Resources 2022b). Commercial fishing is also an important part of the coastal economy in other Gulf of Maine states, with significant fishing activity originating from the ports of New Bedford, Gloucester, Chatham, Barnstable and Boston in Massachusetts, and Portsmouth and Rye in New Hampshire. This section summarizes some of the key fisheries operating in the Gulf of Maine RFI area, their potential interactions with floating offshore wind energy, and some of the stakeholder groups that represent their interests.

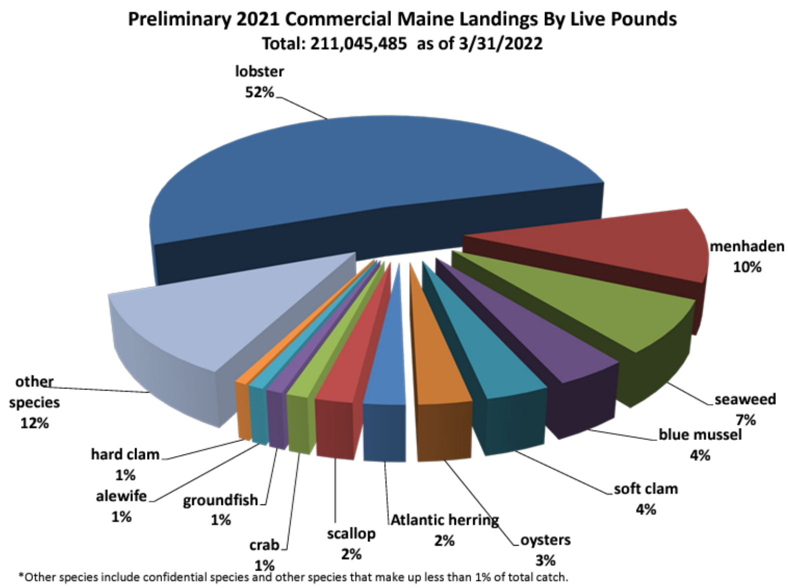

Figure 3. 2021 commercial Maine landings by live pounds. ***Image from the Maine Department of Marine Resources***

2.2.1 Lobster

In decades past, fishermen landed a diverse range of species from the Gulf of Maine each year; however, a shift in fisheries stocks, regulations, ocean conditions, and market demand has led to American lobster *(Homarus americanus)* becoming the dominant species harvested in the region. Lobster is now the single-most valuable species of fish caught in the United States and 80% of it is landed in Maine (NOAA Fisheries 2021; Maine Department of Marine Resources 2022a, b). It has generated more than $1.5 billion in sales and supply chain revenue to the state's economy and directly supports more than 10,000 jobs (Island Institute 2017). The wholesale lobster distribution supply chain in Maine contributes an additional $967 million and 5,500 jobs (Donihue 2018).

Lobster fishing that occurs in federal waters in the Gulf of Maine occurs in multiple lobster management areas (LMAs, which are regulated by NOAA's National Marine Fisheries Service (NOAA Fisheries; Figure 4). These include the Nearshore LMA 1, Nearshore LMA 3, and Nearshore Outer Cape LMA (NOAA Fisheries 2020). Lobsters can be caught with fixed gear traps in "territory" informally established by lobstermen. Each lobsterman (boat/permit) is allocated 800 traps (the fishery is managed by gear and not pounds).

Nearshore LMA 1 hosts 48% of federal lobster license holders, many times higher than any other area in the United States (NOAA Fisheries 2023a). Activity in this area has been increasing in recent years, as warming waters in the Gulf of Maine lead lobsters to move offshore in search of colder temperatures, yet fishing in the LMAs may be further altered by emerging regulations to protect the North Atlantic right whale. The development of offshore wind energy is also likely to displace some of these activities in federal waters, as wind turbines are installed and exclusion areas are created. Setting long lines of traps each connected by rope (i.e., trawl), as is typically done offshore, also increases the potential for entanglement with mooring lines for offshore wind farms.

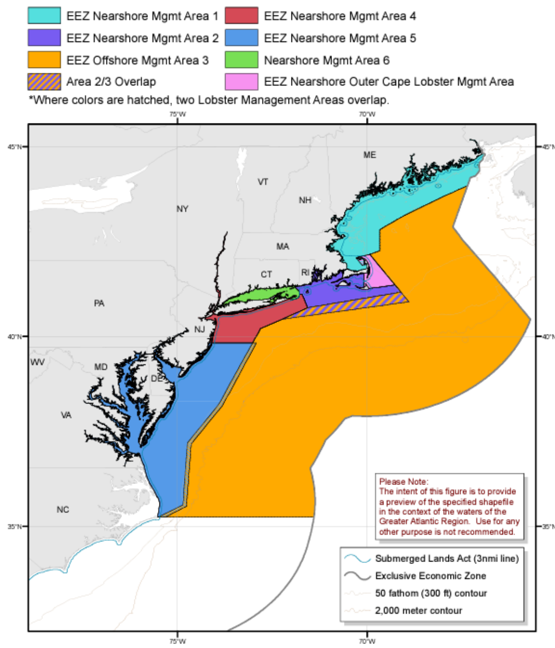

Figure 4. Lobster management areas. ***Image from NOAA Fisheries***

2.2.2 Other Shellfish

In addition to lobster, there are a variety of other shellfish in the region that have both commercial and recreational value. These shellfish include species such as Atlantic sea scallops, hard- and soft-shell clams, periwinkles, and waved whelks. The location of Atlantic sea scallops ranges from Labrador to the Outer Banks of North Carolina, with fishing seasons from December to April in Maine state waters and year-round in federal waters (UMaine undated). Most scallops are harvested by mechanical drag, which uses metal gear of different sizes and configurations to capture animals from the surface of the seafloor; in state waters, some scallops are harvested by hand. Atlantic-sea-scallop-managed waters include the Northern Gulf of Maine Scallop Management Area (Figure 5). Framework 36 to the Atlantic Sea Scallop Fishery Management Plan implements total allowable landings in northern Maine of 434,311 lb for fishing year 2023 (NOAA Fisheries 2023b). Hard-shell clams (e.g., ocean quahog and Atlantic surf clams) can be harvested year-round, typically using a hydraulic or hand dredge. Soft-shell clams can also be harvested year-round, with a peak from May through October, and are dug by commercial and recreational harvesters using rakes and hoes.

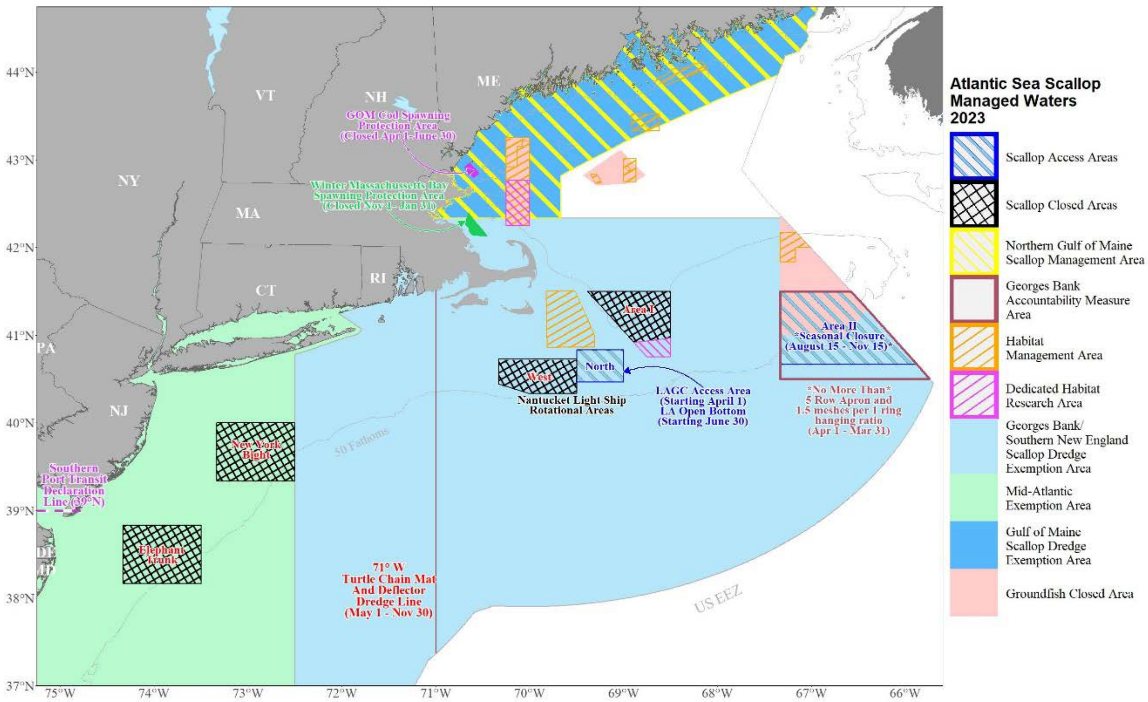

Figure 5. Northern Gulf of Maine management for fishing year 2023. ***Image from NOAA Fisheries***

2.2.3 Groundfish

The groundfish fishery, or the Northeast multispecies fishery, includes 13 species: Atlantic cod, haddock, yellowtail flounder, pollock, American plaice, witch flounder, white hake, windowpane flounder, winter flounder, Acadian redfish, Atlantic halibut, Atlantic wolffish, and ocean pout (NOAA Fisheries 2022). After stocks declined in the 1970s and 1980s, significant efforts have been made to rebuild the fishery, leading to a substantial decrease in fishing activity and landings over the past decade. The groundfish fishery is managed regionally by the Northeast Fishery Management Council and federally by NOAA Fisheries. Fishermen primarily use mobile gear methods (e.g., bottom trawl, sink gillnet, and hook gear) to catch groundfish, with a focus on offshore waters. Example vessel monitoring system data for groundfish shows commercial fishing activity throughout the Gulf of Maine (Figure 6); note that such data do not exist for lobster fishing due to requirements related to vessel size. Concerns regarding offshore wind energy include siting of wind turbines and unburied cables in historical, established fishing tow paths, as well as interactions between mooring lines and mobile fishing gear.

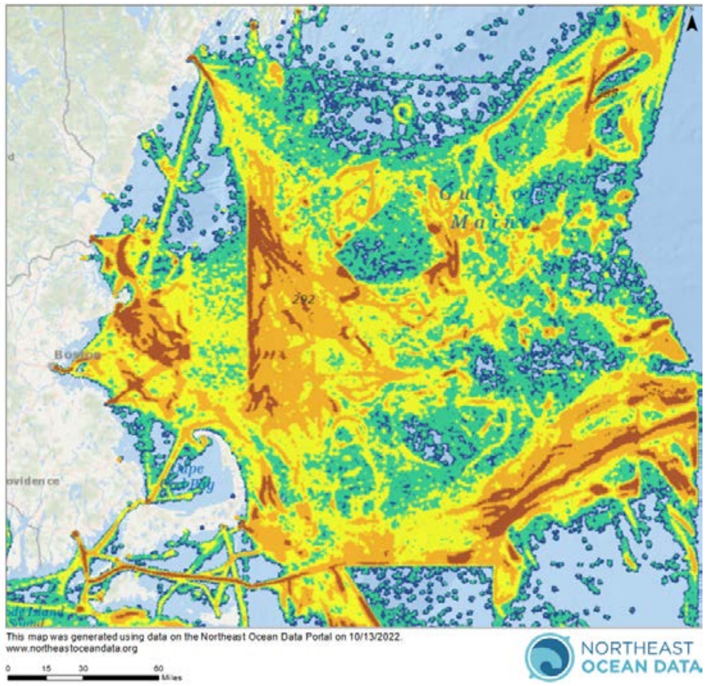

Figure 6. Example of commercial fishing activity in the Gulf of Maine based on groundfish vessel monitoring system data (2015-2016). ***Image from the Northeast Ocean Data Portal***

2.2.4 Small Pelagics

Small pelagics fished in the Gulf of Maine include species such as Atlantic herring and Atlantic menhaden. Herring and menhaden (also known as pogies or bunker) are critically important bait fish for the lobster fishery but have experienced significant fluctuation in landings in recent years (herring: 65 million lb in 2017 and 5 million lb in 2021; menhaden: 9 million lb in 2017 and 22 million lb in 2021) (Maine Department of Marine Resources 2022c). The fishery primarily uses mobile gear offshore (midwater trawls) but can also use fixed structures (e.g., weirs).

2.2.5 Additional Fisheries

There are a variety of other commercial and recreational fisheries in the region beyond what has been described. While a complete description of fisheries is not possible, a few examples are provided here to demonstrate the range of fishing gear type considerations in the region. The tuna fishery in the Gulf of Maine includes species such as the Atlantic bluefin and Bigeye. Tuna are unique in making long migrations across the open ocean between spawning and feeding areas. Each type of tuna has a slightly different fishing season (within the range of June to October) with typical gear types including the harpoon, purse seine, and longline. Squid are fished in the region year-round, including both longfin and shortfin (inshore spring through early fall and offshore during the rest of the year; UMaine undated). They are typically harvested with small-mesh bottom trawls; however, in spring and summer, coastal pound nets and fish traps are used when the squid migrate inshore to spawn. These are just some examples of fisheries in the region that are relevant to this study; a more detailed list of all fisheries in the region and associated gear types can be found at UMaine (undated).

2.2.6 Commercial Fisheries Stakeholders

For more than a century, commercial fishing businesses, associations, and related advocacy organizations have had a strong presence in the Gulf of Maine region. Fishing operations such as the Maine-based O'Hara Corporation and the Massachusetts-based Cape Seafoods, Inc. actively engage in fisheries policy and regulatory processes, as well as in discussions around related developments such as offshore wind energy. Fishery associations play an important role in the region, particularly in Maine where license holders are required to own and operate their own boats. As a result, many regional fishermen have little capacity to engage formal government processes and rely heavily on associations such as the Maine Lobstermen's Association and the Northeast Seafood Coalition, as well as other fisheries-related organizations such as the Maine Coast Fishermen's Association, to track and influence key decision-making processes.

Table 1 provides a summary of the various fishing entities in the region of interest—a subset of which contributed to this study.

Table 1. Fishing Entities in the Gulf of Maine (in Alphabetical Order)

Entity	Regional Scope	Fishery Represented	Sector	Website
Atlantic Offshore Lobstermen's Association	Atlantic states (Maine to North Carolina)	Lobster	Nonprofit	http://offshorelobster.org/main/
Cape Cod Commercial Fishermen's Alliance	Massachusetts	Multiple species	Nonprofit	https://capecodfishermen.org
Cape Seafoods, Inc.	Massachusetts	Herring, mackerel, squid	Fishing corporation	https://www.capeseafoods.com/
Downeast Lobstermen's Association	Maine, with members also from New Hampshire and Massachusetts	Lobster	Nonprofit	http://www.downeastlobstermen.org/
Maine Coast Fishermen's Association	Maine	Multiple species	Nonprofit	https://www.mainecoastfishermen.org/
Maine Lobstering Union–Local 207	Maine	Lobster	Union	https://www.mainelobsteringunion.com/
Maine Lobstermen's Association	Maine	Lobster	Nonprofit	https://www.mainelobstermen.org/

Entity	Regional Scope	Fishery Represented	Sector	Website
Massachusetts Fishermen's Partnership	Massachusetts	Multiple species – represents 15 commercial fishing associations from all gear and geographic sectors of the state's fishing industry	Nonprofit	https://mass-fish.org/
Massachusetts Lobstermen's Association	Northeast	Lobster – fixed gear	Nonprofit	https://lobstermen.com/
Northeast Seafood Coalition	Massachusetts, Maine, New Hampshire	Cod, haddock, flounders, and other groundfish species	Nonprofit	https://northeastseafoodcoalition.org/
O'Hara Corporation	Massachusetts, Maine	Herring, mackerel, scallop	Fishing corporation	https://www.oharacorporation.com/
Responsible Offshore Development Alliance	Board represents Atlantic states	Multiple species	Nonprofit	https://rodafisheries.org/
Responsible Offshore Science Alliance	Primarily East Coast	Multiple species	Nonprofit	https://www.rosascience.org/

2.3 Regional Fisheries Regulators, Managers, and Additional Ocean Users

Several entities play a role in managing and regulating offshore waters, with either direct relevance to or implications for regional fisheries and associated fishing practices for commercial and recreational species (Table 2). These entities include the NOAA National Marine Fisheries Service, BOEM, U.S. Coast Guard, fishery management councils, and state agencies.

The Gulf of Maine is an actively used region, even beyond the commercial fishing sector. Within the BOEM Request for Interest area, other human uses include commercial shipping and, to a lesser extent, recreational fishing and boating. Marine life and habitat must also be considered in siting and other decision-making processes. The Northeast Regional Ocean Council's ocean planning and data portal characterizes these uses in detail, including related regulatory frameworks (e.g., Northeast Regional Planning Body 2016). Table 2 summarizes relevant noncommercial fishing stakeholders.

Table 2. Additional Stakeholders in the Gulf of Maine RFI Area

Entity	Regional Scope	Sector	Role	Website
Atlantic States Marine Fisheries Commission		Multiple species	Fisheries manager	https://asmfc.org/
Maine Department of Marine Resources	Maine	Multiple species	Fisheries regulator	https://www.maine.gov/dmr/
Massachusetts Division of Marine Fisheries	Massachusetts	Multiple species	Fisheries regulator	https://www.mass.gov/orgs/division-of-marine-fisheries
New England Fishery Management Council	New England	Multiple species	Fisheries manager	https://www.nefmc.org/
New Hampshire Fish and Game Department	New Hampshire	Multiple species	Fisheries regulator	https://www.wildlife.state.nh.us/
NOAA Fisheries	Federal	Multiple species	Fisheries regulator	https://www.fisheries.noaa.gov
Maine Association of Charterboat Captains	Maine	Multiple species	Recreational fishing	http://www.mainechartercaptains.org/
Stellwagen Bank Charter Boat Association	Massachusetts	Multiple species	Recreational fishing	https://stellwagenbank.org/
Northeast Charterboat Captains Association	New England	Multiple species	Recreational fishing	https://www.northeastcharterboatcaptainsassociation.com/
U.S. Coast Guard Atlantic Area	New England	Maritime transportation	Regulator	https://www.atlanticarea.uscg.mil/Our-Organization/District-1/
Anderson Cabot Center for Ocean Life at the New England Aquarium	New England	North Atlantic right whale and other relevant species	Applied marine research	https://www.andersoncabotcenterforoceanlife.org/

3 Methods

3.1 Stakeholder Discussion Protocol

The primary goal of the project was to gather fisheries stakeholder feedback on the rope/chain hybrid mooring design and the conventional chain catenary mooring design, with a focus on how the two designs might interact with current marine users in the Gulf of Maine and how that affected social acceptance. To gather these insights, the project team used its stakeholder characterization research to develop a stakeholder discussion protocol, identify a diverse set of relevant stakeholders, and host a set of 10 discussions. This section outlines the approach to those discussions.

Stakeholders identified for discussions included commercial fishermen, fisheries regulators, and other marine users based in Maine, Massachusetts, and New Hampshire. The team sought input from a diversity of fisheries and gear types (e.g., mobile, fixed) that are relevant to the Gulf of Maine RFI area. Individuals were contacted by email and 10 virtual sessions were scheduled with those who responded affirmatively, with one to four stakeholders participating in each call.

To prepare for the discussions, the team developed a set of realistic graphics that reflected the modeling scenarios being evaluated and placed them in the context of fishing activity (Figures 7−11). The graphics were based on a water depth of 100 meters (328 feet [ft]), a depth relevant for the Gulf of Maine where fishing activities can potentially occur at all water depths. Feet were used as the primary unit of measurement as opposed to meters because, along with fathoms, feet are the most common unit used by fishermen. While larger than those being deployed in 2022, we modeled a 15-megawatt wind turbine as it represents the larger-capacity turbines that are anticipated to be used in the Gulf of Maine RFI area. We modeled a single turbine, as opposed to an array, due to uncertainties around turbine spacing and other elements of array design. Finally, the graphics indicated the range of movement of the turbine and mooring lines to help participants consider potential interactions in different sea states (Figure 8). After considering feedback from DOE and UMaine, the resulting images were incorporated into a presentation that was shared with participants for consideration ahead of each discussion.

At the outset of each discussion, the project team walked the participant(s) through the slide deck, which comprised three sections: project background, overview of mooring configurations, and discussion questions. Within project background, participants were informed that their anonymous feedback would be shared with DOE and UMaine and possibly eventually shared in a public-facing report, as determined by DOE and UMaine. The two mooring configurations were first presented individually (Figures 9 and 10) and then in comparison (Figure 11).

After any clarifying questions were addressed, we led the participant(s) through the discussion questions. Development of discussion questions was informed, in part, by previous fisheries engagement work related to offshore wind (e.g., New York State Energy Research and Development Authority 2022). We began with a series of background questions to better understand the stakeholder's type and spatial footprint of activities. The team then solicited responses to the same set of questions for each design.

To further consider the two designs, participants were asked to rank the rope-chain hybrid design's accessibility and acceptability as compared to the conventional design. Accessibility was defined as the ability to complete the participant's desired tasks without inhibition from the floating offshore wind turbine's mooring system. Acceptability was framed as a broader concept that might reflect a participant's thoughts on accessibility but could include other aspects of the floating offshore wind turbine's mooring design (e.g., use of a rope versus a chain).

Before concluding the discussion, the team invited additional feedback, including thoughts on how to further mitigate impact and desired next steps for research into mooring configurations and fisheries interactions. Once interviews were completed, the team all summarized the feedback received and identified the key themes that emerged.

3.2 Presentation Graphics

The NREL team created the following graphics (Figure 7-11) that were incorporated into the slide deck and briefly presented at the outset of the discussion. An additional figure (Figure 12) was added for clarity in this report but was not provided in advance to discussion participants. For scale, this figure shows a comparison of the size of a person next to representative sections of mooring rope and a mooring chain link.

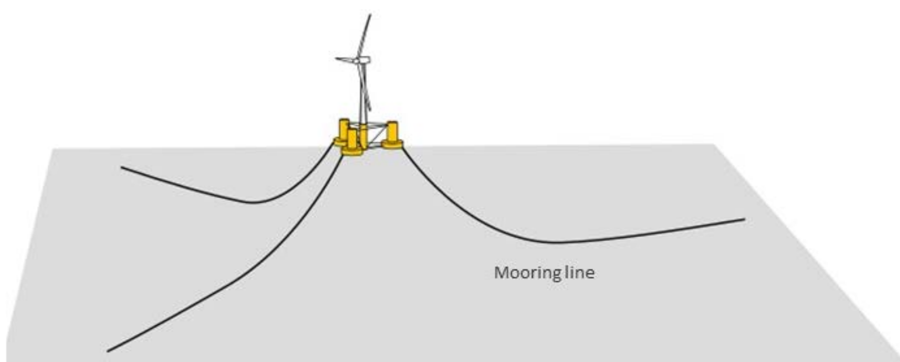

Figure 7. An example floating offshore wind turbine with mooring lines. ***Image created by Matt Hall, NREL***

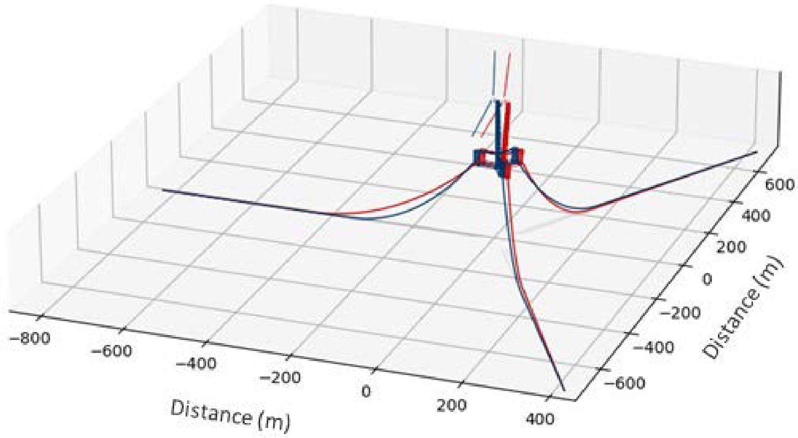

Figure 8. Example output from NREL mooring design tool showing structure positions before and after wind forces*. Image created by Matt Hall, NREL*

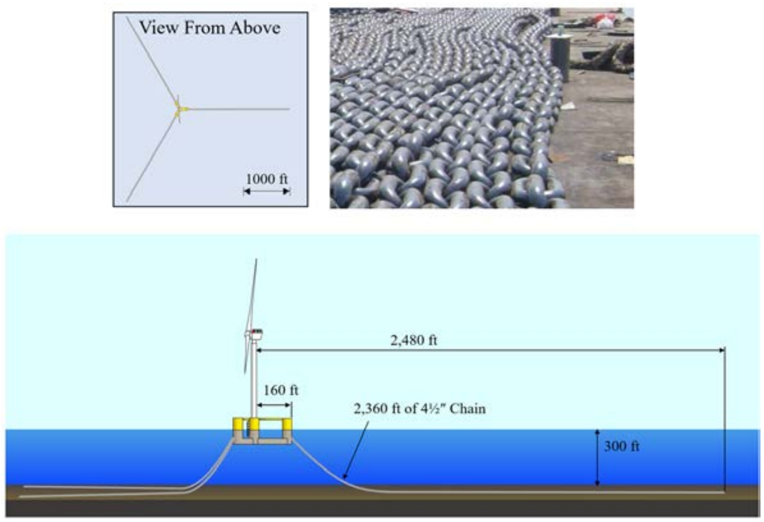

Figure 9. For the conventional mooring design, the overview graphic (upper left) shows mooring lines from above, example chain links (upper right), and the footprint of the platform and mooring lines (bottom middle). *Images created by Stein Housner and Matt Hall, NREL*

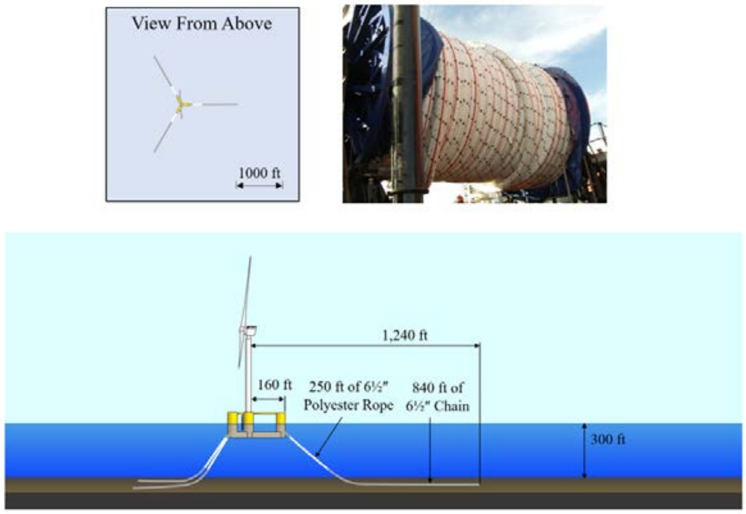

Figure 10. For the hybrid mooring design, the overview graphic (top left) shows mooring lines from above, example synthetic fiber rope (top right), and the footprint of the platform and mooring lines (bottom middle). ***Top left and bottom middle graphics created by Stein Housner and Matt Hall, NREL; top right photo from Lankhorst Offshore***

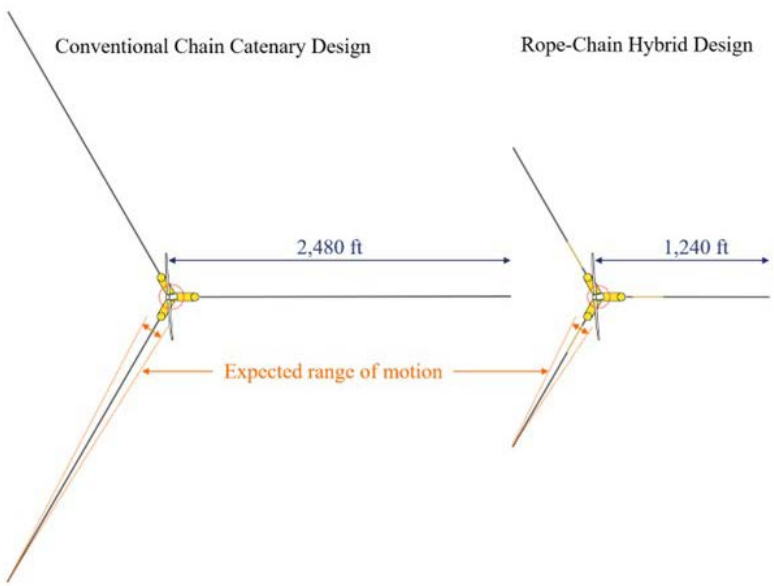

Figure 11. Comparison of horizontal length of the conventional and hybrid mooring lines, including expected range of motion in both cases (orange circle and lines). ***Image created by Matt Hall, NREL***

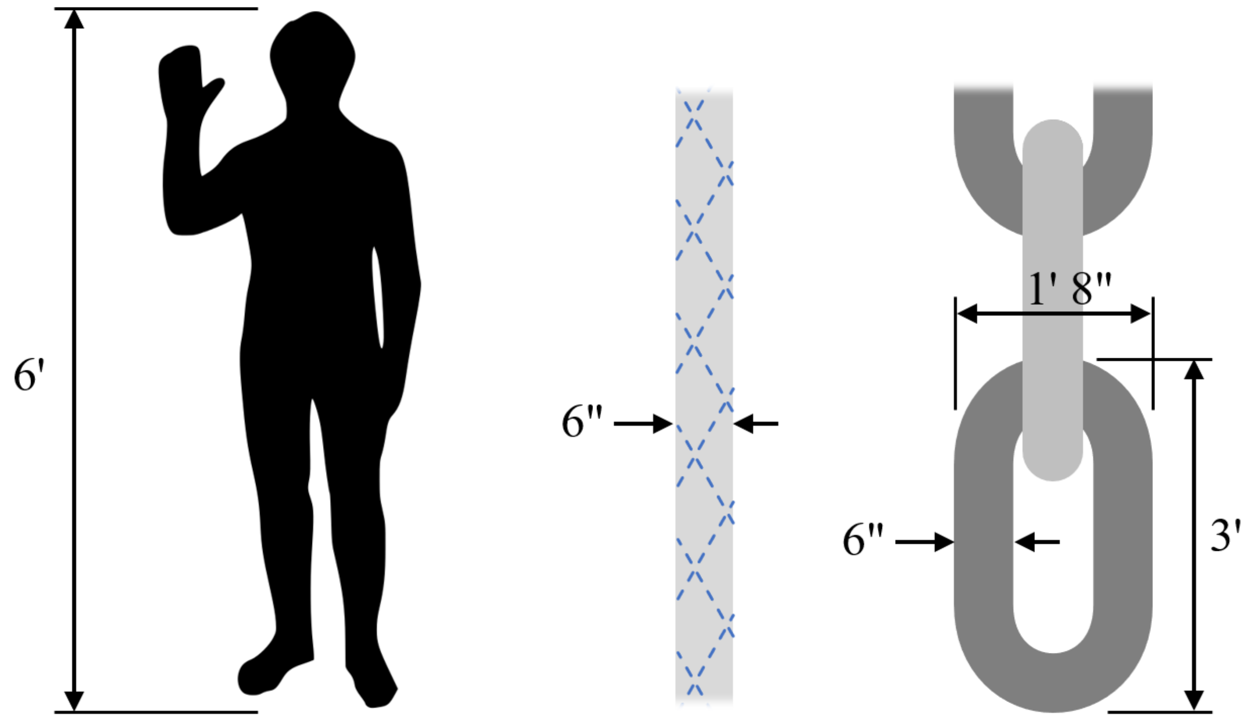

Figure 12. For scale, comparison of the size of a person (left) next to representative sections of mooring rope (middle) and a mooring chain link (right). ***Image created by Matt Hall, NREL***

3.3 Discussion Questions

After a brief presentation on the floating offshore wind turbine mooring designs, we asked participants to respond to the following questions.

Participant Introduction

1. Primary affiliation (for identification in report)
2. Position: Owner, Owner/Operator, Captain, Other
3. How many years of experience do you have as a fisherman or other ocean user in the region?
4. Primary port(s), zones and/or region of interest
5. Fisheries or other ocean use(s)
6. Describe primary gear type (including # and sizes) and vessel sizes (for fishermen) or other ocean use details
7. Describe the spatial footprint of your activities (horizontal and vertical)
8. Are there other relevant considerations for your activities?

Feedback on Mooring Configurations

9. How do you anticipate each of the mooring configurations could interact with fishing gear/ocean use (including consequences)?
    a. Where in the water column?
        i. What part of the gear or ocean use?
        ii. How would environmental conditions affect this?
    b. Where on the seafloor?
        i. What part of the gear or ocean use?
        ii. How would environmental conditions affect this?
10. How would you anticipate safely operating around or interacting with this type of mooring?
    a. Do you see any potential hazards from a safety standpoint?
    b. How would environmental conditions affect this?
11. How much space do you anticipate giving this mooring horizontally? Vertically?
    a. Would this change in different conditions?
    b. What would be the impact to your operation due to this anticipated change?

Accessibility

12. On a scale of 1−5, how much more ***accessible*** is the rope/chain hybrid design compared to the chain catenary design for fishing activities or other ocean use?

1	2	3	4	5
Significantly more accessible	Somewhat more accessible	Neutral	Somewhat less accessible	Significantly less accessible

    a. What are the main reasons for this ranking?

Acceptability

13. On a scale of 1−5, how much more ***acceptable*** is the rope/chain hybrid design compared to the chain catenary design for fishing activities or other ocean use?

1	2	3	4	5
Significantly more acceptable	Somewhat more acceptable	Neutral	Somewhat less acceptable	Significantly less acceptable

    a. What are the main reasons for this ranking?

Final Thoughts

1. What additional considerations do you have related to mooring configurations and your activities (fishing access or other ocean uses)?
2. Can you think of other ways that developers could limit impacts to your activities through mooring design?
3. Can you think of ways that you could adjust your activities to minimize impact of mooring lines?
4. Is there anyone else you think we should talk to about this project?
5. What would you like to see as next steps for this work?

4 Results and Discussion

We conducted discussions with key stakeholders to introduce the floating mooring designs and gather their feedback. This section summarizes the background of stakeholders who participated in these discussions, in addition to their feedback on the conventional and hybrid mooring designs, accessibility and acceptability rankings, and additional feedback on considerations for floating mooring designs in the Gulf of Maine.

4.1 Stakeholder Background

From November 8−22, 2022, we held virtual stakeholder discussions to gather feedback from fishermen, fishing representatives, and regulators from Maine, Massachusetts, and New Hampshire, including the U.S. Coast Guard, who have expertise related to potential interactions with mooring systems. Feedback was anonymous and summarized herein, and affiliations released as agreed upon with discussion participants; names of participants remain confidential. Ten discussions were held with various individuals/entities, as shown in Table 3. Participants were either fishing company owners (including captains and owner/operators) or represented management and staff from within their respective organizations. All participants had at least 10 years of experience within their respective fields, and most had over 20 years of experience. The region of interest represented by participants was primarily New England and its associated ports, though a couple of participants brought larger Atlantic regional perspectives.

Table 3. Summary of Stakeholder Background

General Topic	Response	# of Respondents (out of 10 total)
Primary Affiliation	Fishing industry	4
	Fisheries organizations	4
	Government	1 state; 1 federal
Position	Fishing company owner	4
	Other (i.e., management or staff)	6
Years of Experience	10−20 years	3
	>20 years	7
Region of Interest	New England	8
	Atlantic region	2

4.2 Spatial Requirements and Related Considerations

During each stakeholder discussion, we gathered further background information on the specific details of fishing activities and other ocean uses (Table 4). Among fishing industry participants, the fisheries and gear types represented included lobster trapping, groundfish and squid trawling, scallop dredging, and tuna harpooning. Fisheries organizations represented a wide range of commercial and recreational fisheries associated with various gear types, including traps/pots, trawls (bottom and midwater), gill nets, dredges, long lines, and rod and reel (e.g., NOAA 2022). Vessels owned by fishing operators ranged in size from 30 to 110 ft. Fisheries and government participants represented a range of vessel class sizes.

Table 4. Details of Stakeholder Fishery and Ocean Uses

General Topic	Response	# of Respondents (out of 10 total)
Type of Fishery/Gear or Ocean Use	Specific fisheries	1 lobster/trap 1 groundfish and squid/trawl 1 scallop/dredge 1 tuna/harpoon
	Wide range of fisheries/gear types	4
	Regulatory	2
Vessels	30- to 65-ft boats	3
	80- to 110-ft boats	1
	Multiple vessel classes	6
Spatial Footprint	Highly dependent on particular fishery or other ocean use	See discussion in text

4.2.1 Lobster Gear

For lobstering, we summarize here the feedback provided by a fishing industry participant and an industry representative on spatial requirements. It was conveyed that lobstering activities can potentially cover much of the Gulf of Maine, with some fishing single pots and others using multiple sets of traps attached in series by a single line (e.g., Figure 13). One lobsterman stated that throughout the whole year, they set roughly 800 traps and probably covered more than 200 square miles of water. For setting a single lobster trap, the space needed is the footprint of the boat (because nothing is being hauled behind the boat), and the gear can drop as far as a ¼ mile from the boat, depending on conditions. For trawls, each trawl can be just under a mile long from one buoy to the other, with fishermen trying not to cross over each other. Significant reservations were expressed by the lobster industry about floating wind turbine structures in the Gulf of Maine, because of the use of mooring lines and cables under the water and possible interactions with gear. When fishermen set a trawl, it does not just drop to the seafloor. Rather, each trawl is set individually from the stern of the boat with rope in between, and the currents move the gear as it is set out and settles to the bottom (see Figure 13). As a result, lobster gear movement could become problematic around floating wind turbine arrays. Spatially, fixed-gear fishermen would likely find it difficult to set in or around these wind arrays, versus fixed-bottom wind structures, which they feel they can fish right up to. In terms of using rope in floating wind mooring design, the lobstering industry is rope-sensitive due to restrictions on their own gear. One fixed-gear respondent stated that they are fishing with rope the size of "yarn" and any information they could get on the size of the ropes that might be used in the floating wind moorings would be helpful.[2]

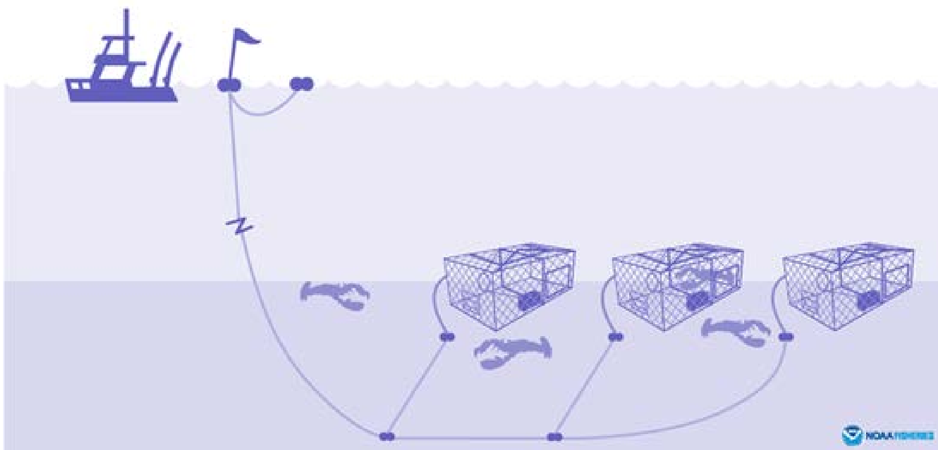

Figure 13. Example of lobster traps set in a long continuous series (called trawls) attached by a rope to a buoy on the surface of the water. ***Image from NOAA Fisheries***

4.2.2 Trawl Gear

For trawling, we gathered feedback from the fishing industry, fisheries organizations, and regulators in the Gulf of Maine. Broadly, a mix of trawls are deployed in the region and include mostly bottom trawls, but some fishermen also use midwater trawls. Gear associated with trawling can be tens of meters wide and is much longer than that, especially depending on the depth and scope. Vertically, a lot of the gear is used on the bottom, so fishermen are using the whole water column from the vessel to the seabed (Figure 14). Where trawlers operate can be based on where other fishermen using other gear types are operating. In some places trap gear is common, so it is more difficult for mobile gear to operate there. There is an understanding that fish are shifting habitat and are not necessarily where they have been historically. In other words, past fishing effort is not necessarily indicative of future effort in terms of spatial extent. For groundfish and squid trawling specifically, we gathered feedback from a participant whose primary focus is on fishing in the Gulf of Maine and who is strictly a trawler. During trawling

[2] The authors note that ropes used in permanent mooring systems are different than the ropes used for fixed-gear fishing. The size of the mooring system ropes is shown in Figure 12.

operations, the participant described always setting gear in a 3:1 ratio with the water depth. For example, in 90 odd fathoms around the State of Maine's proposed Floating Offshore Wind Research Array (500 ft of water), they are roughly setting 1,500 ft of cable, resulting in the net fishing 1,500 ft behind the vessel for both groundfish and squid in the Gulf of Maine.

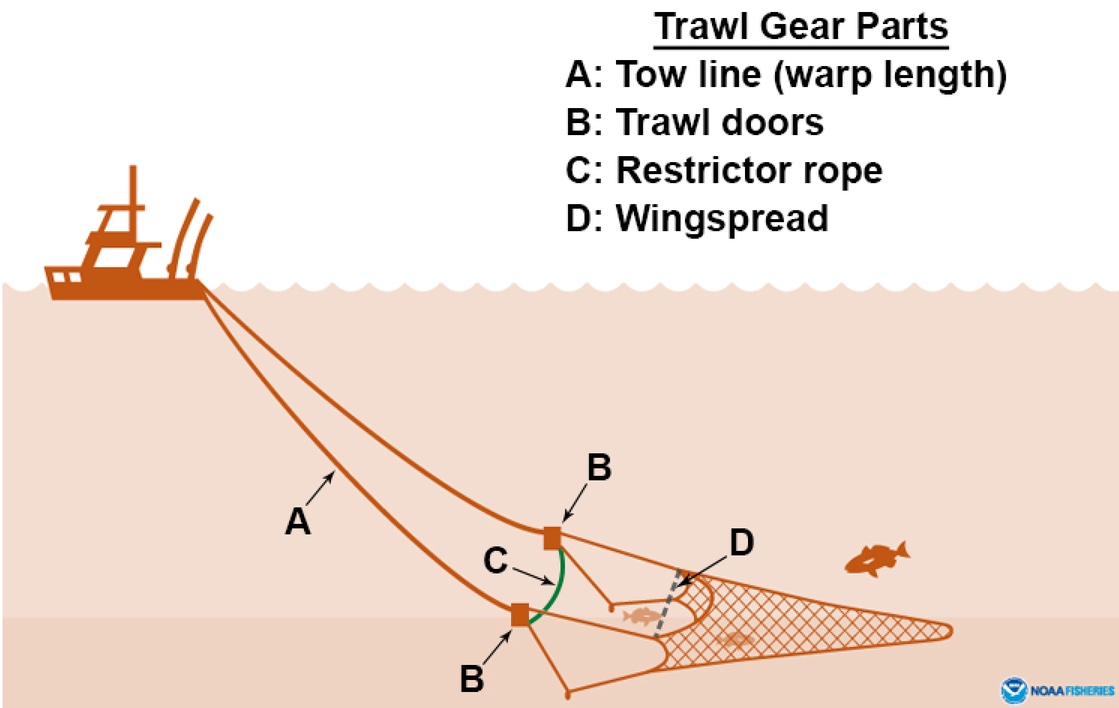

Figure 14. Example of a bottom trawl, which is a fishing practice used for herding and capturing the target species by towing a net along the ocean floor. ***Image from NOAA Fisheries***

4.2.3 Harpoon Gear

For harpooning, we gathered feedback from a fishing industry participant who largely focuses on bluefin tuna. They use a 30-ft haul-in boat and have an electric harpoon wire that strikes into the fish roughly 1 inch. They throw the harpoon and then it disconnects so that it does not rip a hole in the boat. Tuna are considered very strong animals, and in one case the fish was almost 1,000 lb in size. Harpooning can be amazingly efficient, but it depends on where in the fish's body they are harpooned. After being harpooned, the tuna takes off quickly with the 900 ft of half-inch rope that they can swim with for roughly 10 miles. They put out two big floatation balls on top and a flag to observe the movements of the harpooned fish. Thus, the fishermen can tell that one fish traveled as far as 11 miles and another 15 miles. The harpooned fish also swims throughout the water column, including right down to more than 1,000 ft deep. Tuna move long distances, typically using the mid-to-upper water column when they travel, so they can cover much of the RFI area. Bluefin tuna science is largely organized by international entities, such as the International Commission for the Conservation of Atlantic Tunas.

4.2.4 Scallop Gear

For scalloping, we gathered feedback from a fishing industry participant who does some limited work in the Gulf of Maine, largely just up on the shoals. They are a mobile gear fisherman who uses a scallop dredge, with a typical cable length behind the boat that is 3.5–4 times the water depth (i.e., in 30 fathoms of water, the boat would tow 105 fathoms of wire). The participant scallops in roughly 25−60 fathoms of water and mostly on Georges Bank or in the mid-Atlantic, with Stellwagen Bank and Jeffreys Ledge being the only places they scallop in the Gulf of Maine. They conveyed that any mobile gear fishery is subject to currents and tides, so gear may drift from directly behind their boat due to being pushed off course by wind and tide. As a result, they need to build in a buffer for their mobile gear, including when avoiding an obstacle with their vessel. They use two 15-ft scallop drags, so that their width is roughly 30 ft for the drags plus 30 ft for the boat width plus the size of the towing blocks. They estimated that the scallop dredges could be as much as 40 degrees off the stern. Thus, their fishing activities take up a wide swath, but it is smaller than what a net gear boat would have with their spread between doors (see Figure 13; note that doors hold the net open wide on the bottom and mid trawling gear).

4.2.5 Other Ocean Use

For the U.S. Coast Guard, several individuals participated who engage in activities in the First Coast Guard District, which has jurisdiction out to 200 nautical miles. They are interested in any activity on the water surface, including commercial and recreational waterway uses. They do not regulate the fishing gear, but rather the vessels used for safety and navigation. The U.S. Coast Guard regulates the ability to freely and safely navigate on the water and to ensure that nothing is impeding the free flow of navigation. The Coast Guard fleet includes vessels that are up to 400 ft long for the largest response cutters down to the smaller vessels that are deployed from those ships. They need to manage all service and air assets to be sure they can get into a location and perform search and rescue (SAR) missions as needed. For floating wind turbines, one consideration is how the Coast Guard would address a SAR if a fishing vessel were to become attached to the mooring lines. As a result, they are conducting the *Maine, Massachusetts, and New Hampshire Port Access Study* to preserve ocean space for safe navigation, and specifically to evaluate the adequacy of existing vessel routing measures and determine whether additional vessel routing measures are necessary for port approaches. The Coast Guard's expertise in marine spatial planning is contributing to the development of the study, which includes compiling numerous data sets, such as use of a vessel monitoring system and automatic identification system data.

4.3 Feedback on the Conventional Chain Catenary Design

4.3.1 Lobstering

For lobstering, feedback on the conventional chain catenary design is summarized here from a fishing industry participant and an industry representative. The representative said that fishermen always put their safety as number one and that their vessels are their livelihoods, so they will not put themselves into an unsafe situation. From what has been learned at the Block Island Wind Farm, each captain will fish to their own level of comfort. Thus, some captains will not fish around the floating mooring lines and others will, with fishing behavior likely evolving once the structures are in the water and captains gain experience operating in proximity to floating offshore wind turbines. They could take a chance and fish there, but if they must use a grapple to retrieve lost or detached gear off the bottom, then they could potentially interact with mooring lines. The respondent would like to see more information showing sea state and the movement of these floating structures. Furthermore, it is important to know the level of burial of the mooring lines on the bottom and how they are anchored.[3] Participants conveyed that the potential movement of floating turbines and moorings needs to be automated and shared with fishermen, like via a simulator. The spacing between wind turbines was mentioned as an important consideration, and that more spacing would be needed with floating turbines to ensure open access for fishing. One thing that would be helpful is if ground mooring lines had some type of beacon (e.g., a transducer that would give out some type of sound) or otherwise provide marking of where the mooring lines are located. Fishermen can get into some tight spaces, so if the line locations are provided with real-time sensors, then they could work with that. Once the floating arrays are installed and operational, it is possible that they will become a lobster sanctuary and provide productive space, which is what is hoped for.

The lobster fishing industry participant conveyed that while lobstering, they would not move anywhere between the mooring line anchor and the wind turbine platform. Further, they would not get within 0.25 miles of the anchor, because of the amount of tide in the Gulf of Maine. If there was a big storm coming, they would stay even farther away from the anchors. Given compliance with North Atlantic right whale rules and the cost of lobster trawls (~$7,000−$8,000 per trawl), fishermen cannot afford to further affect their bottom line and get tangled in mooring lines. A 25-trap trawl is about 2,500 ft long, or roughly 0.5 miles. The participant conveyed that it is difficult to assess the implications of just wind one turbine with its mooring lines, let alone multiple turbines in an array. Specifically, the participant described the floating wind turbine as a navigation hazard. They had never been around wind turbines but heard that they interfere with radar. In addition, getting gear tangled was described as being a safety issue. For example, if rope on the gear was cut by floating mooring lines, the gear could come back and hit somebody. Once traps land on the bottom they do not move much (probably no more than 0.1 miles). It is when traps are being set that they may drift as a result of the tide—so there is a need to better understand wind and tide for movement, with possibly a ensuring a distance of a ¼ or ½ mile to set gear.

4.3.2 Trawling

For trawling, we summarize feedback on the conventional chain catenary design from both the fishing industry and regulators in the Gulf of Maine. From the regulators' perspective, knowing the touchdown point of the floating mooring lines and the amount of curvature in the water column would be important for the fishermen, rather than the whole footprint of the mooring line. It was suggested that if the mooring line goes straight down, then over time, fishermen will become more comfortable with fishing closer to anything on the bottom or subsurface. The depth of natural burial of the mooring lines into the bottom was identified as an important factor. Participants believe that over time mobile-gear fishermen will get comfortable with those mooring lines being under the seabed, if natural burial occurs. Participants expressed concern about the anchor and whether it will stay dug in. Secondary entanglement issues were identified related to the potential for fishing gear to snag on mooring lines and for this derelict fishing gear to continue fishing at some rate. The regulatory respondents conveyed that how close mobile-gear fishermen will get to the mooring lines is a personal decision, with their behavior based on

[3] The authors note that the level of burial of the mooring lines will be difficult to quantify given sediment transport and other bottom boundary layer processes that will vary over time.

past experiences like fishing around hard bottom (i.e., rocks and reef). Respondents identified the transmission cables as another consideration.

Regarding groundfish and squid trawling, a fishing industry participant said that they would not go anywhere near the conventional chain catenary design given that they are towing $60,000−70,000 worth of gear behind the boat (i.e., doors, net, trawl wires). Furthermore, they would not go within a mile of the floating wind turbine, because they would not know whether the mooring lines were pulling tight. They might go in between the mooring lines if they knew where the anchors were and had a specific location (latitude/longitude) for the lines. If they had a map of where those moorings were, with a ½ mile between moorings between any two wind turbines, they could probably go between that. The chain lines would destroy any net that they tried to put near it, which could be dangerous. If there were heavy seas, the participant could be taking water across the deck, and it would not take long to capsize their boat if they got hung up on the mooring lines. It would be costly if they got hung up, given that the head rope sensor costs $16,000 (the sensor indicates where the net is and what is going into it). The net costs $20,000, and a set of doors is another $20,000. Fishermen are concerned about getting tangled with both the chain on the seabed and in the water column. Between their trawl doors is 260 ft of spread (e.g., Figure 13). With the way tide affects operations, they need at least 3-4 times that spread on either side; hence why they said 2,600 ft or half a mile would be needed between floating wind moorings. As far as the fishermen are concerned, the floating wind turbine would be like an island, and the rougher the water is, the more buffer they would want between them and that object. They set out and tow the trawl nets for 2.5−5 hours, fishing along the bottom before they haul it back; only travelling at 2.5−3 knots while towing.

4.3.3 Harpooning

For harpooning, we summarize feedback on the conventional chain catenary design from a bluefin tuna fishing industry participant. In general, they said that the mooring lines would affect them the most and that they would be terrified of these moorings. For example, they conveyed that the site of the State of Maine's proposed research array is in one of the most important harpooning areas on earth, and is considered sacred ground. They do not like losing a fish, and if it got hung up in the mooring chain, it would die. Anything tied from the water surface to the bottom is a headache for these fishermen. When the fish does not die from the electric harpoon, the participant said that the fish will likely interact with the mooring lines because they cover so much ground. They consider almost a mile in the design shown in Figure 9 to be a big footprint and conveyed that floating wind turbines are stressful and scary for them to talk about. Catching 20−30 fish is a good season, so each fish is important.

For harpooning, they cannot go near the mooring lines in the water column, whereas if there is something laying on the bottom, that is less of a concern. Generally, the fish just die and hit the bottom, so there is always a chance they could interact with something at the bottom. But the length of mooring lines on the bottom is probably less intimidating to them than the lines going from the turbine to the bottom. The mooring line section that is cutting through the water column at an angle is more of a concern. The chain that is in the water is the most important part given their gear type, so the less line that is in the water, the less impact on harpooning activities. Less length in the water is preferable, and could inform the participant's mooring design preference. Above all, safety is the most concerning. The participants also expressed that electromagnetics of offshore wind farms can affect their boat radar. In the dark in the fog, anything can be intimidating to them. For example, if a fisherman was fighting a tuna and it got hung up on mooring lines, they could potentially be killed.

4.3.4 Scalloping

For scalloping, we summarize feedback on the conventional chain catenary design from a commercial scallop fishing industry participant. With a scallop dredge, they conveyed that they would not want to get anywhere near these chains or go over them. They would like to see the anchors marked so they could stay away from them. The participant asked about considerations for the transmission cables and expressed concern over the high voltages that would be carried, because the dredge is made of metal. At first after wind farms are built, they would just stay away from the anchors and lines. They expressed that there will be times after the wind turbines have been constructed and in place for a while, that fishermen will push the envelope, such as when they deplete the area that is most available to them for fishing. Initially, they will stay away but then may move in.

They assume that the chain will most likely be buried under the surface but that sometimes it will be on the surface, which would be a problem for scalloping. If they could be guaranteed that the mooring line was under the surface, then it would not be too much of a concern, but there is always the possibility of a gear snag. A gear snag would result in loss of gear and vessels. A scallop dredge is steel and weighs thousands of pounds, so it interacts strongly with the bottom. If the fishermen were to go over the mooring line, a scallop dredge that snagged could potentially result in a broken chain or link. There is always the possibility of something breaking. For example, the inch and a half bar across the top of the dredge could break. In addition, they said that the larger footprint of the conventional chain mooring design will be more constraining for fishing. For the conventional mooring system, they would not get closer than a half mile to the wind turbine in any direction. If anchors are marked, that would be helpful. In terms of their gear type, they would not treat going over a chain at all like going over a rocky bottom.

4.3.5 Fisheries Organizations

Fisheries organizations provided several additional perspectives on the conventional chain mooring design. They felt that interactions would depend on whether a fisherman could see the mooring lines or not, so whether the lines are visible, for example, on an echosounder. They conveyed that any time there is a structure in the water that species will accumulate. They assumed that the mooring line chains on the seafloor have not been designed for trawling over, such that fishermen would want to avoid them. One respondent wondered if it is possible to "sleeve" the chain to reduce the chance of getting hooked up or whether some type of mattress protection would apply, the latter which could be co-designed with the fishing industry. If weather and currents are bad, they might give the wind turbine a wider berth if the weather was going to be rough or based on the currents. They conveyed that there is going to be electrical cabling as well and were not sure how this would affect the location of the mooring lines. They expressed the need to think about the wind turbines as an array and that they would be concerned if moorings cover the whole array. It was stated that the array layout will determine whether fishermen could operate in between the mooring lines themselves. They think that people would give the wind turbines a wider berth if there is poor visibility or rough currents. If it is not safe to operate any sort of mobile gear, then transit might become the main consideration in rough conditions.

4.3.6 Other Ocean Use

For the U.S. Coast Guard, several individuals provided feedback on the conventional chain catenary mooring design. The question of how the various anchor points would be marked was again raised and whether some kind of surface buoy would be used to show when inside or outside the mooring lines. However, it was noted that surface buoys at each anchor could potentially be considered just one more hazard in the water. It was conveyed that the Gulf of Maine RFI area is relatively large and has a lot of deep-draft shipping traffic that travels in the region. Considering safety for navigation, if a ship was coming into Portland a few miles out and had to emergency anchor, one individual asked about how the wind turbine mooring lines would be marked on a chart. If the vessel drops an anchor in an emergency, then they would need to consider these interactions.

The U.S. Coast Guard's mission is to determine how to best respond to worse-case scenarios (e.g., large container ship disabled and drifting), including their own concern of anchoring and getting tangled or drifting throughout. They think about how new structures would affect SAR or marine environmental response. The federal government marks waterways with aids to navigation (i.e., any device external to a vessel or aircraft intended to assist a navigator to determine position or safe course, or to warn of dangers or obstructions to navigation), including on buoys. As far as cutters or vessels are concerned, they hope that wind energy towers could be used as aids to navigation. They did not see any issues with their Coast Guard vessels being able to navigate wind farms. They conveyed that the effects of wind turbines on marine radar are still highly unknown, as well as on high-frequency radars on land, which provide them with ocean currents. They would like to understand how wind farms are going to affect their SAR operations program in that way. Participants felt it was important to think about how the mooring lines would be marked on a chart, which could be tricky with three different anchoring points. Similar to other respondents, the U.S. Coast Guard noted the need to consider the totality of the design and specifically spacing between the wind turbines as part of the mooring designs, because that spacing will vary by location.

4.4 Feedback on the Rope-Chain Hybrid Design

4.4.1 Lobstering

For lobstering, we summarize feedback on the rope-chain hybrid design from a fisherman and a fishing industry representative. Overall, participants expressed that the 50% reduction in the footprint will be beneficial to lobster fishing by taking up less space with the mooring lines. The primary concern was that while the hybrid design reduces the footprint, it could result in wind projects installing 50% more structures in the water—so turbine spacing would need to be clarified to determine the benefit. It was also conveyed that anything dealing with rope is very sensitive to the lobster industry due to emerging regulations to protect the North Atlantic right whale, which could be a case for sticking with the conventional chain mooring instead. Questions were asked about the breakdown of the rope into microplastics and about the shelf life of the rope versus the chain. It was stated that fishermen do not like new ropes in the water column when they are being asked to remove their own ropes due to whale regulations (e.g., Massachusetts Division of Marine Fisheries 2022). So, it was described as being about perception—that one industry's being asked to reduce rope when another is allowed to use it.

In addition, participants identified storm surges and high winds as concerns in the region where floating technologies are being considered. They asked for new information on floating moorings be disseminated early and often. Furthermore, they need to see visuals of these structures in hurricanes, Nor'easters, and high sea states. One of the regulatory participants also mentioned concern about possible chafing of the synthetic mooring line and the possibility for someone to "burn" (i.e., sever) the line when there is a conflict, suggesting that there might be more risk of failure than with the chain.

4.4.2 Trawling

For trawling, we summarize feedback on the rope-chain hybrid design from both the fishing industry and regulator participants in the Gulf of Maine. It was again suggested that a smaller footprint mooring design might allow a developer to put the wind turbines closer together, which could completely change how fishing activity would interact with the design. The respondents were interested in the touchdown point of the hybrid mooring lines and how far that was away from the floating structure compared to the conventional lines. Depending on the mooring line curvature and touchdown point, they could imagine a scenario where the hybrid line had a greater footprint in the water column than the chain design. For the groundfish and squid trawler fishing industry participant, they said that their answers would be identical to the conventional design, except that this is just a smaller footprint, so it takes up less space. They said that they would not go near this design either. They thought that rope in the water column is great if it holds the floating platform still. They asked about how much testing had been done on this hybrid design, given that the Gulf of Maine has some of the roughest weather in the world. They were skeptical of how engineers would hold these floating wind turbines relatively still (i.e., holding something that heavy still in 60-mile-per-hour winds). They suggested that anytime developers can minimize the footprint of the whole lease array by using bigger wind turbines, then that is a good thing.

4.4.3 Harpooning

For harpooning, we summarize feedback on the rope-chain hybrid design from a bluefin tuna fishing industry participant. They conveyed that as a fisherman, it is hard to speak objectively about these mooring line designs, because of how much they intimidate them. It was conveyed that less length of mooring lines in the water column is the most important factor, no matter how offshore wind engineers accomplish that. If the hybrid design means a shorter length of line in the water column, then there would be less of a chance to interact. The question was raised around whether shorter mooring lines would mean that the developer could simply place more wind turbines into an area. The participant also wondered whether the rope would require more maintenance than chain. Overall, they said that the smaller footprint of the hybrid design makes sense and that siting is a key factor and that there needs to be more discussion around that.

4.4.4 Scalloping

For scalloping, we summarize feedback on the rope-chain hybrid design from a commercial scallop fishing industry participant. The participant said the footprint was the biggest benefit of this design. They liked the idea of the smaller footprint as long as the spacing is not closer between the wind turbines. They conveyed that any scalloping interactions would start at the perimeter of the anchoring system and did not think that the rope would affect their fishing activities. They were not concerned about cable and rope interactions, because they would not plan to ever be that close to the turbine. Questions were again raised about the curvature of the mooring lines and what the touchdown points would be. The participant felt that, with this design, they would have more room for fishing—another 1,000 ft from the turbine that would be open. As long as the spacing between wind turbines is the same, they would get more room with the hybrid design.

4.4.5 Fisheries Organizations

Fisheries organizations provided several additional perspectives on the rope-chain hybrid mooring design. Some of the fishing interactions were the same as described for the conventional mooring design but now with consideration of the smaller footprint. The 50%-smaller footprint seemed like a win in terms of shortening the chain on the seabed and thus fishermen potentially feeling less risk-averse. Questions were again raised about the size of the corridors between turbines. If interturbine distance is the same, regardless of mooring configuration, they wanted to know how fishermen would really be aware that the lanes were bigger. They said that fishermen would really need some kind of chart to know where mooring lines are, or if they can detect the lines by being visible on a sounder. It was conveyed that some sort of marking would be needed on the lines, regardless of the mooring design, and how they are marked would influence the extent to which they would feel comfortable fishing close to them.

In terms of potential changes to fisheries spatial management, a participant asked if the floating wind moorings prohibit mobile gear in the area, and if so, does that create opportunities for fixed gear. As a result, these floating moorings could be creating a system that would eliminate mobile gear usage, and open an opportunity for fixed gear. In terms of fouling, they assume it will occur on either the rope or chain, which would create interesting opportunities for benthic species and feeding opportunities that would cluster fish. The participants think a lot about habitat value and how structures might attract fish. It was mentioned that fouling and attraction of species could encourage recreational fishing around the wind turbines, as seen with the Block Island Wind Farm, especially if there are fewer commercial vessels in the area.

4.4.6 Other Ocean Use

For the U.S. Coast Guard, several individuals provided feedback on the rope-chain hybrid mooring design. Some of the safety considerations were the same as mentioned previously for the conventional mooring design but now considering the smaller footprint. They wondered if with the synthetic rope there would be more "play" and movement, or if that is known at this point.[4] The participants said that the safety concerns are the same as the conventional catenary design but there is less risk with the smaller footprint. The smaller the footprint, the better, when it comes to anything hanging in the water. For example, if trying to hook a vessel that is drifting, there is more time to accomplish it with the smaller footprint. They asked whether there is going to be marine growth on the synthetic line faster than on the chain and how often this would be

[4] The authors note that the synthetic rope systems can be designed to give the same restoring force as chain systems. Ultimately, the floating offshore wind turbine's offset limits will be driven by the dynamic cable, and the mooring system must be designed to support this regardless of material.

cleaned. They asked whether there are there any weak links to any of these mooring systems. For example, if an ocean user hooks onto them, they asked what would break first, with consideration given to intense storms in the region.

4.5 Accessibility Rankings

To provide feedback on metrics, respondents first provided a ranking on the comparative accessibility of the hybrid mooring design and conventional mooring design (Table 5). Accessibility is defined as the ability to complete the participant's desired tasks without inhibition from the floating offshore wind turbine's mooring system. Responses ranged from a 1 (significantly more accessible) to 3 (neutral), with the most responses for a 2 (somewhat more accessible) or 3. Thus, the results indicated a modest increase in accessibility for a turbine using the hybrid mooring design. Many respondents included caveats to their rankings as an important consideration was how far apart the wind turbines were installed.

4.5.1 Lobstering

For lobstering, feedback on accessibility was provided by both the fishing industry and industry representative participants. One respondent said that assuming there would only be one wind turbine in the whole ocean, guesses they could give it a 2. But as soon as it is in an array, it is neutral. Another respondent also said that it all depends on how far apart the turbines are installed. For example, if the spacing is 1-by-1 nmi, then they would say less accessible, 2-by-2 nmi would be neutral, and 2.5-by-2.5 nmi would be a 2 so somewhat more accessible. The 2.5-by-2.5 nmi would be a 2 (somewhat more accessible) because that would give them a corridor where know there are no cables and they would be able to fish, including with beacons on the mooring lines. Also, they recommended that the layout should keep the turbine rows all going in the same direction, for the sake of consistency.

4.5.2 Trawling

For trawling, feedback on accessibility was provided by both the fishing industry and regulatory participants in the Gulf of Maine. One respondent said that for single wind turbine then would give a 1 (significantly more accessible), but if looking at two turbines near each other they would gain nothing (3 – neutral). They could not base their response on just one turbine—they would need a configuration of turbines to decide. So, at this time they would say 3 (neutral), because they do not have information about the spacing. If they knew the spacing, then they might give it a 2 (somewhat more accessible). If they knew how the array was set up, then they might give it a 1 (significantly more accessible), because there would be the opportunity to minimize the footprint. Another respondent said that it was hard to answer this question without knowing more about the spacing between wind turbines and the touchdown point for the mooring lines. Lacking this information, they would give it a 3 (not sure).

4.5.3 Harpooning

For harpooning, feedback on accessibility was provided by a bluefin tuna fishing industry participant. They said that less line would be better, so definitely a benefit, though it would not change the fact that there is a wind turbine there. But given the reduced footprint, they would give it a 2 (somewhat more accessible).

4.5.4 Scalloping

For scalloping, feedback on accessibility was provided by a commercial scallop fishing industry participant. They gave the hybrid design a 2 (somewhat more accessible), which is based on the smaller footprint. They qualified that a 1 response would be to "get rid of everything all together."

4.5.5 Fisheries Organizations

Fisheries organizations provided feedback on accessibility based on their broad perspectives. One respondent said that without knowing the overlap of the lines between turbines, they would say between 2 and 3—2 if there is no overlap and results in fewer lines in the water and 3 if there is overlap. Another respondent said that if it is just one turbine, they would give it a 1 (significantly more accessible) because of the smaller footprint. This smaller footprint assumes creating a larger area for mobile gear, but all depends on how big the lanes are. The participants thought the hybrid designs would be a 2 (somewhat more accessible) for fixed gear, because they would have more area to set gear with shorter mooring lines. Yet another respondent thought that the answer has to be a 2 (somewhat more accessible), given that it could create opportunity for some vessels. However, they said that there is still a lot of structure and mooring in the water, so they do not think significantly more accessible given that there are so many other things in the water along with radar concerns.

4.5.6 Other Ocean Use

For the U.S. Coast Guard, individuals provided feedback on accessibility in relation to their mission. Specifically, for navigating their own vessels, they did not see much difference, because what they care about is what is above the water (e.g., the tower). If it is a vessel they are towing, then that might be a concern because there could be 300-400 ft of line in the water (even 700-800 ft depending on the weather conditions). This is always a concern when hooking a vessel up in tow. Overall, they gave a ranking of 3, because it is mainly the structure in the water they are considering, so no difference with the mooring line configurations.

Table 5. Summary of Comparative Accessibility Rankings: Hybrid vs. Catenary Mooring Design

	1 – Significantly More Accessible	2 – Somewhat More Accessible	3 – Neutral	4 – Somewhat Less Accessible	5 – Significantly Less Accessible
Number of Respondents	2	4	4	0	0

4.6 Acceptability Rankings

To further inform metrics, respondents provided a ranking on the comparative acceptability of the hybrid mooring design and conventional mooring design (Table 6). Acceptability was framed as a broader concept that might reflect a participant's thoughts on accessibility but could include other aspects of the floating offshore wind turbine's mooring design (e.g., use of rope vs. chain). Responses ranged from a 1 (significantly more accessible) to a 4 (somewhat less acceptable), with the most responses received for a 2 (somewhat more acceptable). Thus, the results indicated a modest increase in acceptability for a turbine using the hybrid mooring design. Again, several respondents included a caveat in their rankings based on spacing between wind turbines.

4.6.1 Lobstering

For lobstering, feedback on acceptability was provided by both the fishing industry and industry representative participants. One respondent provided a 1 ranking (significantly more acceptable), because the hybrid would be less destructive to the environment, including to the bottom of the ocean and habitat. They said there would be a lot less chain rolling around and less impact on marine life. It was conveyed that lobster live in almost every part of the ocean's bottom, with some areas being more productive than others. Chains coming across and wiping out that habitat could destroy them—but there is a possibility that lobsters would hear them coming and get out of the way. In general, the participants see a negative impact on ocean life for floating compared to piling style wind turbines. Another respondent said that the hybrid would be more desirable and provided a 2 ranking (somewhat more acceptable), based on the smaller footprint being better. However, in general, they said that floating systems are not acceptable at all and would rather have monopiles or jackets.

4.6.2 Trawling

For trawling, feedback on acceptability was provided by both the fishing industry and regulatory participants in the Gulf of Maine. One respondent said that they would give a 3 ranking (neutral) until they saw how the array was going to be set up. They definitely think the hybrid design was better, if they knew the next wind turbine was far enough away. Another respondent gave a 4 ranking (somewhat less acceptable), feeling that the hybrid is going to be less acceptable, because fishermen may doubt that this new design is sound and may not be convinced that it is strong enough. They think that its acceptance and understanding of what the synthetic technology is, especially if there are negative interactions with the fishing gear.

4.6.3 Harpooning

For harpooning, feedback on acceptability was provided by a bluefin tuna fishing industry participant. They stated that if the hybrid design can reduce the size of the footprint, then it is better for them (ranking of 2). They also hope that a smaller footprint would allow more flexibility for where developers put the wind turbines. Siting was conveyed as the primary consideration for them.

4.6.4 Scalloping

For scalloping, feedback on accessibility was provided by a commercial scallop fishing industry participant. They provided a ranking of 2 (somewhat more acceptable) because of the footprint being smaller, which could make a difference if they are really pushing the limit with fishing activities. In proximity of a floating wind turbine, they think the anchor would be the first point of avoidance for scalloping (rather than the mooring line touchdown point).

4.6.5 Fisheries Organizations

Fisheries organizations provided feedback on acceptability based on their broad perspectives. One respondent said they would rank this as a 2 (somewhat more acceptable), without knowing more about wind turbine spacing. Another respondent said their rankings were tied to whether the fishing industry can maintain business operations and provided a 2 ranking (somewhat more acceptable) if there is less line in the water, but a 3 ranking (neutral) if there is no improvement in access given unknown spacing. Yet another respondent provided a 2 ranking (somewhat more acceptable) as a balance between the benefits of the smaller footprint and potential negatives that the rope might be perceived as less sturdy by the fleet, resulting in durability considerations (or perceptions) for the synthetic line.

4.6.6 Other Ocean Use

For the U.S. Coast Guard, individuals provided feedback on acceptability in relation to their mission. They provide a 3 ranking (neutral), because they typically care more about what is on top of the water than what is on the bottom. They conveyed the importance of marking and letting the mariners know what is there. There was some concern that if a chain breaks it sinks but that if a rope breaks, they do not know whether it would be a floating line or if it would sink if it broke lose. From a captain's perspective, they would be hesitant to pull up close to the floating wind turbine without knowing the depth of the mooring line. Their ranking could change depending on whether navigating through the wind array, conducting SAR operations, or performing marine environmental response (e.g., pulling boom for an oil spill).

Table 6. Summary of Comparative Acceptability Rankings: Hybrid vs. Catenary Mooring Design

	1 – Significantly More Acceptable	2 – Somewhat More Acceptable	3 – Neutral	4 – Somewhat Less Acceptable	5 – Significantly Less Acceptable
Number of Respondents	1	6	2	1	0

4.7 Additional Feedback

After soliciting feedback on the two designs individually and comparatively, participants were asked a series of broader questions to elicit any final feedback. This included an invitation to share any additional thoughts on how to limit the potential interactions, either through the actions of a developer or by modifying marine user activities. Responses echoed many of the same themes that had emerged in previous sections and included the following:

- **Project siting.** Several respondents conveyed siting as a top priority and asked that regulators and developers avoid siting projects in areas of high fisheries value and with sensitive benthic habitat.
- **Wind turbine spacing.** Numerous respondents felt that mooring footprint could not be separated from turbine spacing. They conveyed that as mooring footprints decrease, regulators and developers should avoid reducing spacing between turbines so as not to further restrict the area available for fishing activities. Based on U.S. offshore wind energy projects to date, the authors note that turbine spacing can be determined by a variety of factors, including maximizing efficiency within the wind array, safety

considerations for the fishing industry and other ocean users, and additional regulatory inputs.

- **Anchor and mooring markings.** All respondents identified marking as a priority for understanding the location of mooring lines underwater. To help avoid gear interactions, this could include marking anchors, for example, with buoys that could be lit and/or added to nautical charts, as well as by marking mooring lines with a transponder.
- **Modified fishing activities.** Commercial fishing participants conveyed that they would avoid fishing within proximity to the mooring lines and likely focus their efforts elsewhere. Some suggested that as knowledge of potential interactions with floating offshore wind turbines and mooring lines increase, they might consider fishing in greater proximity particularly if it is a financially lucrative area.

Additional considerations raised in the final section of the discussions included:

- **Durability of technology.** Some participants questioned the ability of the floating mooring technology to withstand ocean and weather conditions in the Gulf of Maine. In particular, they raised concerns about the sufficiency of only three mooring lines and the durability of the rope. One participant voiced an interest in expanding testing in the Gulf of Maine, as opposed to simulated tank testing, before broader deployment. In response, engineers have highlighted that polyester ropes have been used in permanent mooring systems by the oil-and-gas industry for over 30 years, where durability is not considered a concern, as long as the system is designed and installed correctly.
- **Impact to fisheries survey research vessels.** Fisheries surveys and the tracking of protected species play a critical role in fisheries management and related research efforts. Concern was expressed that the siting of floating offshore wind turbines and their mooring lines may limit the access of vessels active in the Gulf of Maine, including the 208-ft NOAA Ship Henry B. Bigelow,[5] and potentially impact the accuracy of sampling and survey efforts.
- **Co-location of offshore aquaculture.** One respondent expressed an interest in the potential for co-location of aquaculture within floating offshore wind energy projects but anticipated that permitting for both uses would be complex until both industries mature.

In closing, participants were asked about their desired next steps for research on the interactions between floating offshore wind turbine mooring designs, fishing, and other marine uses. Responses highlighted an interest in:

- **Expanding the ways in which marine users can understand and experience interactions with various mooring designs.** Suggestions included generating graphics that demonstrate interactions at a broader range of depths including those deeper than 100 meters (e.g., 100 fathoms or 600 ft), as well as animations, videos, and/or virtual reality experiences that capture mooring line motion and potential interactions with a range of gear types in different sea states. Some participants also expressed an interest in learning

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[5] More information on the Bigelow research vessel is available on the National Oceanic and Atmospheric Administration's website: https://www.omao.noaa.gov/mo/ships/henry-b-bigelow.

from areas where floating offshore wind turbines have been deployed, including the United Kingdom.

- **Understanding interactions with array power cabling.** While modeling and communicating power cabling aspects were outside the scope of this effort, several respondents noted it as an important additional element of discussions around marine use interactions with floating offshore wind turbines. They would like to learn more about how inter-array cabling could potentially impact fishing activity, and how this compares to mooring system interactions.
- **Increasing opportunities for co-design and stakeholder engagement.** Most participants expressed an interest in continued research into this topic, continued communication with the fishing industry, and expanded investment in opportunities for co-design that brings fishermen and engineers together.

5 Conclusions

The team held discussions on floating offshore wind mooring designs with the fishing industry, fisheries organizations, and regulators in the Gulf of Maine who have expertise related to potential floating offshore wind turbine mooring line interactions. Based on 10 discussions with participants, we gathered feedback on how conventional chain catenary mooring designs and rope-chain hybrid mooring designs might interact with fixed and mobile-gear fisheries, including for lobstering, trawling, harpooning, scalloping, and other ocean uses. A major safety consideration identified by participants was the potential to snag fishing gear either on the portion of the mooring line resting on the seabed or the portion hanging in the water column. In addition to the horizontal footprint of the mooring system, multiple other characteristics were of interest to participants including the curvature of the lines, the touchdown point of the lines, natural burial of the lines in the seabed, and considerations for anchoring (e.g., markings, burial depths).

All respondents provided feedback on accessibility and acceptability rankings for both designs. Across all rankings, the hybrid design was most often identified as being somewhat more accessible and acceptable than the conventional design based on the smaller footprint and the potential to leave more space open for fishing activities. However, the rankings included a significant caveat with respondents largely not able to separate the footprint of a single wind turbine's mooring lines from array considerations related to turbine spacing. Generally, participants felt that if the hybrid design with the smaller footprint maintained an adequate corridor between turbines for fishing activities, then the reduced seabed footprint presented advantages. However, not all respondents felt this way, and some had greater concerns about the use of synthetic rope in the hybrid design. In response to spacing considerations, we note that a smaller mooring footprint would typically not be expected to affect the turbine spacing, which is mainly driven by energy yield considerations based on wind resource and wake effects, as well as safety considerations for the fishing industry and other ocean users, and additional regulatory inputs.

Most participants expressed an interest in continued research into this topic, continued communication with the fishing industry, and expanded investment in opportunities for co-design that brings fishermen and engineers together. In September 2022, the National Offshore Wind Research and Development Consortium awarded a new project to NREL with the Responsible Offshore Science Alliance and UMaine to develop co-design solutions for U.S. floating offshore wind farms and fishing compatibility. The new project will develop and apply a fishing co-design framework, with case studies in the Gulf of Maine and Central Atlantic, that incorporates fishing coexistence constraints and metrics when choosing the numerous floating wind array design variables that can be optimized. Additional opportunities for responsible floating offshore wind energy development should build on the findings in this report and other activities that are gathering feedback from the fishing industry and other ocean co-users to help ensure that information is shared and considered jointly as early as possible in the U.S. floating wind design process.

Future research could focus on quantifying a risk profile related to coupling the probability of impacts and consequences of their occurrence, as well as quantifying mitigation opportunities related to floating wind interactions with ocean users. However, there is currently not enough data on or experience with floating offshore wind farm scenarios in the Gulf of Maine to quantify these impacts on and mitigations for the fishing community and other stakeholders. The current study gathered feedback from a range of ocean users on how they might interact with the floating designs presented and quantified metrics for acceptability and accessibility. Respondents identified a modest increase in accessibility and acceptance for a single turbine using the rope-chain hybrid mooring system design, given the smaller footprint and the potential to leave more space open for fishing activities. Numerous possible next steps and additional considerations were identified by respondents in the previous section related to project siting, array spacing, mooring line marking, visualization of mooring systems, co-design with ocean users, and other topics. These identified topics should be addressed in future studies to help develop and quantify a risk profile that would then help to inform solutions for minimizing effects on fishing activities and other marine uses.

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