Estimating the Costs of Using On-Demand Gear in Massachusetts Lobster Fisheries

Citation

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About

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Executive Summary

The Massachusetts Division of Marine Fisheries (DMF) continues to lead the way in managing lobster fisheries to be prosperous while reducing impacts to protected resources and endangered species. DMF has done this in close partnership with fishing industry stakeholders, conservation organizations, academic experts, and fellow agencies throughout the Commonwealth and the region. In late 2020, with funding provided by the National Fish and Wildlife Foundation through the support of Shell USA and the National Oceanic and Atmospheric Administration, DMF began work under a grant to fully engage on some of the most pressing emerging issues in lobster fishery conservation and management. DMF must balance its duties to responsibly manage the Commonwealth's public trust resources with its obligations to conserve all marine life impacted by the activities it permits. By commissioning this study to establish a modeling framework that can estimate the costs and revenue impacts associated with using on-demand (commonly known as 'ropeless') fishing gear in Massachusetts lobster fisheries, DMF continues to advance our collective knowledge of the issues, challenges, and opportunities associated with this important approach to reducing impacts to North Atlantic right whales, which are critically endangered.

A comprehensive understanding of the ways that on-demand gear could be integrated into lobster fisheries will require significant additional research, including a more thorough evaluation of the operational constraints and parameters of various types of on-demand gear and their economic impacts to fishing businesses. Recent studies have begun to estimate the costs of acquiring on-demand gear, but none have yet incorporated its operational costs (i.e. the impacts of using the gear to the profitability of lobster fishing operations) into economic assessments.

This report presents a novel approach to estimating the operational costs of using on-demand gear in Massachusetts lobster fisheries. Our model estimates the time required to use on-demand gear based on factors including vessel length, gear configuration, and fishing area. We use on-demand gear testing program data, economic assessments based on surveys of vessel owners/operators, and geospatial analyses that characterize fishing operations based on speed and location during a baseline period of 2015-2019 to estimate the changes in costs and operating revenue associated with the use of on-demand gear on a per-trip basis for Massachusetts fishing vessels.

We parameterized the model using a scenario approximating the complete conversion of Massachusetts fishing vessels operating in state and federal waters to using one type of on-demand gear. We introduced additional cost considerations including an annuity trap sale, reduced bait use, and a low cost loan for gear purchase. We used Automated Information System location data cross-referenced with Vessel Trip Reports to estimate the time required to haul static line (i.e. traditional, or vertical line & buoy) fishing gear and used data from NOAA's on-demand gear testing program to estimate the time required to haul on-demand gear. We used these haul duration estimates to calculate the amount of time required to achieve the same level of productivity as the baseline period and the costs and revenue associated with that level of throughput for Massachusetts lobster fisheries.

Our simulation results indicate that the complete conversion of Massachusetts lobster fishing vessels to using the type of on-demand gear we included in our model during the 2015-2019 baseline period would have resulted in the following operational and economic outcomes:

- The average per-trap throughput rate (the time required to haul, sort catch, and redeploy) would have increased by 1.82 minutes across all Massachusetts lobster fishing vessels, inversely proportional to the number of traps fished per trawl;
- The average annual net revenue across all Massachusetts state and federal lobster fishing vessels using on-demand gear, assuming the gear would be acquired using a low-cost loan, would have been -$29,300, a decrease of $47,263 per vessel on average;
- The average annual net revenue across all Massachusetts state and federal lobster fishing vessels using on-demand gear, assuming all on-demand gear acquisition costs were subsidized, would have been $1,377, a decrease of $16,586 per vessel on average;
- The average Massachusetts statewide lobster landings value would have decreased by $40.81 million;
- Lobster landings in Massachusetts would have been reduced by 3.74 million pounds.

Overall, these results indicate that the operational time costs and resulting decreases in catch revenue associated with the decreased efficiency of the type of on-demand gear we used to parameterize the model could be significant, reaching a similar level of cost to the acquisition of the gear itself for some classes of lobster fishing vessel. In order to paint a more complete economic picture, future estimates of the costs of on-demand gear use in lobster fisheries should account for operational factors in addition to the costs of acquiring the gear. While the on-demand gear use scenario we present here was designed to represent the upper bounds of potential economic impact to lobster fishing operations, additional operational issues that are unknown or poorly characterized at this time could increase costs further. Alternatively, management scenarios that call for the use of on-demand gear differentially across vessel size class, management area, season, or other factor could result in reduced fixed and variable costs. Future lobster fishery management scenarios designed to reduce risk to right whales should be developed and evaluated with on-demand gear acquisition and operational costs in mind.

The model presented here is capable of incorporating data from additional on-demand gear testing efforts, estimating costs and revenues from additional operational, economic and management scenarios, incorporating additional lobster management areas, and forecasting costs and revenue based on catch and effort estimates or scenarios. Other types of on-demand gear may be significantly less expensive or require significantly less time to operate than the gear used in our simulation. The results of future research into the operational impacts of technical changes required by the use of on-demand gear in high-density settings or areas where gear conflict is common can be incorporated into our model to provide cost estimates for numerous scenarios that are relevant to current and future fishery management discussions. The use of this model in the future and in the context of expected significantly increased research effort will enable stakeholders, gear developers, and fishery management agencies to base their assessments of on-demand gear feasibility on factors including the economic impacts to fishing operations.

1. Introduction

Switching to fishing gear that can reduce the risk of North Atlantic right whale entanglements continues to be a primary focus of take reduction efforts, with tens of millions of dollars and thousands of person hours devoted to the discussion and evaluation of the issue. The regulation and management of New England lobster fisheries continue to be among the most politically and economically dynamic in the history of modern US fisheries. In the past year, the fishery vacillated from its highest grossing season in history to one of the lowest when adjusted for volume; the DC Circuit Court ruled that the relevant NOAA biological opinion ('bi-op') on the impacts of the fishery to the whales and resulting rulemaking promulgated in late 2021 (the 'Phase 1' rule[1]) were not sufficiently restrictive;[2] the same court summarily dismissed a separate legal challenge of the bi-op and rule brought by the fishing industry for being too restrictive;[3] a more restrictive take reduction plan was developed by the Atlantic Large Whale Take Reduction Team; the US Congress passed a law deeming the Phase 1 rule "sufficient" for the next six years;[4] and the DC Circuit Court of Appeals reversed the District Court decision and vacated the bi-op while leaving the Phase 1 rule in place.

Rarely does fishery management read like high drama. Throughout and despite the wild swings driven by all three branches of the federal government, hundreds of millions of dollars continue to be on the line for the fishing industry and the right whale remains critically endangered. However, a new area of consensus has emerged: 'innovative' fishing equipment and techniques are likely to become a significant new part of commercial American lobster fishing operations for some portion of the fishery. A significant amount of additional information will be required if new fishing gear that can reduce the risk of entangling right whales can be successfully integrated into New England lobster fisheries.

On-demand fishing gear is a class of equipment that allows the marking and retrieval of fixed gear without using a persistent vertical line and buoy. The gear generally consists of submerged buoyancy devices that are actuated by time-release mechanisms or acoustic signals transmitted from the surface. The various types, configurations, and manufacturers of on-demand fishing gear systems have been documented extensively in the literature, most comprehensively in the report Ropeless is Real by K. Sawicki (2020).[5] To facilitate smoother consideration of the potential use of these gear innovations and to rapidly generate the requisite data and knowledge, the US Congress has appropriated tens of millions of dollars for fiscal year 2023, and potentially hundreds of millions of dollars cumulatively in future budget cycles, to support the development and implementation of innovative gear, including on-demand (also known as 'ropeless') gear, and the technical, social, legal, and regulatory systems required for its use. For

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[1] 86 FR 51970
[2] Ctr. for Biological Diversity v. Raimondo, No. CV 18-00112-JEB (D.D.C. July 8, 2022)
[3] Maine Lobstermen's Ass'n, Inc. v. Nat'l Marine Fisheries Serv., No. CV 21-2509-JEB (D.D.C. September 8, 2022)
[4] Pub. L. No. 117-328, 136 Stat. 4459 (2022), Division JJ, Section 101(a)
[5] Sawicki, K. (2020). Ropeless is Real: A Solution for Fishermen and the North Atlantic Right Whale. Sustainable Seas Technology, Inc., Middle Haddam. Available from https://sustainableseasdotblog.files.wordpress.com/2020/05/ropeless-is-real-final-ks-2.pdf

a detailed summary of these issues from multiple perspectives, see the 2022 report Assessing the Feasibility of On-demand Gear in New England Lobster Fisheries by Homarus Strategies and DMF, supported by the National Fish and Wildlife Foundation.[6] On-demand fishing gear and the lobster fishery itself are highly complex and specialized systems; this report assumes that the reader has at least a basic understanding of both.[7]

This body of work has become the most high stakes and expensive fishing gear innovation effort in US history. The evaluation of on-demand gear and other novel fishing gear in New England lobster fisheries should include an assessment of the costs expected to be incurred by users (unless otherwise noted, the topics discussed in this report can be assumed to apply to all types of alternative fixed gear designed for the purposes of reducing the risk of entangling right whales, including on-demand gear). Since the publication of last year's report discussing the issues, opportunities, and challenges of on-demand gear in New England lobster fisheries, the Massachusetts Division of Marine Fisheries (DMF), fishing industry members, nonprofit organizations, and others have focused their efforts in this arena on two bodies of research: technical issues (e.g. scaling up on-demand gear testing activities, developing integrated technological frameworks, etc.) and socioeconomics. Recognizing that efforts to understand the social, cultural, and economic impacts of using on-demand gear are central components of this gear switching discussion, DMF commissioned the following study to produce a flexible modeling framework that can estimate the operational costs of using on-demand gear in Massachusetts lobster fisheries.

To date only two economic studies evaluating the costs of acquiring on-demand gear in US lobster fisheries have been published. In 2022, C. Alkire applied a learning curve model to estimate the current and future price trajectory of on-demand gear and estimated the cumulative costs of gear acquisition for different subunits of the US lobster fishery under some management and operational scenarios.[8] Earlier this year the Conservation Law Foundation commissioned a similar economic modeling analysis estimating the purchase costs of on-demand gear across different subunits of the lobster fishery using a learning curve model and estimates of operational variables including gear loss rates and variable on-demand gear conversion rates.[9] While these analyses provide estimates of one of the most costly aspects of switching to on-demand gear, namely its purchase, other significant operational factors associated with the use of on-demand gear that impact fishing vessel costs and revenues have not been studied in detail until now.

Here we present the structure and outputs of our model simulating a switch to 100% on-demand gear use by all state and federally permitted lobster fishermen and fishing vessels based in

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[6] Oppenheim, N.G. (2022). Assessing the Feasibility of On-demand Gear in New England Lobster Fisheries. Homarus Strategies LLC, Brunswick, Maine, USA.
[7] For a detailed description of the management of US lobster fisheries, see https://www.fisheries.noaa.gov/species/american-lobster.
[8] Alkire, C. (2022). Decline in on-demand fishing gear costs with learning. *Frontiers in Marine Science*, *9*, 2254.
[9] Conservation Law Foundation. Financial Impact of Transitioning Two Sectors of the Northeast Lobster Fishery to On-Demand (Ropeless) Fishing. 2023.

Massachusetts, one of many possible scenarios. We developed our framework using fishery-dependent cost and effort data from a variety of sources described below. The model is designed to be iterative, with the ability to incorporate additional sources of data, new variables, and more sophisticated approaches to incorporating statistical uncertainty as additional on-demand gear and their operational frameworks are developed and tested. The model results include cost and revenue estimates for Massachusetts lobster fishing vessels across a variety of operational variables (e.g. vessel size, fishing gear configuration, and management area). When compared with the baseline economic conditions of Massachusetts lobster fisheries, a more complete understanding of the cost and revenue impacts from switching to on-demand gear can be realized.

2. Economic baseline & model framework

The following section describes the steps we took to integrate the data required to develop an economic baseline and operational modeling framework, including the acquisition of fishery-dependent data, the estimation of fishing vessel costs and revenues, developing an operational model, the incorporation of spatial data to inform the model, the use of on-demand fishing gear testing program data to estimate fishing gear operating efficiency, and the estimation of costs associated with the acquisition and use of on-demand gear. Consistent with a common approach in this regulatory setting, we used a model vessel approach in order to report economic and operational variables and model outputs across classes of vessels with similar characteristics.[10] Model vessels represent groups of vessels with common operational features including length, average number of traps per trawl, and fishing area. Fleet-wide effects are estimated by multiplying by the number of observed vessels in each class.

Fishery-dependent data acquisition

Individuals with lobster fishing permits issued by DMF, or those with permits issued by the National Marine Fisheries Service who land their catch in Massachusetts, are required to submit monthly and annual reports summarizing their fishing activities. Forms required by Massachusetts-based fishermen to DMF are shown in Appendix 1. Trip-level reports include state permit ID, the dates over which fishing occurred, weight of all species landed, statistical area where fishing took place, the amount of gear fished, and port of sale. End-of-year reports summarizing overall fishing activities include state permit ID, vessel length and value, abundance and value of fishing gear, gear configuration (maximum endlines and average traps per trawl), bait cost, and volume of fuel used. Together, these reports provide a wealth of information about the operational and business characteristics of lobster fishers from Massachusetts, the seasonality of the fishery, and spatial heterogeneity of the fishing fleet.

State and Federal Vessel Trip Reports (VTR) from DMF and the National Marine Fisheries Service from 2012 to 2019 were accessed via the Atlantic Coast Cooperative Statistics Program and NOAA VTR databases and were aggregated to characterize the activities of the entire Massachusetts lobster fishing fleet. We selected the 2015 to 2019 period as our baseline time series because of the relatively uniform fishery management requirements in place and relatively stable pre-pandemic market conditions.

As with many large fishery-dependent datasets, the Massachusetts lobster fishing reports occasionally contained missing or anomalous values potentially associated with self-report bias or transcription errors that needed to be considered prior to analysis to ensure data quality and consistency. Date of sail and landing date were assessed to evaluate their capacity to aggregate

[10] See for example the Draft Environmental Impact Statement, Regulatory Impact Review, and Initial Regulatory Flexibility Analysis for Amending the Atlantic Large Whale Take Reduction Plan: Risk Reduction Rule, pp. 6-189, available from nhttps://www.greateratlantic.fisheries.noaa.gov/public/nema/PRD/DEIS_RIR_ALWTRP_RiskReductionRule_VolumeI.pdf

fishing activity over time and to determine trip duration. Gear configurations were assessed via self-reported traps per trawl and were also estimated using self-reported number of traps hauled and maximum number of vertical lines being used. Self-reported trawl lengths were available from 2015-2019 (n = 228,048), while maximum number of traps and vertical lines were available from 2012-2019 (n = 409,149). Because of this large difference in sample size, we chose to use the calculated trawl lengths.[11]

Further dataset quality control evaluated the quality of self-reported volume of lobster landed. Individual landings volumes were standardized to the amount of gear fished per trip (lbs. trap haul^{-1}) and these values were aggregated per statistical area. Catch rates were processed using an outlier analysis, whereby values outside the 3x interquartile range per statistical area were excluded from further analysis (Table 1).[12]

Table 1. Summary of state and federally managed lobster fishery landings in Massachusetts, in real 2019 USD. Source: ACCSP, July 2023.

	2015	**2016**	**2017**	**2018**	**2019**
Landings (lbs)	16,450,853	17,784,921	16,493,125	17,697,243	17,029,462
Revenue	$84,449,033	$87,755,150	$84,683,114	$90,453,895	$95,456,028

Developing an economic baseline

The costs incurred by commercial lobster fishing vessels are relatively poorly characterized in the literature. The most comprehensive economic data describing the fishery are included in periodic harvester survey reports administered by the Northeast Fisheries Science Center's Social Sciences Branch[13] and harvester supplemental reports submitted to DMF. We used the most recent available economic data to estimate actual costs incurred by commercial fishing vessel operators over the baseline time series (Table 2). Operational costs incurred by a fishing vessel include repair & maintenance, upgrades, vessel related costs, business expenses, crew and captain payments, principal and interest, and operating costs (e.g. fuel and bait). Average actual costs from Zou *et al.* were adjusted to estimated percent of overall costs incurred by a fishing vessel (Table 3) and indexed against operating costs reported on DMF fixed gear supplemental reports to give total costs per vessel per year for all Massachusetts-based lobster fishing vessels. Massachusetts fixed gear fishing vessel permittees are required to include annual expenditures on bait, trap replacement costs, and overall fuel consumption in their supplemental reports. We derived annual average fuel prices from the US Energy Information

[11] Trawl lengths were calculated by dividing the maximum number of traps hauled by the maximum number of endlines fished. To account for longer trawls that required two endlines per trawl, calculated trawl length values greater than 1.75 were multiplied by 2 to give the number of endlines. DMF, personal communication.
[12] Tukey, J. W. (1977). *Exploratory data analysis* (Vol. 2, pp. 131-160).
[13] Zou, C., Thunberg, E., & Ardini, G. (2021). Economic profile for American lobster (Homarus Americanus) fleets in the Northeastern United States. US Department of Commerce, Northeast Fisheries Science Center, Reference Document 21-03.

Administration[14] and the motor fuel index from the Federal Reserve Bank of St. Louis.[15] Cost for bait and fuel were inflation adjusted using the consumer price index ("CPI: motor fuel index" in the case of fuel prices) to 2019 USD. Landings revenues were inflation adjusted using the producer price index ("Producer Price Index by Commodity: Processed Foods and Feeds: Unprocessed and Prepared Seafood"). All price indices were downloaded from the Federal Reserve Bank of Saint Louis FRED database. Ex-vessel landings prices for lobster, Jonah crab, and black sea bass (which are frequently harvested by fixed gear permittees) were provided by DMF. Fuel and bait prices were also recorded in Zou *et al*. under the aggregated category "vessel operating costs".

We took the average values across the three survey deployments in Zou *et al.* to determine that these costs accounted for 26.01% of total annual costs in their sample. Total annual costs for our dataset were then extrapolated based on the observed fuel and bait costs representing 26.01% of total costs. These estimated values were then cross-referenced with nominal total annual fishing costs reported in Zou *et al.* by comparing estimates from each source across model vessel categories and determining statistically similar values for all size classes, except the vessel class <35 ft, which had very few survey responses. The resulting indexes allowed us to estimate average annual costs for each Massachusetts permitted lobster fishing vessel.

Table 2. Summary of cost categories incurred by Northeast lobster fishing vessels from Zou *et al.* (2021). All costs are survey averages adjusted to 2018 USD.

Cost category	2015	2012	2011
Repair and maintenance	16,391	18,224	16,743
Upgrade and improvement	29,293	20,229	26,207
Vessel related costs	14,417	9,203	7,155
Business related costs	10,934	10,357	8,058
Crew & captain payment	63,862	50,664	43,158
Principal payment	16,086	15,218	15,807
Interest payment	2,728	4,521	5,868
Vessel operating costs	48,758	46,272	46,529

Table 3. Summary of cost categories as a percentage of overall costs incurred by Northeast lobster fishing vessels, from Zou *et al.* (2021).

Cost category	2015	2012	2011	Mean
Repair and maintenance	8.10%	10.43%	9.88%	9.47%
Upgrade and improvement	14.47%	11.58%	15.46%	13.84%
Vessel-related costs	7.12%	5.27%	4.22%	5.54%

[14] All Grades Conventional Retail Gasoline Prices: eia.gov/dnav/pet/PET_PRI_GND_DCUS_NUS_A.htm
[15] No. 2 Diesel Ultra Low Sulfur (0-15 ppm) Retail Prices: fred.stlouisfed.org/series/CUSR0000SETB#0

Business related costs	5.40%	5.93%	4.75%	5.36%
Crew & captain payment	31.54%	29.00%	25.46%	28.67%
Principal payment	7.94%	8.71%	9.32%	8.66%
Interest payment	1.35%	2.59%	3.46%	2.47%
Vessel operating costs	24.08%	26.49%	27.45%	26.01%

We calculated annual landings values from trip reports for each vessel during each year of the baseline time series using an annual landings-weighted price derived from DMF/NOAA dealer report data. We then estimated average annual costs across Massachusetts lobster fishing vessels in each year of the baseline time series by indexing annual total cost estimates against reported costs included in harvester supplemental reports. These indexed values were binned by vessel length (Table 4) and annual average trawl length (Table 5). This allowed us to calculate the baseline annual net revenues for vessel size and gear configuration (i.e. trawl length) categories of fishing vessels landing catch in Massachusetts ports operating in state and federal waters.

Table 4. Estimated average annual costs and revenues for Massachusetts lobster fishing vessels from 2015 to 2019 inclusive, by vessel length. All financial values are given in 2019 USD.

Vessel length (ft)	n vessel years	Annual fuel cost	Annual bait cost	Annual total cost	Annual revenue	Annual net revenue
(0,35]	1,837	3,638	6,602	39,512	46,754	7,362
(35,45]	1,262	12,605	20,357	127,512	155,407	27,585
(45,55]	111	29,033	31,520	237,538	263,258	34,557
(55,Inf]	70	100,925	85,467	714,796	805,338	89,349

Table 5. Estimated average annual costs and revenues for Massachusetts lobster fishing vessels from 2015 to 2019 inclusive, by average trawl length. All financial values are given in 2019 USD.

Vessel annual mean traps/trawl	n vessel years	Annual fuel cost	Annual bait cost	Annual total cost	Annual revenue	Annual net revenue
(0,5]	732	2,638	2,634	20,280	24,783	4,674
(5,10]	852	4,966	9,988	57,648	69,627	11,868
(10,15]	365	10,492	19,119	114,511	152,634	35,913
(15,20]	541	16,850	25,259	162,435	193,774	30,853
(20,Inf]	156	48,254	48,113	374,842	392,267	25,484

Developing an operational model

To estimate the differences in costs and revenue between static line gear and on-demand gear, we used fishing activity from VTR and fishing effort information from DMF supplemental reports to estimate vessel operating costs based on gear throughput (the number of traps fished per trip aggregated across trips per annum).

Our primary challenge was to estimate the amount of time each vessel spent performing the various tasks associated with a trip: steaming to fishing grounds, locating/hauling/setting gear, and returning to port. In order to derive these estimates, we created a novel model structure that disaggregated the process of hauling lobster fishing gear into discrete steps (Figure 1).

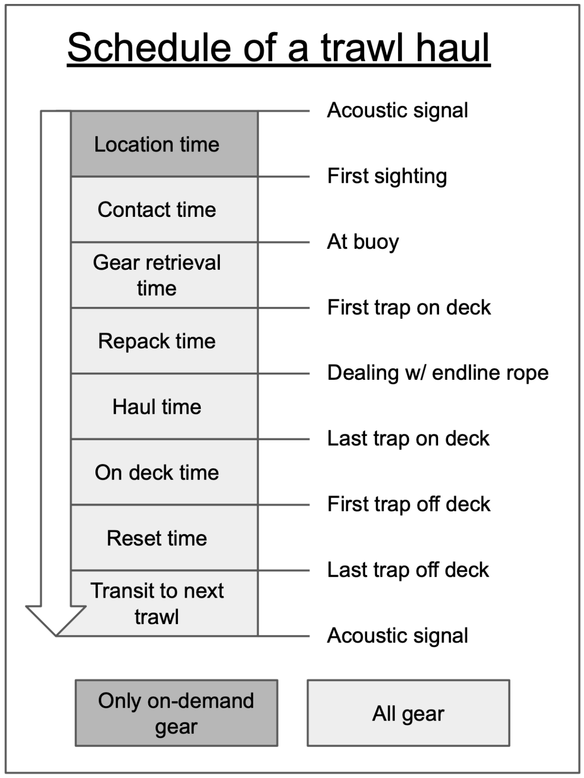

Figure 1. Schedule of a trawl haul: the steps required to fish a trawl of lobster traps. The 'location time' step is not taken during the use of static line gear because gear is already marked at the surface by a buoy.

We used information from publicly available Automatic Identification System (AIS) datasets to determine fishing vessel locations and speed during fishing trips. Publicly available AIS data are currently one of the most effective ways to determine a vessel's location while it is fishing. We used a gaussian mixture model (GMM) to classify vessel speeds during fishing trips into two distributions reflecting hauling and steaming activity (Figure 2). Vessels fitted with AIS broadcast the vessel's name, location, speed, status, and other information at regular intervals, and this information is received by ground or satellite-based receivers and stored at a particular time interval ('ping rate').

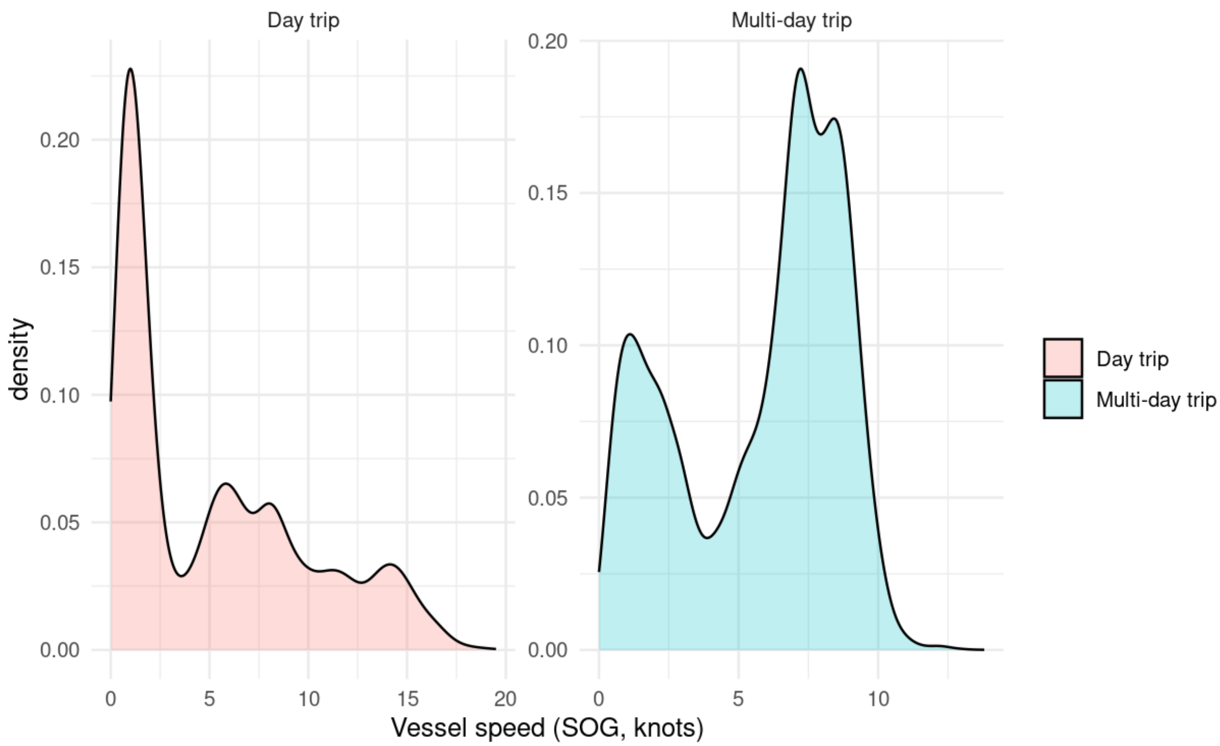

Figure 2. Relative proportion of vessel speeds during all trips in the VTR data set, organized by duration of trip.

The development of our AIS-based fixed gear fishing operational model follows Mendo *et al.* (2019)[16] and DeVoe (2021).[17] Publicly available AIS data from 2019 were downloaded from NOAA.[18] We cross-referenced Maritime Mobile Service Identity (MMSI) numbers for 2019 fishing vessel permits in the AIS dataset with those in the VTR dataset using vessel name and permit number. We excluded all vessels without matching MMSI and permit number, which left 158 trips taken by 14 vessels based in Massachusetts ports (Figure 3). We cross-referenced AIS data from these vessels with the VTR dataset in order to correlate trip information with spatial location information and exclude trips declared for species besides lobster. Unique trips in the AIS dataset were confirmed using a trip sorting tool developed by Global Fishing Watch.[19] Because many of the trips in the NOAA AIS dataset were incomplete or had significant gaps, we removed any non-matching trips in the VTR and AIS databases, after matching and merging on MMSI and trip end date. We also removed trips that had an average ping rate of fewer than 20

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[16] Mendo, T., Smout, S., Photopoulou, T., & James, M. (2019). Identifying fishing grounds from vessel tracks: model-based inference for small scale fisheries. *Royal Society Open Science*, *6*(10), 191161.
[17] DeVoe, W. (2022). Lobster Vessel Tracking Ping Rate Analysis. Report presented to Atlantic States Marine Fisheries Commission American Lobster Management Board, March 31, 2022. Available from http://www.asmfc.org/files/Meetings/AmLobsterBoard_March2022/AmLobsterBoardMaterials_March2022.pdf, pp 96.
[18] https://coast.noaa.gov/htdata/CMSP/AISDataHandler/2019/index.html
[19] https://globalfishingwatch.org/data-download/datasets/private-voyages-confidence-4:v20220922

pings per hour (one ping every 3 minutes), except for trips with greater than 1000 total pings, where the rate was relaxed to 12 pings per hour (one ping every five minutes).

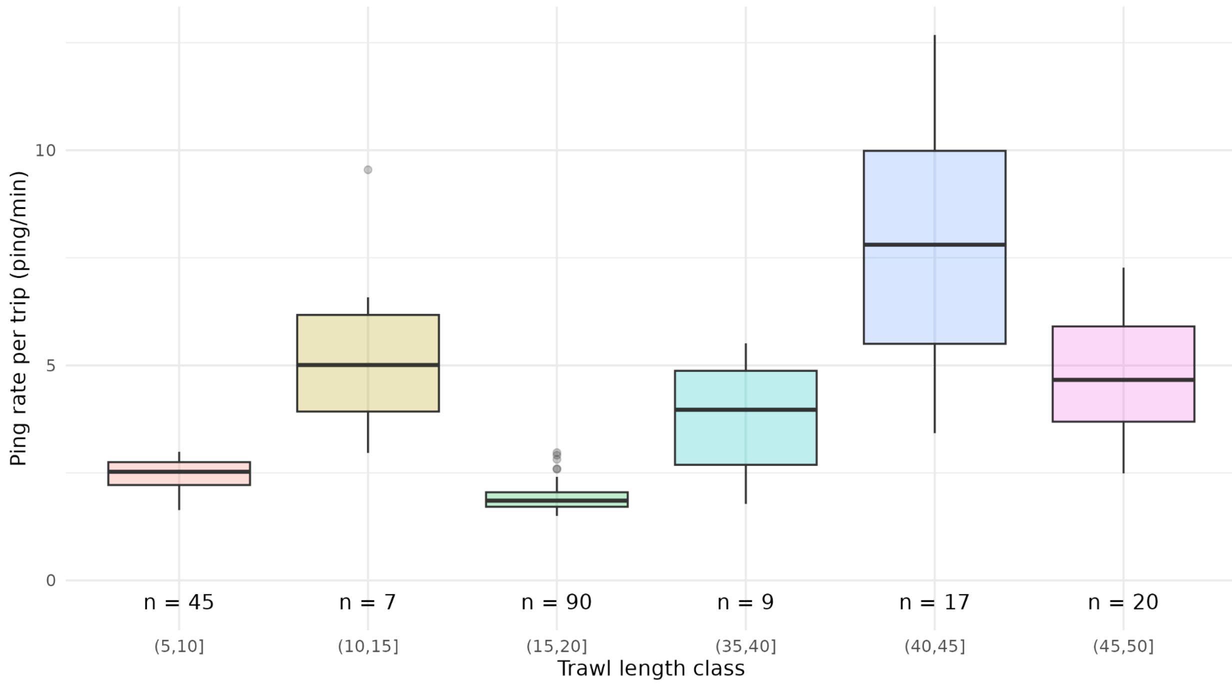
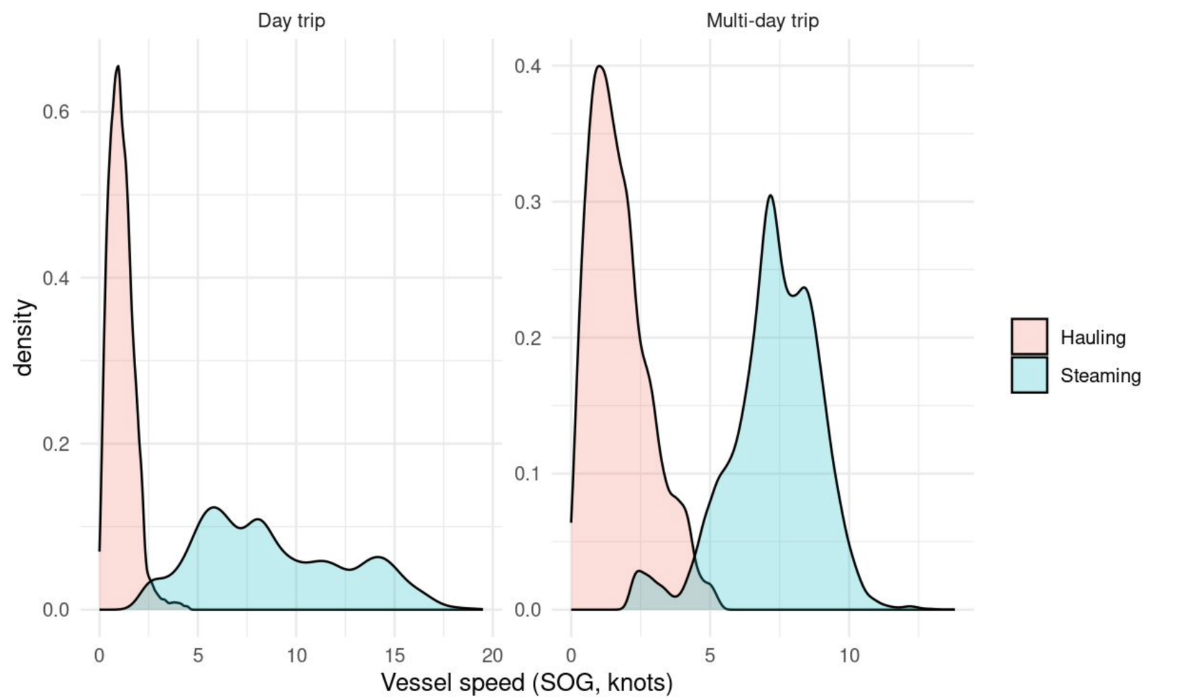


Figure 3. Distributions of AIS ping rates during all trips in the VTR dataset, organized by average trawl length used by each vessel. Samples of 3 or fewer vessels are removed to protect confidentiality.

The GMM was used to classify vessel speeds into two distributions (hauling and steaming) across trips for each of the 14 vessels (Figure 4). This was accomplished using all available AIS data for a given vessel throughout 2019 to take advantage of larger sample sizes (versus at the trip level), assuming vessel speed behavior is consistent throughout the year. The GMM assigns a probability of membership in each distribution; each observation was binned into the distribution it is more likely to be from (>50% probability).[20,21] With each AIS ping classified as either hauling or steaming, we calculated the amount of time each vessel spent hauling and steaming during each trip.

[20] Mendo *et al.* (2019)
[21] DeVoe (2022)



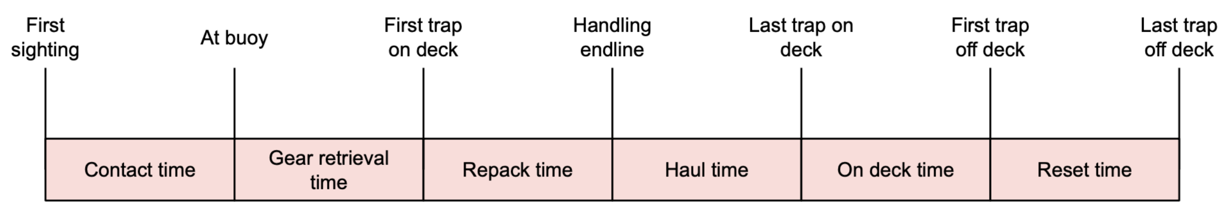


Figure 4. Gaussian mixture model applied to the proportion of vessel speeds during all trips in the VTR data set, organized by duration of trip. Pings falling under the red colored curves were classified as occurring during hauling activity; pings falling under the blue colored curves were classified as occurring during steaming activity.

We used data provided by the Northeast Fisheries Science Center's on-demand gear testing program to determine the average amount of time necessary to complete each of the trawl hauling steps when operating static line gear and on-demand gear (in this case, the EdgeTech 5112 system and a hull-mounted transducer). These data reflect the on-demand gear testing program's testing activities for one testing season in 2022 conducted by one fishing vessel fitted with a hull-mounted transducer (the use of through-hull transducers rather than hand-deployed systems can significantly reduce the amount of time required to locate and call on-demand gear to the surface because these functions can occur while the vessel is steaming towards the gear). This vessel was operated by fishermen and crew with a great deal of experience operating on-demand gear and static line gear. The on-demand gear testing program uses a standardized protocol deploying 40-trap trawls with a EdgeTech on-demand system at one end and a static endline at the other. Vessels testing the gear are outfitted with Vessel Monitoring Systems (VMS) including cameras recording digital video. Vessel operators record the amount of time required to locate, contact, retrieve, and re-deploy trawls fitted with on-demand gear and control deployments consisting of 40-trap trawls fitted with two static endlines.

Cross-referencing GMM results with trap haul counts and trawl lengths from VTR allowed us to calculate the amount of time spent hauling per trawl and per trap on each trip. We calibrated the haul schedule time step duration used in the model against a ‘standard’ 40-trap trawl, the trawl length used by the on-demand gear testing program (Table 6). We calculated the static line trap throughput rate by taking the sum of the total number of traps hauled across all trips and vessels in the sample, and dividing it by the time spent hauling as estimated by the GMM.
The estimated average time required to haul a 40 trap trawl using static line gear was 47.6 minutes; the estimated average time required to haul a 40 trap trawl using on-demand gear was 55.5 minutes, a 14.4% increase.

Table 6. Duration (minutes) of trawl haul schedule steps for static line (yellow) and on-demand (purple) gear.

Haul schedule step	**Static line gear**	**On-demand gear**
Location time (*l*)	0	4.4
Contact time (*c*)	2.5	2.2
Gear retrieval time (*g*)	5.4	5.0
Haul/on deck/reset time (*h*)	39.3	39.3
Recoil/repack time (*r*)	0.5	4.5
Total time	47.6	55.5
Trap throughput rate	1.19	1.39

The trawl haul schedule time step duration estimates were used to calculate the amount of time a vessel spent hauling a particular gear type (gt) during a fishing trip with known trap haul count and trawl configuration such that:

$$Trip\ Haul\ Time_{gt} = \frac{h}{40} * n_{traps} + (c_{gt} + g_{gt} + l_{gt} + r_{gt}) * n_{trawls}$$

where h is the haul/on deck/reset time, c is contact time, g is gear retrieval time, l is location time, and r is recoil/repack time.

We validated the operational model against a limited set of on-demand and static line gear hauls performed by the NOAA on-demand gear testing program. VMS video recordings of three on-demand and three static line trawl hauls were randomly selected by the on-demand gear testing program and were analyzed by New England Marine Monitoring to give estimates of the amount of time required to haul traps and sort catch between on-demand gear and static line gear. We compared the median haul time from the on-demand gear testing program data against the AIS-based calculation of haul time (Table 7). Although the values were similar, we selected the AIS-based value from the GMM because it had a significantly greater sample size (~3000 trawl hauls) over a broader range of vessels than the VMS-based value from the on-demand gear testing program (six trawl hauls) from one vessel.

Table 7. Trap throughput rates for 40-trap trawls; AIS-based rate is the average value from gaussian mixture model analysis, VMS-based rate is the median value from on-demand gear testing program video analysis.

	AIS	VMS
Haul/on-deck/reset time (min)	39.3	42.0

Economic scenario

To estimate the overall costs of using on-demand gear in Massachusetts state and federal lobster fisheries, we developed an economic scenario that characterizes the changes in costs incurred by fishing vessel operators if they were to switch to using on-demand systems to retrieve all of their gear all the time in all locations. Some of these cost changes are relatively straightforward, including a reduction in bait costs proportional to the reduction in number of traps fished when on-demand gear is used, based on the cost of bait from DMF supplemental reports. We assumed a baseline gear loss rate of 12.3% and an annual loss rate for on-demand equipment and traps of 1.6%, after Sawicki (2020),[22] reflecting a best-case scenario for the reduction of gear loss associated with using on-demand gear. The value of the difference in annual loss rates was valued using trap values collected by DMF.

Based on numerous interviews with fixed gear fishermen operating in state and federal waters conducted in 2021,[23] we assume here that trip lengths would remain consistent under an on-demand gear use scenario; in other words, lobster fishermen using on-demand gear would experience a reduction in gear throughput over the course of each trip resulting in a reduced number of traps fished proportional to the increased amount of time required to haul the gear. Interview subjects who operated fixed gear fishing vessels generally attributed this operational assessment to the time-limited nature of their fishing operations, where the ability to haul a given number of traps or trawls on a trip was limited by gear throughput; this was common across state and federal fishing vessels as well as vessel operators taking single and multi-day trips. Other complex economic factors were also included in the model. Using on-demand gear could require fishing vessel operators to incur additional costs in some areas and could yield reduced costs in some areas. We assigned differential costs across variables including vessel

[22] Sawicki (2020).
[23] Oppenheim (2022).

size class, fishing operation, area fished, and others, and the model was built to incorporate additional cost categories as needed.

We assumed that Massachusetts fishing vessel operators converting their operations to using solely on-demand fishing gear would not be likely to operate the same number of traps efficiently. We therefore incorporated a trap annuity sale into the model simulating the action of selling a number of traps in proportion to the level of fishing effort reduction imposed in the model by using on-demand gear relative to baseline conditions. We estimated the value of the trap sale based on trap values given by DMF fixed gear supplemental reports, while acknowledging that a wholesale one-time shift to on-demand gear across the industry might reduce trap prices due to excess supply.[24] We structured the value of the payout from these trap sales as a 15 year annuitized payment in the form of:

$$Annuity\ payment \ = \frac{r * p}{1 - (1+r)^{-n}}$$

where r is the interest rate, p is the value of the traps sold, and n is the annuity term (duration). We chose a 15 year horizon for annuity payments consistent with assumed useful life of on-demand fishing gear equipment, from CLF (2023).[25] The interest rate is assumed to be 3.94%, equal to the opportunity cost of capital for businesses in 2019 from the Federal Reserve Bank of St. Louis.[26]

Besides throughput-related changes in operating efficiency, one of the significant costs associated with switching to on-demand gear is the purchase price of the equipment. Due to the significant estimated upfront costs of acquiring on-demand gear,[27] fishing vessel operators may have opportunities to finance the acquisition of gear via low-rate loan programs. We modeled such a program assuming a 3.94% annual percentage rate being made available for the acquisition of on-demand gear, based on the 2019 opportunity cost of capital as above, which in today's capital market conditions could be considered a best-case scenario for a subsidized on-demand gear purchase loan program. We structured the loan as 15 year annuitized costs in the form of:

$$Annual\ financing\ cost \ = \frac{r * p}{1 - (1+r)^{-n}}$$

where r is the interest rate, p is the principal, and n is the loan term. We used estimated costs of EdgeTech 5112 release systems ($4000/unit) and deck boxes/transducers ($8250/vessel) from CLF (2023). We assumed that fishing vessels fishing ≥15 traps/trawl on average would require and therefore purchase two releases per trawl, and those fishing <15 traps/trawl would require/purchase one release per trawl.

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[24] Trap transfers between permits were not considered in this analysis.
[25] CLF (2023).
[26] Moody's Seasoned BAA Corporate Bond Yield: https://fred.stlouisfed.org/series/BAA
[27] CLF (2023).

3. Model results

In order to demonstrate our model's capacity to estimate on-demand fishing gear throughput and the costs associated with switching to on-demand gear across fishery demographics, we developed a limited set of scenarios with parameters simulating the acquisition of on-demand gear to outfit all trawls fished during the baseline time series. These simulations were designed to be reflective of a complete transition to using the EdgeTech 5112 system in all Massachusetts lobster fisheries. In other words, the model was used to simulate the net industry revenue of Massachusetts state and federal waters lobster fisheries if EdgeTech on-demand gear were used on all fishing gear rather than static line gear, all else (the density of fishing gear placement, gear conflict, etc.) being equal.

The estimated gear throughput rates as a function of trawl length are given in Table 8 for static line and on-demand gear. Gear throughput rates are lower for shorter trawls due to the relatively greater fixed time costs associated with hauling trawls. On-demand gear throughput rates are greater than static line gear due to the additional fixed time costs associated with calling and locating the gear (not required for static line gear) and greater amount of time spent recoiling/repacking the gear (configuring/preparing on-demand or static line gear for deployment). The model estimates that the average per-trap throughput rate (the time required to haul, sort catch, and redeploy gear) across the Massachusetts lobster fishing fleet would increase by 1.82 minutes under the on-demand gear scenario.

Table 8. Estimated gear throughout rates as a function of average annual trawl length for static line (yellow) and on-demand (purple) gear.

Traps per trawl	n	Static line gear per-trap throughput rate (min)	On-demand gear per-trap throughput rate (min)
(0,5]	729	6.28	11.28
(5,10]	848	1.86	2.69
(10,15]	359	1.56	2.10
(15,20]	539	1.41	1.82
(20,Inf]	156	1.23	1.47

We used the gear throughput model to estimate average annual costs and revenue during the baseline time series for each Massachusetts fishing vessel under the on-demand gear economic and operational scenarios, organized by model vessel categories including annual average traps per trawl (Table 9), vessel length (Table 10), and management area (Table 11).[28]

[28] Because some vessels reported landings revenue without reporting costs in their supplemental reports, annual net revenues do not necessarily equal revenue less cost.

The model estimated negative average annual net revenue values for all vessel categories when on-demand gear costs are assumed via the annual loan payment; annual net revenue values decrease less significantly if gear acquisition costs are reduced to zero.

Table 9. Average annual costs and revenue, annual net revenue for Massachusetts lobster fishing vessels using static line gear (yellow), and simulated annual credits, costs, revenue, and net revenue for the vessels under the on-demand gear use scenario (purple), by average annual traps per trawl. All financial values are given in 2019 USD.

Traps per trawl	n	Annual costs	Annual revenue	Annual net revenue, static line	Annual bait cost credit ODG	Annuity trap sale credit ODG	Annual avoided trap loss credit ODG	Annual loan payment for ODG	Annual revenue ODG	Annual net revenue ODG	Annual net revenue ODG, 100% subsidy
(0,5]	729	20,340	24,851	4,684	1,118	673	1,185	51,931	14,124	-55,017	-3,086
(5,10]	848	57,703	69,756	11,943	3,070	1,151	4,638	18,272	48,341	-18,832	-560
(10,15]	359	115,102	153,218	35,885	4,960	1,567	7,587	27,969	113,740	-16,791	11,178
(15,20]	539	162,605	194,257	31,177	5,645	1,678	9,624	26,224	151,043	-21,049	5,175
(20,Inf]	156	374,842	392,267	25,484	7,109	2,442	21,859	22,052	336,334	-22,698	-646

Table 10. Average annual costs and revenue, annual net revenue for Massachusetts lobster fishing vessels using static line gear (yellow), and simulated annual credits, costs, revenue, and net revenue for the vessels under the on-demand gear use scenario (purple), by vessel length. All financial values are given in 2019 USD.

Vessel length (ft)	n	Annual costs	Annual revenue	Annual net revenue, static line	Annual bait cost credit ODG	Annuity trap sale credit ODG	Annual avoided trap loss credit ODG	Annual loan payment for ODG	Annual revenue ODG	Annual net revenue ODG	Annual net revenue ODG, 100% subsidy
(0,30]	768	19,333	20,421	1,063	1,131	549	1,428	31,487	12,871	-34,776	-3,289
(30,35]	707	61,013	75,707	14,834	3,063	1,202	4,699	32,383	52,893	-31,425	958
(35,40]	567	103,531	124,456	21,476	4,228	1,449	6,913	30,205	92,344	-28,140	2,065
(40,45]	439	161,659	200,703	36,674	5,988	1,827	9,787	28,909	153,639	-21,333	7,576
(45,50]	81	217,439	249,719	38,855	6,809	1,848	11,182	24,581	193,326	-22,939	1,642
(50,161]	66	683,989	751,871	67,883	11,122	3,918	37,423	20,596	650,220	-11,902	8,694

Table 11. Average annual costs and revenue, annual net revenue for Massachusetts lobster fishing vessels using static line gear (yellow), and simulated annual credits, costs, revenue, and net revenue for the vessels under the on-demand gear use scenario (purple), by management area. All financial values are given in 2019 USD.

Area fished	n	Annual costs	Annual revenue	Annual net revenue, static line	Annual bait cost credit ODG	Annuity trap sale credit ODG	Annual avoided trap loss credit ODG	Annual loan payment for ODG	Annual revenue ODG	Annual net revenue ODG	Annual net revenue ODG, 100% subsidy
LMA1	2,141	82,058	100,212	17,341	3,556	1,189	5,470	26,288	74,324	-24,307	1,981
LMA2	219	57,384	34,787	-22,284	1,819	682	2,775	29,697	25,236	-56,854	-27,157
LMA3	72	64,5992	702,868	56,876	10,542	3,801	36,352	29,424	607,833	-16,184	13,240
OCLMA	199	75,089	127,605	54,440	2,755	1,719	5,622	80,718	88,362	-58,721	21,997

Total actual and simulated revenues and costs across Massachusetts state and federal lobster fisheries for the baseline time series are given in Table 12. The model estimated that the on-demand gear scenario being implemented during 2015-2019 would have resulted in 3.74 million fewer pounds of lobster harvested per year on average in Massachusetts (an average decline of 21.9%), resulting in an average loss of $23.61 million in landings revenue per year statewide. Under the economic scenario presented here that factored in a bait cost credit, annuity trap sale credit, avoided trap loss credit, and annuity loan payment to acquire on-demand gear, the model estimates that fleetwide annual average net revenue would have been -$25.00 million, a decline of $40.81 million.

Table 12. Summary table of average annual cost, revenue, net revenue, and harvest for Massachusetts lobster fisheries during the 2015 - 2019 baseline time series using static line gear (yellow); simulated annual credits, costs, revenue, net revenue, and harvest for the fisheries under the on-demand gear use scenario (purple). All financial values are given in 2019 USD.

Input/output	Value
Annual cost ($M)	81.91
Annual revenue ($M)	97.72
Annual net revenue ($M)	15.81
Annual lobster harvest (million lbs)	17.09
Bait cost credit ODG ($M)	3.05
Annuity trap sale credit ODG ($M)	1.08
Avoided trap loss credit ODG ($M)	5.24
Annual loan payment for ODG ($M)	26.57
Annual revenue ODG ($M)	74.11
Annual net revenue ODG ($M)	-25.00
Annual lobster harvest ODG (million lbs)	13.35

The proportion of Massachusetts fishing vessels that reported operating at a profit or a loss during the baseline time series compared against simulated values from the model are given in Table 13. A more detailed breakdown of the attributes of fishing vessels that the model determined would operate profitably or at a loss under the on-demand gear scenario is given in Table 14. In general, the vessels that were predicted to be capable of operating profitably while switching to on-demand gear were the higher performing vessels with greater catch per trap haul. Vessels operating in the Outer Cape Lobster Management Area (OCLMA) that fished longer trawls were more likely to be able to operate profitably while switching to on-demand gear than any other segment of the lobster fishery.

Table 13. Proportion of fishing vessels operating at a loss and profitably on average over the 2015 - 2019 baseline time series, by simulated gear type.

Gear used	Loss (%)	Profitable (%)
Static line	42.2	57.8
On-demand	79.8	20.2

Table 14. Descriptive operational statistics for Massachusetts fishing vessels under the on-demand gear scenario, by average annual trawl length and profitability status. All financial values are given in 2019 USD.

Traps per trawl	Profitable?	n	Annual trips	Annual lobster harvest (lbs)	Annual crab harvest (lbs)	Annual traps hauled	Lobster per trap (lbs)	LMA 1 (%)	LMA 2 (%)	LMA 3 (%)	OCLMA (%)	Annual net revenue using static line gear
(0,5]	Loss	706	32	4679	175	3,394	1.38	71	14	0	14	4183
(0,5]	Profitable	5	52	16,847	0	10,806	1.56	100	0	0	0	66,341
(5,10]	Loss	683	58	9.975	130	10,643	0.94	93	5	0	2	-3,375
(5,10]	Profitable	146	86	29,668	387	20,527	1.45	97	1	0	2	83,963
(10,15]	Loss	232	68	19,128	520	16,308	1.17	77	16	0	6	-10,277
(10,15]	Profitable	117	108	49,025	978	28,027	1.75	79	6	0	15	127,420
(15,20]	Loss	325	77	26,398	2172	20,111	1.31	94	5	1	1	-35,622
(15,20]	Profitable	199	96	54,191	1403	28,687	1.89	84	0	0	16	140,917
(20,Inf]	Loss	97	45	28,543	150,180	21,310	1.34	42	13	43	1	-89,416
(20,Inf]	Profitable	50	54	80,282	271,917	35,074	2.29	42	2	52	4	251,113

4. Discussion

This framework provides, for the first time, a general quantitative estimate of the costs and revenue impacts of operating a particular type of on-demand gear. Prior studies have provided estimates of the costs of acquiring on-demand gear at current prices and, potentially, future prices if economies of scale are achieved.[29,30] However, until now the general understanding of the financial impacts of switching to on-demand gear was limited to acquisition costs.

The financial impacts of reduced gear throughput efficiency was estimated to be similar in size as to the cost of acquiring the gear. While it could be assumed that the on-demand gear use scenario we chose here represents the high end of potential economic impact to fishing operations, additional operational issues that are unknown or poorly characterized could increase costs further. Alternatively, proportionally reduced levels of on-demand gear use across vessel size classes, management areas, or during periods of low entanglement risk could reduce these operational costs considerably.

The model framework we present here is a starting point from which the operational costs of using additional types of on-demand gear in different fishing areas by different classes of fishing vessel can be determined, all under a variety of economic and operational conditions. The model described above is effectively a hindcast, useful for estimating the costs of operating on-demand gear during some predefined period in the past. Further scenario development and the incorporation of additional economic and operational data into our model framework should provide greater clarity as on-demand gear testing programs advance.

Boundaries of this work & future applications

A number of factors limited the application of our model solely to the scenario presented here. On-demand gear testing program data were available for only one model of on-demand fishing gear for the development of this report, and only one lobster fishing vessel had generated sufficient testing data while using a through-hull transducer to transmit acoustic signals to the gear (as opposed to a hand-operated transducer, which requires stopping the vessel and adds significant amounts of time to the gear hauling process). Significant increases in funding for on-demand gear testing programs managed by federal and state agencies, academic institutions, and private parties are likely to result in additional information and data that could be used to parameterize our model for additional gear types. A standardized on-demand gear testing and data gathering framework across programs that generates timing information for all parts of a trawl haul would provide complete datasets allowing for the comparison of operating efficiencies and costs across gear types.

It should be noted that our model analyzed fishing operations associated specifically with the use of lobster pots on vessels permitted by Massachusetts and the National Marine Fisheries

[29] CLF (2023).
[30] Alkire (2022).

Service to harvest lobsters and Jonah crabs. Our results include revenues from lobster, Jonah crabs, and black sea bass landings (the three most valuable species caught in these fisheries), but do not include landings revenue from any other targeted or incidentally harvested species.

The economic conditions in which Massachusetts lobster fisheries and other fixed gear fisheries in the region will operate in the future are highly fluid, resulting in a great deal of economic and regulatory uncertainty. These conditions as they exist today are already poorly characterized in the literature, and only continued/increased participation in NOAA survey efforts to determine costs incurred by lobster fishing vessel operators or entirely new socioeconomic survey efforts can address these data deficiencies.

While it is unclear how lobster fishermen might pay for on-demand gear in the future, the development of programs to subsidize gear purchases could clarify the economic scenarios used to parameterize the model. Additionally, climate change impacts to lobster abundance, distribution, and phenology could significantly alter the economic conditions of the fishery, requiring the development of more sophisticated socioeconomic and ecological parameters in future modeling efforts.

It is unclear how operational factors impacting the use of on-demand gear including gear density, gear conflict between fixed/fixed and fixed/mobile gear operators, regulatory considerations like trap limits or area closures, realized rates of gear loss from storms and other natural events, crew training/competency, virtual gear marking efficiency, and acoustic signaling distance might impact gear throughput rates, change catch rates, or add additional operating costs. Operational conditions including season, sea state, and depth are likely to impact gear throughput, and these variables should be captured in any on-demand gear testing program in order to better understand how they impact revenue and fishery productivity using the gear. Production economies of scale could reduce the costs of acquiring on-demand gear, and subsidies could eliminate them entirely. Lobster harvested with on-demand gear could receive a price premium in limited local markets, possibly offsetting some of the operational cost impacts associated with using the gear. However, each of these operational, economic, and regulatory factors can be integrated into our modeling framework through simulation approaches or with sufficient data being made available from gear testing programs.

In addition to the broadening of modeling scenarios to include additional and broader technical and operational variables, this work will improve significantly from the incorporation of more sophisticated spatial information, chiefly derived from GPS trackers installed on lobster fishing vessels. Starting this year the Atlantic States Marine Fisheries Commission has initiated a program to require the collection of spatial data on all federally permitted lobster fishing vessels using GPS tracking devices at around a 1 minute ping rate. The incorporation of these spatial data would allow us to significantly refine the operational elements of the model that rely on spatial data to characterize gear throughput. It is possible that spatial data will also enable the determination of otherwise challenging spatial information, including gear density across spatial domains, changes in fishing operations and behavior based on weather conditions or gear type, and other complex factors that might have significant aggregate impacts to costs and revenues.

Developing an advanced simulation approach

Anticipating several of the issues raised above, we began the process of developing a simulation model approach to estimate future operational costs of on-demand gear use in lobster fisheries. This approach is capable of simulating catch variability across statistical management areas at a finer scale with variable time steps. Under this approach, the productivity of the Massachusetts lobster fishery is determined by a suite of spatiotemporally heterogeneous gear configurations, haul frequencies, fishing effort, and catch rates. Due to data availability and the seasonality of the Massachusetts lobster fishery, we evaluate the spatiotemporal variability of lobster fishing activity using a monthly time step. The total monthly catch of an individual lobster fishing vessel, or permittee, is determined by the number of traps fished (Traps), frequency at which gear is hauled (f_{haul}), and the rate at which those traps capture lobster (CPUE):

$$Catch_{m,SA,i} = CPUE_{m,SA,i} * f_{haul_{m,SA,i}} * Traps_{m,SA,i}$$

where m is month, SA is statistical area, and i is each individual lobster vessel. Catch per unit effort (CPUE) is calculated as the total weight of lobsters landed per trap fished while traps hauled and haul frequency were self-assigned from VTR. Traps hauled and haul frequency can further be described based on vessel-specific operational logistics, rates of gear turnover, and trap distribution:

$$Traps_{m,SA,i} \sim \frac{Traps_{m,SA,i}}{Trawl_{m,SA,i}} * \frac{Trawl_{m,SA,i}}{Trip_{m,SA,i}}$$

$$f_{haul_{m,SA,i}} \sim \frac{Trip_{m,SA,i}}{N_{vessel_{m,SA,i}}} * N_{vessel_{m,SA,i}}$$

Using these relationships, we use a new function to describe the total monthly production of the all lobster fishing vessels operating in each statistical area:

$$Catch_{m,SA} = CPUE_{\bar{x}_{m,SA}} * \frac{Traps_{\bar{x}_{m,SA}}}{Trawl_{\bar{x}_{m,SA}}} * \frac{Trawl_{\bar{x}_{m,SA}}}{Trip_{\bar{x}_{m,SA}}} * \frac{Trip_{\bar{x}_{m,SA}}}{N_{vessels_{m,SA}}} * N_{vessels_{m,SA}}$$

This equation can be downscaled to estimate production at the individual trip level and can be modified based on gear configuration and trip frequency to evaluate how operational changes and dynamic fisheries management may modify catch rates.

The model inputs are calculated per month and statistical area to summarize the seasonality and spatial heterogeneity of the Massachusetts lobster fishery, allowing us to seasonally adjust operational variables like fishing activity, catch, and others (Figure 5(A)). When coupled with economic variables, the model can provide net revenue estimates as with the model results described in this report, though at finer spatial and temporal scales including monthly time steps (Figure 5(B)). An interpolation procedure can be used to estimate operational variables when there are insufficient data to maintain the ‘rule of three’ in reporting confidential fishing information. The average and standard deviation of CPUE, traps per trawl, trawls per trip, and trip frequency are calculated, and sinusoidal curves are fit to each time series per statistical area (SA) using a least squares approach in the form of:

$$P = \alpha * \sin sin\,(\omega * t + \theta) + \beta$$

where P is the predicted value, α is the amplitude, ω is the period, t is the time in months, θ is the phase shift, and β is the vertical shift.

The model can also incorporate a Monte-Carlo simulation approach to recreate annual landings patterns over the 25 fished statistical areas along coastal Southern New England. Monthly (m) catch rates were simulated one thousand times per statistical area (SA) with the equation:

$$Catch_{m,SA} = CPUE_{\bar{x}_{m,SA}} * \frac{Traps_{\bar{x}_{m,SA}}}{Trawl_{\bar{x}_{m,SA}}} * \frac{Trawl_{\bar{x}_{m,SA}}}{Trip_{\bar{x}_{m,SA}}} * \frac{Trip_{\bar{x}_{m,SA}}}{N_{fishers_{m,SA}}} * N_{fishers_{m,SA}}$$

using average parameter values and a randomly selected standard deviation that varied per model run. Monthly simulation outputs are summed to estimate annual landings and the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of the simulated catch can be calculated for each statistical area.

We anticipate that this simulation approach will greatly enhance the capacity to evaluate the performance of on-demand gear in terms of operational impacts to revenue. This spatial modeling approach could provide significant additional value in the effort to estimate and fully characterize the economic impacts of on-demand fishing gear by incorporating additional elements of high management value including, for example, vessel speed limits (moderating the frequency of trawl hauls during trips), or other spatial management factors including static or dynamic closures that could impact the ability to place gear in a certain location.

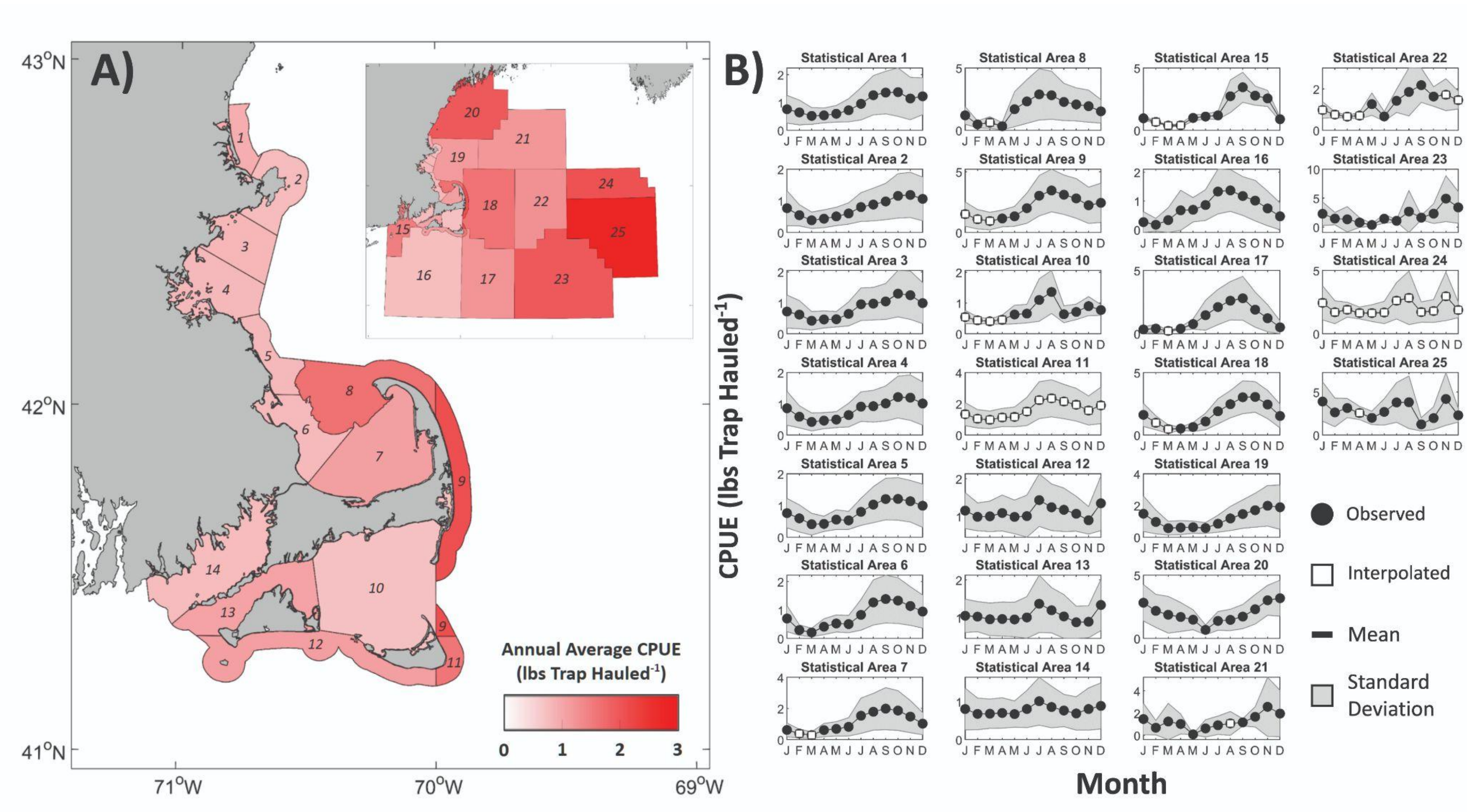

Figure 5.A. Sum of simulated catch per unit effort (CPUE) across Massachusetts lobster statistical reporting areas. B. Simulated CPUE ± standard deviation by month across statistical reporting areas, with interpolated values shown in white.

Appendix 1

Massachusetts trip reporting forms referenced in the report

2021 FIXED GEAR SUPPLEMENTAL REPORT

COMMONWEALTH OF MASSACHUSETTS
DIVISION OF MARINE FISHERIES, ANNISQUAM RIVER MARINE FISHERIES STATION
30 EMERSON AVE, GLOUCESTER, MA 01930

PLEASE PRINT IN INK ONLY
If you have any questions, please contact the Statistics Project at (978) 282-0308.

MA COMMERCIAL PERMIT ID: ___________________________

NAME (as it appears on permit application): ____
(Last) (First) (MI)

ADDRESS: ____
(No.) (Street) (City/Town) (Zip Code)

PLEASE COMPLETE THIS SUPPLEMENTAL REPORT AND SUBMIT WITH YOUR PERMIT RENEWAL APPLICATION. THIS SHOULD BE COMPLETED BY ALL 2021 MA COMMERCIAL PERMIT HOLDERS HOLDING *FIXED GEAR PERMITS OR ENDORSEMENTS* WHOSE TRIP-LEVEL CATCH AND EFFORT INFO WAS REPORTED TO NMFS. <u>BE SURE TO SIGN & DATE THIS REPORT.</u>

Fixed gear permits and endorsements include: Lobster (coastal, offshore, seasonal), Gillnet, Fish Pot (conch, scup, sea bass).
Fixed gear types: Lobster traps, conch pots, fish pots, and gillnets.

I. **PRIMARY VESSEL:** List the vessel associated to this permit in 2021. If vessel changed in 2021, list the latest vessel.

Boat Name	Reg/Doc Number	Length (ft)	Home Port	Value of Vessel ($)

II. If you <u>**DID NOT FISH** fixed gear</u> in 2021, please check the box, and then skip items III and IV. ⟶ ☐

III. **MAXIMUM BUOY LINES and AVGERAGE TRAPS PER TRAWL**: List the maximum number of buoy lines in the water at any one time during each month and average traps per trawl for that month for each gear type fished in 2021.
-- *Max Buoy Line example*: If you set 80 10-trap trawls with 2 buoy lines per trawl, the max buoy lines for that month would be 160.
-- *Average Traps per Trawl examples*: Enter 1 if you haul all singles. Enter 10 if you have an average of 10 traps per trawl, etc.

GEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Lobster Pots	Max Buoy-lines												
	Avg Traps/ Trawl												
Sea Bass Pots	Max Buoy-lines												
	Avg Traps/ Trawl												
Scup Pots	Max Buoy-lines												
	Avg Traps/ Trawl												
Conch Pots	Max Buoy-lines												
	Avg Traps/ Trawl												
Gillnets	Max Buoy-lines												

IV. **LOBSTER FISHERMEN <u>ONLY</u>:** Please fill out items A - D below for the calendar year 2021.

A. **BAIT**: Total amount (in dollars) spent on bait: |$ _ _ _ _ _|

B. **TRAP VALUE**: Estimate the average value of <u>**ONE**</u> ***lobster*** trap including rope and buoy: |$ _ _ _ _ _|

C. **EMPLOYMENT**: Counting yourself, what was the maximum number of people employed on your vessel at any one time? -- *For example, if you employed one sternman, you would answer two (2).* |_ _ _ _ _ _|

D. **FUEL**: Total gallons of fuel used for the year while fishing: Gasoline: |_ _ _ _ _ _| Diesel: |_ _ _ _ _ _|

SIGNATURE: ____ **Date**: ______________________

Knowingly falsifying any information contained within this report constitutes the act of perjury and may result in a fine, imprisonment or loss of license (MGL, Chapter 130, Sections 2, 21, 33).

PLEASE COMPLETE AND SUBMIT WITH PERMIT RENEWAL

MA Division of Marine Fisheries - Monthly Trip-Level Commercial Report

Name: John Doe **Phone #:** 508-123-4567 **Vessel Name:** FV Big Bug

Permit ID #: 123456 **Email:** FVBigBug@Lobman.com **Vessel Reg. or Doc. #:** MS 9999 AA

Port or Town Landed #1: Gloucester **Fishing from shore (please answer Yes or No)?** *No*

Port or Town Landed #2: Salem **Report Month & Year:** July, 2020

Port: Port catch was landed
Stat Area*: 1 - 25 (see maps)
MNG Area*: LMA (1-3, OC) or DSGA (BB4, N7, etc.)
Gear code*: Code of gear type used
Depth Fished: Average bottom depth in fathoms, 1 fathom=6 feet
Fishing Time: Soak time - days for fixed gear; hours for mobile/hand gear
Gear Hauled: # Traps/nets/hooks hauled in stat area or DSGA

FIXED GEAR ONLY, gear & b-lines fields from start of trip
Strings Hauled: Number of strings/trawls hauled in stat area
Gear in area: # Traps/nets in stat area
B-lines in area: # Buoylines in stat area
Total Gear: Total # traps/nets in the water, regardless of stat area
Total B-lines: Total # buoylines in water, regardless of stat area
Ten Min. Square(s)*: 10 minute square(s) fished, fed permit only

Catch Source: Record trip as standard (S), carred (C), withdrawn from car (W), or aquaculture (A)
Disp Code*: Fate of landed catch
Tog CT: Count of individual tautog landed

Dealer Sold To: Company name and permit number of dealer catch was sold, please be specific.

*See reverse for codes and notes

Start-End Date	Start - End Time	Port # 1 or 2	Gear Code*	Stat Area*	MNG Area*	Depth Fished	Fishing Time	Gear Hauled	Strings Hauled	Gear in Area	B-lines in Area	Total Gear	Total B-lines	Ten Min. Square(s)*	Catch Source	Disp Code*	Species Code*	Quantity*	Unit*	Dealer Sold To (Name & Permit #)	Tog CT
7/12-12	*0800-1300*	*1*	*760*		*CCB4*		*5 H*								*A*	*001*	*OYS*	*2100*	*CT*	*John Doe Dealer #9999*	
7/13-13	*0600-1500*	*2*	*160*	*19*	*1*	*35*	*5 D*	*250*	*25*	*350*	*70*	*800*	*160*	*XX, YY*	*S*	*001*	*LOB*	*300*	*LB*	*Everyday Lobster #0000*	
7/4-4	0500-1600	1	160	2	1	25	3 D	150	15	450	90	600	120		S	001	LOB	70	LB	Gloustah Lobstah #1234	
"	"	"	"	2	"	"	"	"	"	"	"	"	"		C		"	80	"		
"	"	"	"	3	"	"	"	80	8	150	30	"	"		S	001	"	60	"	Gloustah Lobstah #1234	
7/5-5	0700-1100	1	620		N7		4 H								S	"	CLSO	120	"	C.A. Shellfish Co. #1111	
7/8-8	0500-1600	1	160	2	1	15	8 D	200	20	450	90	600	120		C		LOB	127	"		
"	"	1	"	3	"	"	8 D	50	5	150	30	"	"		"		"	58	"		
7/10-10	0500-1600	1	160	2	1	15	6 D	200	20	450	90	600	120		S	001	"	101	"	Gloustah Lobstah #1234	
"	"	1	"	3	"	"	6 D	50	5	150	30	"	"		"	"	"	72	"	Gloustah Lobstah #1234	
7/10															W	"	"	100	"	Gloustah Lobstah #1234	
7/12-12	0500-1100	2	300	3		5	6 H								S	"	STB	150	"	Salem Seafood #2222	
7/14-14	"	"	"	"		"	7 H								"	"	"	39	"	Salem Seafood #2222	
7/16-16	1200-1600	1	620		N7		4 H								"	"	CLSO	145	"	C.A, Shellfish Co. #1111	
7/17-17	0500-1600	1	160	2	1	15	7 D	220	22	450	90	600	120		"	"	LOB	273	"	Gloustah Lobstah #1234	
"	"	"	"	"	"	"	"	"	"	"	"	"	"		"	031	CRJ	10	CT		
7/18															W	001	LOB	85	"	Doe Retail Boat #9999	

Did Not Fish (check here): ☐ **Month(s) and Year:** ________ **Signature:** ________ **Date:** ________

Knowingly falsifying any information contained within this report constitutes the act of perjury and may result in a fine, imprisonment or loss of license (MGL, Chapter 130, Sections 2, 21, 33).

Submit by the 15th of following month by **FAX: (617-727-3337), email (dmf.stats@mass.gov)**, or by **mail: MA DMF, 30 Emerson Ave, Gloucester, MA 01930**

Please email or call the Statistics Project at 978-282-0308 x101 with any questions.

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