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Proceedings of the 2022 Virtual Lobster Economic Modeling Workshops: March 23, March 29, April 8

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts
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Proceedings of the 2022 Virtual Lobster Economic Modeling Workshops: March 23, March 29, April 8

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Editorial Notes

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EXECUTIVE SUMMARY

During a series of 3 workshops, participants discussed challenges and opportunities for modeling the economics of the Gulf of Maine American lobster (*Homerus americanus*) fishery. The overall goal of the workshops was to inform participants about prior efforts to model the lobster fishery's economic dynamics and identify elements and processes to consider for future modeling efforts. Attendees included staff from the Northeast Fisheries Science Center (NEFSC), Fisheries and Oceans Canada (DFO), the University of Maine, Sea Grant, the Maine Lobster Dealers Association, the Maine Center for Coastal Studies, the Maine Department of Marine Resources, the Gulf of Maine Resource Institute, the Maine Lobstermen's Association, the Island Institute, and the Atlantic States Marine Fisheries Commission (ASMFC).

The first workshop included a presentation on the previous simulation frameworks and models that characterize the harvest sector of the fishery. The session's discussion focused on identifying major drivers of the fishery's performance, key inputs that determine vessel landings and expenses, and sources of heterogeneity across lobster fishers. The second session focused on previous modeling work to characterize the fishery's market sector and challenges to consider when developing models that relate prices and sources of lobster demand. The last session included a presentation of a conceptual framework for a simulation model based on the literature review and feedback from the previous 2 sessions. The discussion in the last session focused on identifying a basic structure for an operating model, data availability, and data needs.

We anticipate proceedings from these workshops will inform those interested in understanding the economics of the lobster fishery, including those building models to characterize the fishery dynamics and to support management. The following list provides a summary of key elements to consider for building economic models of the fishery as found throughout the workshop discussions:

- A basic simulation model contains 3 standalone modules: biological, harvest, and market. Figure 1 depicts the simulation model structure and relationship across the individual modules.
- An extension to a basic framework includes vessel entry-exit and fishing behavior modules that consider latent effort dynamics, technical capacity changes, and the spatial dynamics of effort allocation.
- The standalone modules must produce outputs that enter as inputs into the other modules to create a feedback loop simulation. For instance, the biological model produces available biomass as output, which enters the harvest model as inputs (Figure 1).
- The biological module accounts for the population dynamics of lobster.
- The harvest module characterizes the landing patterns of individual vessels. A basic harvest module uses available biomass, vessel characteristics, indicators for effort (such as the number of traps, trips, and traps hauled), labor, bait, fuel, and time indicators as inputs. The module produces vessel-level catch as output.
- An extension to the basic harvest model will consider the role of trap density, technical capacity, fishing location choice, bait quality, captain's experience, and other sources of heterogeneity across vessels.
- The market module characterizes the landing and price relations. A basic model will take domestic landings, imports from Canada, personal income, inventories,

and variables that account for seasonality to generate price as an output. However, the workshop's discussion suggests that lobster price is highly uncertain and that many other factors influence the price. More work needs to be done to identify modeling approaches for lobster prices.

- An extension to the basic market module will consider product differentiation (such as shell quality and size) and the dynamics of international markets (such as tariffs, global prices, international demand, and emerging markets). The module will also need to consider the highly uncertain nature of lobster prices and the complex dynamics in the supply chain of lobster.

At the end of the workshops, the group agreed that there is a need to build an economic operating model compatible with existing lobster population dynamic models. Each operating model component can be built as a standalone module but must be compatible with other modules within the simulation (i.e., compatibility across programming languages and temporal and spatial scales). NOAA has proposed a conceptual framework for the economic operating model and fostering collaboration for others to build individual modules. NOAA has taken the lead in initiating building an economic simulation model, but the end-user of the model is the ASMFC. The economic operating model will support a Management Strategy Evaluation (MSE), a process that ASMFC expects to engage in 2025. Finally, the group agreed to identify venues to continue the discussion initiated during the workshops and strengthen collaborations to build an economic model for the lobster fishery.

1. INTRODUCTION

1.1 Background

Over the past decade, landings in the American lobster (*Homerus americanus*) fishery have fluctuated without trend around record high catches with around $725 million worth of lobster in 2021, making the fishery one of the most valuable in the United States. However, spatial shifts in lobster distribution and potentially declining recruitment patterns make the fishery's future uncertain, with some studies projecting a steep decline in the coming years (Oppenheim et al. 2019). Thus, there is a pressing need for managers and stakeholders to have appropriate data and models available to them ahead of any downturns in the Gulf of Maine fishery to understand how the fishery can be made more resilient. Much of the quantitative work needed to model and project the dynamics of the lobster population already exist or are under active development, but economic models tied to fishery dynamics are largely lacking.

A team of Northeast Fisheries Science Center (NEFSC) researchers from the Social Sciences and the Population Dynamics Branches identified the need. They started conducting research to support the development of an economic operating model compatible with existing lobster population models. The team includes Drs. Kathryn Bisack (Social Sciences Branch), Burton Shank (Population Dynamics Branch), Eric Thunberg (Office of Science and Technology – Economic and Social Analysis Division), and Smit Vasquez Caballero (Social Sciences Branch contractor). The team completed a literature review on simulation and economic models of the lobster fishery. Plans include the development of a conceptual simulation model based on findings from the literature review, along with input from experts in the lobster fishery. The team invited researchers, stakeholders, and interested parties to a series of workshops to identify key economic dynamics affecting the performance of the lobster fishery as well as available data and data gaps to build a simulation model (Appendix A1). The team anticipates that the workshop will provide a venue to foster collaboration among participants to initiate the estimation of independent economic models that will serve as components of a simulation tool for the lobster fishery.

1.2 Workshop goals and objectives

The primary goals of the series of workshops were to:

- inform interested parties about the current effort to develop a conceptual framework for an economic operating model for the lobster fishery;
- share literature findings on the economic models that characterize the American lobster fishery's harvest and the market sector and to request feedback to identify key economic dynamics of the fishery;
- identify a basic structure of an economic operating model, potential extensions, available data, and data needs; and,
- identify collaborations and synergies for building an economic operating model in support of a simulation model for the fishery.

1.3 Meeting organization

We carried out the series of workshops virtually on March 23, March 29, and April 8, 2022 (Appendix A2). Each session was 2 hours long and had the same format: an introduction, a presentation, and an open discussion. Burton Shank moderated the sessions, and Alicia Miller served as a note taker. During the introductions, a team member presented an overview and scope of the project. Afterward, Smit Vasquez Caballero presented findings from the literature review. At the end of each presentation, the team posed a few questions to the participants to motivate the open discussion. All participants had the opportunity to provide their answers on a virtual whiteboard. The moderator used participants' responses to open a dialogue to provide perspectives, comments, and questions. Each discussion aimed to identify key elements and processes not included in the literature.

In the first workshop, the presentation included an overview of past simulation models for the American lobster fishery and models that characterize the harvest sector. The session's discussion aimed to identify fundamental dynamics affecting the fishery's performance and those that describe the harvesting sector. The second session included a presentation on models that characterize the market sector of the fishery. The session's discussion aimed to identify critical elements that affect the price and demand for lobster and the uncertainties associated with the market. The final session described the structure of a potential simulation model, building on findings from the literature review and feedback from the first 2 sessions. The last session's discussion aimed to identify the basic structure of a model, the data available for building such a model, and the potential for collaboration among participants to develop each component of the model.

2. PROJECT OVERVIEW AND DYNAMICS OF THE LOBSTER HARVESTING SECTOR (WORKSHOP I)

2.1 Opening

Kathryn Bisack, economist in the Social Science Branch, opened the meeting by reviewing the session agenda and provided the workshop's ground rules. The opening continued with background information and an overview of the project. There are challenges in the American lobster fishery that call for developing a decision tool to support management. Some of the challenges are a shift in the distribution of lobster stocks northward and into deeper waters, the decline in recruitment patterns, the overlap between the spatial distribution of lobster and the North Atlantic Right Whale (NARW), and interactions with the offshore wind development and aquaculture sectors.

The project goal is to initiate the development of an economic operating model, compatible with existing biological models, to support a Management Strategy Evaluation (MSE) process for the American lobster when required. The economic operating model should characterize the key features of the American lobster fishery, including the harvest and market sectors at relevant spatial and temporal scales. Kathryn emphasized that the economic operating model is not to predict or forecast the fishery but rather to characterize the observed dynamics of the fishery and support an MSE when developed. The team approach is to go from a simple to complex model, first by conceptualizing a simple economic operating model that can be estimated with available data, then by identifying data gaps and data collection needs to build a more complex operational model that integrates the fishery's spatial, biological, and economic dynamics.

The project is broken down into 5 tasks. The first task is to review the literature to identify lobster simulation models that will inform the development of the economic operating model. The second task is to review bioeconomic models that characterize the dynamics of the lobster industry. The third task is to create a set of recommendations for implementing an economic operating model. Part of this task is to share findings and preliminary ideas with American lobster scientists, managers, and stakeholders to solicit feedback on model development. The fourth task is to identify available economic and biological data and gaps where further data needs to be collected. The project has a duration of 1 year; if time permits, the team will begin the final task, with the empirical estimation of the parameters modules of the recommended economic model.

The opening concluded with a brief description of the policy instruments available for fisheries management in general and those available for the American lobster fishery. Policy instruments or management measures include regulatory and non-regulatory instruments. The former takes a command-and-control form and directs fishers' behavior, including instruments such as technology standards, gear restrictions, and output restrictions. The latter instruments incentivize fishers to voluntarily achieve policy management goals (e.g., tradable quotas and user rights). The list of management tools used in the lobster fishery fall within the first category, regulatory instruments; it includes gauge size, trap limits, seasonal closures, limited entry, hauling hours, and gear restriction. Appendix A3 contains slides accompanying the opening presentation; policy instruments available to managers are depicted in slides 7-8 in Appendix A3.

2.2 Previous lobster simulation models

Smit Vasquez Caballero presented the characteristics of previous lobster simulation models; Appendix A4 shows slides used in the presentation. The presentation started by providing a brief definition of the simulation (Appendix A5, slide 2). A simulation seeks to characterize a system using mathematical relationships, coding, and computer programming to evaluate the performance of the system over time. Due to the inherent complexity of coupled natural and human systems, a simulation cannot capture all the elements and processes of a system. Instead, it captures only patterns observed from available data and relies on assumptions about unobserved processes.

Edward Richardson and John Gates developed a simulation for the American lobster fishery in the 1980s. The simulation was motivated by concerns about the risk of recruitment collapse and the overcapitalization of the fishery. It evaluated 2 available management tools to address such concerns: an increase in minimum legal size and a reduction in aggregated fishing mortalities (Richardson and Gates 1986). John Gates and Jon Sutinen developed an updated version of the simulation, called SIMLOB, in the mid-1990s in a collaborative effort between the University of Maine and the University of Rhode Island. SIMLOB had greater scope than the original simulation developed by Richardson and Gates. It aimed to evaluate a broader range of policy options and changes in fleet dynamics; unfortunately, documentation describing the simulation's structure and elements is unavailable.

Richardson and Gates's simulation contains linked biological, harvest, and market modules (Appendix A4, slide 4). The authors refer to the harvest module as an inshore and offshore fleet dynamics model and to the market module as an economic model. For a range of fishing mortalities and minimum sizes, the biological model calculates available biomass (total yield), size, and location (i.e., inshore and offshore) yield compositions (Appendix A4, slide 5). The relation between the inputs and the output takes the form of a yield function that accounts for biological parameters such as growth rate, recruitment, and natural mortality. The harvest module models the harvest sector by relating economic harvesting costs and fishing mortality to fishing effort (Appendix A4, slide 6). Economic cost functions link directly to harvest production functions, which characterize a vessel's ability to transform inputs (i.e., fishing effort) into outputs (i.e., landed catch, weight).The relationship between inputs and outputs comes together in a series of vessel class-specific and state-specific cost functions. The market module determines price. Aggregate catch with average weights for a range of size classes are inputs used to estimate ex-vessel and wholesale prices (Appendix A4, slide 7). The relationship between inputs and outputs in the market module, in economic terms, is an inverse demand function.

The simulation relies on a series of interdependent relationships across modules (Appendix A4, slide 8). The outputs produced in the biological module—yield and size composition—are entered as input in the market module to generate ex-vessel and wholesale prices as outputs. The harvesting sector and the biological module rely on fishing mortality as input to produce 2 outputs. The harvesting and market module outputs are combined to compute vessel-level profits, consumer surplus, and producer surplus. The simulation structure allows the authors to evaluate the impact of the 2 management alternatives on the changes in the fleet's profitability and the benefits to both consumers and producers.

The functions within each module were estimated using data from different sources (Appendix A4, slide 9). The values of the parameters of yield function in the biological module came from the literature. The authors used vessel cost survey data to estimate the cost function in the harvest sector model. To estimate the inverse demand function in the market model, the authors used ex-vessel price data from the National Marine Fisheries Service (NMFS) and wholesale prices from the Fulton Market database.

The simulation relies on a set of assumptions in each of the modules. For instance, the yield function assumes constant recruitment and independent inshore and offshore dynamics. Cost functions assume vessels fall within 1 of 5 inshore vessel classes and 1 offshore vessel class. Total cost functions increase linearly with fishing effort and mortality. The demand functions in the market module assume that the quantity and average size of live American lobster from Canada were constant.

We use Richardson and Gates's (1986) model as a framework to develop a new conceptual simulation model of the current fishery. Further, to improve the Richardson and Gates model, the new simulation framework will need to relax the strong assumptions mentioned above and include uncertainties in the relationship between inputs and outputs of each simulation module. Smit Caballero reiterated that the series of workshops aims to explore alternative ways to characterize the harvesting and market sectors of the fishery and explore what elements are necessary to consider when building each of the simulation modules.

2.3 Discussion

The team asked 3 questions to the participants to motivate a discussion about the presentation and issues to consider when developing a new simulation model: What are the foreseen challenges and opportunities likely to drive the performance of the fishery? What sectors are necessary to characterize the dynamics of the fishery? What data constraints limit the possibility of building a simulation model for the fishery? After participants recorded their answers on a virtual whiteboard, they had the opportunity to provide their perspectives on each question.

The first question, identify foreseen challenges and opportunities likely to drive the performance of the fishery, covered a broad range of themes. Challenges and opportunities related to the abundance of lobster include environmental conditions, increased storm events, changes in spatial distribution and size structure, and intra-annual volatility due to heat waves. Challenges in the harvesting sector include a low supply of bait from the herring industry, fuel price volatility, changes in gear and area restrictions from the NARW protection rules, and area restrictions due to offshore wind development. The participants also mentioned overseas markets and fisheries certification as 2 issues likely to drive the market dynamics. Additionally, participants also state challenges arising from regulatory changes, licensing rules, demographic changes, and changes in coastal development patterns.

Participants discussed the decrease in the supply of bait in the fishery. This bait supply shock is likely to be driven by the low abundance of herring—a primary source of bait—the lack of suitable substitutes for herring, and the existence of regulation on what can be used in the waters as bait. Participants listed a few substitutes for herring, including menhaden, frozen rockfish, skates in Rhode Island, hardier baits, pig hide, and Louisiana pogies. However, none of these are perfect substitutes; the demand for herring continues to be high, but the low supply keeps driving herring prices up. Databases lack information on bait sources and therefore restrict the ability to understand factors that affect the supply of bait in the lobster fishery. Josh Stoll's lab has collected bait information from sea sampling; however, this effort relies on a small sample size of 3 trips per month.

The second discussion question asked participants to identify the elements necessary to characterize the economic dynamics of the fishery. Participants listed several elements that characterize the fishery's harvest sector, such as fishing behavior, vessel investments, entry-exit behavior, choice of fishing area and location, vessel costs, availability of crew, trips and catch per trip, and the supply curve of bait. The participants also mentioned regulatory constraints and trade dynamics between the U.S. and Canada, the U.S. and China, and the U.S. and the E.U. Participants noted that trips and catch per trip data, available through dealer data, can serve as a source of data to start modeling the economic dynamics of the fishery. When participants were asked about additional modules to consider in a simulation framework, Alexa Dayton suggested a module for the fleet's capitalization rates and technical efficiency. She also suggested adding an environmental component that impacts both the harvest and the biological modules.

The last discussion question asked participants to identify data constraints that limit the ability to build a simulation model for the fishery. Some of the constraints include changes in population dynamics limiting the ability to estimate biological parameters; low spatial and temporal resolution of both biological and economic data; lack of access to Canadian landing, inventory, wholesale, and frozen data; limited information on the spatial distribution of different classes of vessels; lack of information on vessel characteristics; and lack of bait data. During the discussion, a participant mentioned a current effort to collect economic data at Josh Stoll's lab, collecting socioeconomic data to construct community-level indicators[1].

2.4 Harvest sector models

During the second presentation of the first workshop, Smit Caballero provided an overview of models that characterize the harvest sector of the lobster fishery, which typically include 4 harvest components: catch, revenues, costs, and profits. The early literature links catch with the following inputs: vessels' characteristics—size, age, horsepower—number of traps, number of trips, and distance traveled to fishing grounds (Dow et al. 1975). Other models used daily data on inputs, such as the number of traps hauled, soak time, bait per trap, aggregated number of traps (as a proxy for congestion), legal-size biomass of lobster, and monthly indicator variables (Holland 2011). Alexa Dayton's work uses quarterly data on labor, bait, time of year of fishing activity, fuel consumed, expected fishing effort, and capital investment to model catches (Appendix A5, slide 3). Smit Caballero explained that the authors used a vessel-level production function as a tool to model the relationship between the different determinants of catch and vessel-level catch (Dayton 2018; Dayton et al. 2014). A production function serves as the vessel-level technology that takes a set of inputs to produce catch as an output (Appendix A5, slide 4). The authors did not develop the models to simulate the fishery dynamics; instead, the models allowed the authors to answer research questions related to the substitutability of inputs or test for differences in production function across different types of vessels.

Models to estimate gross revenue, net revenue, and profits are straightforward. Gross revenue is the product of catch and prices; net revenue is the difference between gross revenue and operating costs; profit is the difference between net revenue and opportunity and fixed costs (Appendix A5, slide 5). Thus, to calculate gross and net profits, one must use catch, landing prices, and different sources of costs—such as operating, fixed, and opportunity costs—as inputs. Finally, costs are the product of input quantities and input prices.

An essential component of modeling the harvest sector of the fishery is to identify the cost structure of the fishing vessels. Costs are classified into operating, fixed, and opportunity costs (Appendix A5, slide 8). Operating costs include daily expenses for fishing, such as fuel, bait, and boat repair expenses. Fixed costs include expenses not directly associated with fishing trip effort, such as expenses associated with insurance, interest payments, license fees, property taxes, and dockage fees. Finally, opportunity costs include capital and captain's labor. The former measures

[1] Josh Stoll's project is titled "Fishing in hot water: defining sentinel indicators of resilience in the American lobster fishery." The project is funded by Sea Grant and aims to collect data to find indicators of the lobster industry's health and develop social resilience indicators.

the returns that the investment capital may earn in an alternative investment venture; the latter measures the forgone earnings of captains by not participating in an alternative occupation.

Previous researchers have relied on different data sources to estimate the catch, revenue, costs, and profits (Appendix 5, slide 9). Holland (2011) uses a port sampling catch and effort survey running since 1966, collected by the Maine Department of Marine Resources, merged with a cost survey carried out by NMFS. Dayton et al. (2014) uses confidential firm-level data and survey responses from a sample of 1,007 fishers in 2011; Dayton et al.'s (2014) survey data was merged with NMFS Federal dealer-reported catch and transactions to obtain catch and price information.

The presentation ended by listing several caveats identified in the literature review (Appendix A5, slide 10). First, data availability determines the temporal dimensions (stratification) at which authors modeled catch. For example, Holland (2011) estimates a production function on daily catch, given data on a trip-by-trip basis. On the other hand, Dow et al. (1975) and Dayton (2018) aggregated catch data quarterly. Another caveat is the lack of spatial considerations in any modeling approaches. Holland (2011) and Dayton (2018) account for vessel characteristics in the production function to capture the heterogeneities across vessels on their harvesting technologies. However, more work needs to be done to stratify vessels into different classes to capture sources of heterogeneity beyond vessel attributes, such as motivation for fishing or technical capacities.

2.5 Discussion

After the harvest modeling presentation, the discussion focused on the following 3 questions: What are the determinants of fishery participation? What are the fundamental inputs that determine vessel-level landings and expenses? What are some sources of heterogeneity across lobster fishers? After participants added their responses to a virtual whiteboard, there was an open discussion for each question.

The first question sought to identify elements that drive lobster fishers' decision to fish or not in a given season, how long to fish, and how much effort to allocate during a season. Some responses referred to individual attributes of fishers including having access to other fisheries opportunities, age, and whether other people in the family fish (or fished before). Some of the responses related to regulatory constraints, such as availability of licenses, permits, and displacement by closures. Answers also referred to the availability and cost of fishing inputs, such as crew availability, supply of bait, gear, and fuel. Another set of answers included conditions in the market, such as ex-vessel price, overseas markets, high demand due to holidays, commercial reliance, and commercial engagement. A couple of participants mentioned weather and space at the dock as essential drivers of fishers deciding to fish or not. In the discussion, a couple of participants mentioned the need to understand the determinants of latent fishing effort.

The second question asked participants to list inputs that play a role in determining the level of landings and expenses at a vessel level. Several responses match inputs considered in past harvest models for the fishery, including available biomass, bait, fuel, labor, number of trips, number of traps hauled, trap density, and vessel characteristics. However, other inputs not considered previously include the captain's experience, size of business, license class, and the location and the proximity of biomass. Lastly, 1 participant also listed that an element of tradition also plays a role since some fishers always fish in the same location. Participants agreed that the number of traps, number of trips, and number of traps hauled are crucial in determining catch. Considering the trap density is also very important, as is considering technical capacity, quality of bait, and availability of bait.

The third question's goal was to identify ways to distinguish the harvest performance across different vessels (i.e., sources of heterogeneity). The responses included vessel characteristics, specifically, captains' characteristics such as age, gender, residency, access to finance, and outside opportunities. Most responses identified differences across fishers due to spatial considerations, such as state vs. federal permit, spatial constraints, differences in infrastructure and access to market, and differences in fishing dependence between the island and mainland fishers. Another source of heterogeneity is the difference in fishers' short-term and long-term goals, likely driven by regional differences in resource abundance as well as regional differences in outside opportunities, which can then drive differences across fishers' opportunity costs.

During the discussion, a participant mentioned that vessels could be classified into at least 5 categories for modeling purposes based on a combination of technical characteristics, such as engine size, engine age, number of traps per trawl, crew details, and steam time. Another participant suggested considering cultural grouping based on non-economic indicators, and Josh Stoll's lab is building social indicators to look at this source of heterogeneity. Chao Zou mentioned that another source of heterogeneity is the difference across fishers' objectives. He suggested that lobster fishers might not be motivated by profit maximization, as suggested by the economics theory. Anecdotal evidence suggests that some fishers participate year round in the fishery to maintain space, especially in highly competitive areas, rather than profit maximization behavior. Fishing behavior may also be different between offshore and inshore fishers resulting in various degrees of spatial competition. Lastly, a participant mentioned that resource availability and technical capacity are vital in understanding fishers' location choices.

3. LABOR MARKET DYNAMICS AND FACTORS THAT AFFECT LOBSTER PRICES (WORKSHOP II)

3.1 Opening

Eric Thunberg introduced the team, the agenda, the project scope, and the project approach. During the introduction, Eric Thunberg presented the same information as in the opening of the first session; see section 2.1 and Appendix A.2.

3.2 Workshop I recap

Smit Vasquez Caballero followed the opening remark by presenting a recapitulation of the first session. His presentation summarized Richardson and Gates's (1986) simulation model and presenting a word cloud of all the keywords he identified from the participants' responses to all discussion questions in the first session (Appendix A6, slide 3). The word cloud shows several high-frequency keywords, such as regulation constraints, fishing location, outside opportunities, available biomass, age of fishers, crew availability, trap density, and bait prices. The high-frequency words allow us to identify themes that are significant drivers of the economic performance of the fishery to consider when developing a new simulation framework.

Smit Caballero classified the keywords in one of the 3 modules in Richardson and Gates' (1986) simulation framework, such as environmental conditions, intra-annual volatility, spatial distribution, stock trajectory, available biomass, and changes in catch-per-unit-effort are elements belonging to the biological module (Appendix A6, slide 4). Some of the keywords classified in the market module include fisheries certification, overseas markets, trade dynamics, ex-vessel price, holidays, and access to markets. On the other hand, themes related to bait—such as bait efficiency, prices, quality, substitutes, and supply curve—are placed under the harvest module.

As captured by the keywords, some other themes look at issues beyond the 3 modules in Richardson and Gates' (1986) simulation (Appendix A6 slide 5). The list of keywords calls for developing additional modules. For example, the list relates to the spatial behavior of fishers, fishing location, displacement by closures, proximity to biomass, and trawling up or not. Another set of keywords relates to the participation behavior, such as outside opportunities, availability of licenses, permits, space at the dock, crew availability, and weather. Lastly, another set of themes is related to the interaction of the lobster fishery with other sectors, such as competition for ocean space, offshore wind developments, non-economic values, island vs. mainland dependence on the fishery, and demographic change.

3.3 Market models

Smit Caballero described modeling approaches used to characterize the market sector of the fishery, including the Richardson and Gates (1986) approach. Lobster market models identify the relationship between quantity landed and price while accounting for the sources of demand for lobster. The presentation started with a figure that depicts a stylized version of the different sources of demand for lobster, a primary demand, and 2 derived demands (Appendix A6, slide 7). The figure identifies 3 sources of demand (Dayton et al. 2014). There is the demand from consumers to retailers, supermarkets, and restaurants; the demand from retailers to wholesalers; and the demand from wholesalers to harvesters. One specific characteristic of the lobster fishery is that wholesalers purchase lobster from U.S. domestic and Canadian suppliers. Given the different sources of demand, the literature review distinguishes 3 sets of markets: a retail market, a wholesaler market, and an ex-vessel market (Richardson et al. 1986; Dayton et al. 2014).

The market sector is characterized by identifying the determinants of prices at the wholesale and ex-vessel markets. Richardson and Gates (1986) identified yield, average weight, and import from Canada as the main determinants of wholesale and ex-vessel prices. Further, Wang and Kellogg (1988) listed domestic landings, imports from Canada, seasonal demand, inventories, size, and personal income as factors that play a role in determining wholesale prices, while domestic landings and wholesale prices determine ex-vessel prices (Appendix A6, slide 8). Given the hierarchical structure of the lobster market, the later literature includes elements that drive the demand in the retail and wholesale market directly in ex-vessel price models. Thus, instead of modeling each price separately, they estimate ex-vessel prices as a function of factors that determine the demand in all markets (Appendix A6, slide 9). The determinants of the ex-vessel prices include domestic landings, personal income and changes in income, imports from Canada, inventories, and an element of seasonality (Cheng and Townsend 1993; Dayton 2018; Holland 2011; Richardson and Gates 1986; Wang & Kellogg, 1988).

The relationship between ex-vessel price and its determinants is modeled with an inverse demand function (Appendix A6, slide 10). The function takes quantity landed, information for personal income such as gross domestic product (GDP) per capita, imports from Canada, inventories—storing of live lobsters—and variables accounting for the seasonality in demand for lobster as input. To estimate lobster universe demand functions, price and landing data are used. Price data were often obtained from the NMFS dealer database (Dayton 2018). Early landing information appears in the Office of Data and Information Management rports from NMFS (Cheng and Townsend 1993). Import information comes from the National Fishery Statistics Program, NMFS, the NOAA Office of Science and Technology database, or the Department of Oceans and

Fisheries (DFO) Canada. Information on exchange rates, per capita income, and changes in GDP comes from macroeconomic statistic sources such as the Federal Reserve Bank of St. Louis (Dayton 2018).

Smit Caballero finalized the presentation by mentioning that past estimations of inverse demand function have omitted relevant information known to play an essential role in determining ex-vessel price and demand for lobsters. He mentioned 3 main caveats: the role of product differentiation, international markets, and spatial considerations. Early demand functions included size or weight as determinants of both ex-vessel and wholesale prices; however, recent literature ignores lobster quality and size as determinants of price. Past work assumes that the exchange rate between the U.S. and the Canadian dollar fully captures the lobster trade dynamics. However, exchange rates may fail to account for the possibility that imports of live and frozen lobster from Canada may serve as a mechanism to reduce the seasonal variability in domestic lobster supply (Thunberg 2007). In addition, trade lobster dynamics go beyond trade relations with Canada. Future work needs to consider international demand from Asia and European countries. Finally, the literature estimates a single inverse demand function under the assumption of a single aggregate market; that is, there is a spatial homogeneity in the landing and price relationship for the American lobsters. Future estimation of market demand functions assignment should address these caveats.

3.4 Discussion

The discussion following the presentation was motivated by raising the following questions: What are the main elements that determine ex-vessel and wholesale prices? What are the key elements of the demand and supply? What are key determinants of domestic and international demand and supply for lobster? What are the sources of uncertainty in the price determination for lobster?

The responses to the first question included elements already considered, such as landings, import prices and quantities, and inventories. However, responses also included other elements such as shell quality (hardness), international prices of other seafood products, prices of substitutes (other species of lobster or other crustaceans, such as crab), and expenses such as labor, material, electricity costs. Kathleen Reardon (Maine Department of Marine Resources [DMR]) stated that not the right people were at the table to provide a well-informed answer to this question. She also mentioned that there is much unknown about the role of product differentiation on price; grading does not appear in the data. It is unknown whether harvesters grade at the dock before dealers process and grade further.

Annie Tselikis (Maine Lobster Dealers Association) stated that the workshop lacks people who buy and sell lobster to provide informed answers about the market sector of the fishery. She also stated that the price of lobster is highly uncertain, that a price model will be unlikely to characterize the uncertainty in the market, and that any outcomes of a predicting pricing model will likely harm the lobster industry. In response to participants' answers, Annie Tselikis stated that labor, material, and electricity costs factor into what goes on wholesale prices but do not impact harvesters. The market dictates import prices and is highly variable from year to year. The lobster quality is important, but lobster substitutes are not; however, these elements do not factor into the ex-vessel price. Burton Shank acknowledged that key players were likely missing and were not intentionally excluded, rather their identities were unknown to the team, and he therefore requested their names for future meetings. One of the workshop's goals is to identify stakeholders with firsthand experience with both the harvest and the market sector of the fishery and get them involved in the development of the economic operating model. Burton Shanks clarified the team is not developing an economic operating model for price prediction in the future. Instead, the model will seek to characterize general patterns and processes observed in the fishery; the model will serve as a tool to evaluate the impact of alternative management scenarios, not to influence the price.

The second discussion question sought to identify the key elements of the demand and supply of lobster. Answers on the virtual whiteboard related to supply included the recruitment of small lobsters and molt timing. On the demand side, the answers included adaptability of the markets, summer tourist season, tariffs, inflation, and the discretionary spending available to U.S. households. During the discussion, Annie Tselikis mentioned that many things impact demand, including tariffs, taxation, international trade wars, Chinese New Year, and other holidays; the impacts of these variables change from year to year. Demand constantly varies, and the supply chain shows resiliency in finding markets and outlets for the best value. Finally, she mentioned that the cost of shipping does not affect supply and demand, and neither do biological events, such as molting.

The next question sought to identify the key determinants of lobster's domestic and international supply and demand. As key determinants of demand, the participants listed the following: tariffs, trade wars, geopolitical issues, emerging international markets, competition with other exporter countries (e.g. Australia), views of environmental groups, disposable income, cultural factors, and the perception of lobster as luxury goods. The supply determinants include weather, crew availability, alternate fisheries participation, and management measures. During the discussion, the importance of geopolitical issues as a driver of international lobster was reinforced. According to Annie Tselikis, competition with other countries does not play a significant role since lobsters are priced differently. Emerging markets play an important role, as seen with the increase in demand from Greece, the Middle East, and Asian countries. Participants also stated that key domestic demand drivers are discretionary spending, seasonal consumption, tourism, and cultural norms. Seasonality in the domestic demand is driven by tourism and holidays, specifically holidays such as Christmas, Chinese New Year, and Mother's Day.

On the supply side, Annie Tselikis mentioned that the domestic and Canadian supplies are closely tied and that Canadian regulations play an important role in supplying hard shell and high-quality lobster. The domestic supply has evolved out of the tourist industry and changes in fishers' participation in other fisheries, especially in Maine. Kathleen Reardon mentioned that anecdotal evidence suggests that fishers no longer participate in winter fisheries; instead, they continue participating in the lobster fishery year round. Other participants supported the idea that fishers are recreating a business model in the winter.

Annie Teslikies stated that the dealer community had built a business operating based on volume. Processing plants are designed to process between 40,000 to 100,000 pounds of lobsters daily to meet domestic and international demand. The processing plants are vulnerable to significant adjustments to supply because they cannot operate with less than 40,000 pounds of lobster per day.

The next discussion question asked participants to identify the sources of uncertainty in the price determination for lobster. Participants listed the following answers: transportation, fuel costs, tariffs, the shrink rate and mortality, competition with other international fisheries, geopolitical issues, and the mismatch between the demand and supply. One of the participants mentioned that the wholesale price of live lobster is highly variable; prices change overnight. The uncertainty is driven by the constant fluctuations in many factors that affect domestic and international demand for lobster.

The discussion session ended by brainstorming about what a basic market sector model might look like. Adam Cook (DFO Canada) suggested using probability distribution sampling from the recent past rather than identifying demand drivers. Alexa Dayton suggested that there might be a need to develop different models for 2 markets based on product differentiation, one being a good luxury demand driven by factors that affect the global market for lobster. Kanae Tokunaga (Gulf of Maine Research Institute [GMRI]) suggested considering applying a time series approach based on machine learning methods. Patrice McCarron indicated the team needs to consider that developing a model based on past observations may not inform impacts of management alternatives; the industry might not be doing business in the future the same way as in the past. She also mentioned that models might do a poor job characterizing uncertainty in the market sector. She suggested market models need to be built with caution and based on well-informed feedback from those in the industry; otherwise, the models will not provide meaningful information.

4. CONCEPTUAL ECONOMIC SIMULATION MODEL (WORKSHOP III)

4.1 Opening

Eric Thunberg started the third workshop by introducing the team and providing an agenda overview. He described the challenges facing the American lobster fishery, including the shifting distribution of lobster stocks, declining recruitment patterns, the overlap between lobster and NARW, and the interaction with offshore wind developments and aquaculture. Eric explained that biological models for the fishery are well developed but that there is a need for an economic model of the fishery to support lobster management. The lack of an economic operating model prevents the ASMFC from initiating an effort to implement an MSE process. The project's broader goal is to identify the key economic features of the American lobster fishery and which components of an economic model can be built with existing data. To achieve this goal, the team seeks to complete the following tasks: review previously developed lobster simulation models, review more recent bioeconomic models, and recommend the scope of an economic operating model. The workshops aim to provide an overview of the findings from the first 2 tasks and ask for feedback to identify gaps in the literature review to complete the third task. The team sees its role in developing an economic operating model as a short-term engagement by providing the background work for other collaborative partners to develop and implement the model.

As part of the opening, Jeff Kipp gave a presentation on the ASMFC perspective on developing an economic operating model (Appendix A7). He provided an overview of the economic objectives in the management plan. The overall goal of Amendment 3 of the Interstate Fishery Management Plan for American Lobster is to have a healthy American lobster resource and a management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders (ASMFC 1997). Amendment 3 states 2 economic objectives to achieve the overall objective: Objective 3 relates to the collection, analysis, and dissemination of biological and economic data to understand harvest, and Objective 5 relates to promoting economic efficiency in the harvesting and use of resources (ASMFC 1997).

According to Jeff Kipp, the 2020 Stock Assessment identified an MSE and the identification of economic reference points as high-priority research recommendations (ASMFC 2020). The 2020 assessment also recommended conducting economic analyses that consider landings, ex-vessel value, costs, number of active participants, and related economic variables to inform economic-based reference points. The lobster Technical Committee proposed an MSE work plan that identifies economic models essential to a successful future lobster MSE. Jeff Kipp concluded his presentation by stating that the ASFMC lobster management board has prioritized current efforts on Draft Addenda XXVII and XXIX and whale risk reduction and wind energy development. Therefore, considerations for an MSE have been postponed until further discussion during the winter 2023 meeting.

After Jeff Kipp's presentation, Amalia Harrington provided a brief overview of the Sea Grant's role in research and extension. She described the American Lobster Initiative, which provides funding to support research projects aimed at increasing the understanding of life-history parameters, larva studies and early biology, spatial distribution, and the socioeconomics of the American lobster fishery. Sea Grant is currently seeking proposals related to developing new gear technologies and the socioeconomic impacts of bringing gear technology to the fishery. The goal of creating economic models to characterize the lobster fishery falls within the broad objective of the American Lobster Initiative; Sea Grant potentially serves as a funding source for proposals along this line of research.

4.2 Overview of lobster economic modules

The presentation started with Smit Caballero summarizing Richardson and Gates' (1986) simulation, which provides a framework to build a new simulation. Richardson and Gates' framework introduces 3 standalone modules: biological, harvest, and market (Appendix A8, slides 2). Production and demand functions for the lobster fishery provides a basic understanding of the inputs required to build the both modules. The workshop discussion provides additional inputs and processes to consider for a conceptual simulation framework. Additionally, the discussions suggest an additional set of modules needs to characterize the elements that drive the lobster fishery dynamics.

Richardson and Gates' (1986) biological module uses biological parameters such as fishing mortality, natural mortality, growth, and recruitment to produce available biomass and size composition as output. Future harvest models should consider the implication of environmental conditions, spatial distribution, and intra-annual volatility on biomass (Appendix A8, slide 4). Including inputs that account for these elements can allow exploring the implication of climate change on the abundance and spatial distribution of lobster.

A basic harvest module would include the following inputs: biomass, vessel characteristics, number of trips, number of traps hauled, soak time, aggregate traps, and information about bait (Appendix A8, slides 5 and 6). Further, a harvesting module should also consider different attributes of bait, such as quality, efficiency, prices, quality, and alternative substitutes. However, other elements that characterize the dynamics of the harvesting sector are related to fishers' behavior and not to the harvest production function. For instance, during the discussions, participants mentioned that outside opportunities play a crucial role in fishers' decisions to participate and when to participate in the fishery. Other factors that affect participation behavior include the availability of licenses, age, crew availability, and space at the dock. Modeling the relation of these factors with the decision to participate or not in the fishery requires a standalone entry-exit behavior model. Other behavioral elements not characterized in a production function include businesses' size, the captain's experience, tradition, weather, and displacement by closures. The essential inputs in a market module are domestic landings, personal income, inventories, imports from Canada, and seasonality trends (Appendix A8, slides 7 and 8). An extension to a basic market model may consider the role of size and quality, international demand and supply, and uncertainty in determining ex-vessel and wholesale prices.

After describing each of the 3 modules, including their inputs and outputs, Smit Caballero described how a simulation could integrate standalone modules, similar to Richardson and Gates' (1986) model. A simple model will contain biological, harvest, market, and profits modules (Appendix A8, slide 11). The endogenous inputs and outputs in the simulation include variables that measure fishing mortality, available biomass, vessel-level catch, aggregated catch, and prices. The relationship between aggregated catch and fishing mortality provides the basis for the feedback loop in the simulation process. A stylized version of the simulation would work as follows: fishing mortality and other inputs are used in the biological module to generate an indicator for available biomass as one of the outputs. A measure of available biomass enters the harvest module, along with other inputs, such as effort, and produces vessel-level catch as an output. Vessel-level catch is aggregated to the industry-level catch, which produces a measure of fishing mortality that enters the biological model as input to generate the next period output. The market module uses aggregate catch and other relevant inputs to generate price as an output. The profit module uses ex-vessel price, landings, and harvest costs as inputs to generate vessel-level revenue and profits as outputs. The inputs in the profit module are outputs generated internally within the simulation.

Potential extensions of the simulation include adding modules to simulate individual vessel entry-exit behavior and fishing location choice behavior. The entry-exit model estimates the likelihood that a vessel will participate in the fishery given a set of inputs. The likelihood of participation by different vessel classes could generate time trajectories of fleet size, generating aggregate catch. The model's output can be combined with the time trajectory of prices to estimate fleet size profitability using functions from the profit module. The spatial behavioral module can use proximity to biomass, experience, tradition, weather, and displacement of the closures to estimate the likelihood of selecting a fishing location choice among several alternatives, creating a time trajectory of effort allocation across space. A spatial behavioral model could generate spatial fishing mortalities connected to a spatially explicit biological model. The simulation can also increase complexity by increasing the space and temporal dimension of each module. An introductory module may assume that inputs and outputs are homogeneously distributed across space, measured on aggregated values. However, a complex model will relax this assumption, add spatial considerations to the biological and harvest models, and create outputs with spatial distributions, such as spatial biomass distribution and fleet fishing location choices.

The presentation ended with Burton Shank describing the general characteristics of an existing biological model (Appendix A8, slide 17-18). The model is written in R and is structured to mirror the lobster length-based stock assessment model. It tracks populations by sex in 5 mm length bins in monthly time steps, lacks spatial structure, and produces as output catch numbers and mortality at size. The model has time-invariant and time-varying inputs. The former includes sizes at recruitment, recruitment seasonality, growth, seasonality of molting, size at maturity, and length-weight relationship. The latter includes fishing and natural mortality, recruitment, legal selectivity, gear selectivity, and conservation selectivity.

An intermediate model could add spatial distribution of stocks, allowing for spatial economic processes such as spatial distribution of effort across fishing location choices. The spatial distribution of stocks could be added to the existing model using different degrees of complexity. The simple approach involves building a monthly climatology of lobster biomass based on surveys to create a distribution map, then spatially applying the aggregate biomass to the map. The complex approach involves building a spatially explicit population model with local dynamics and depletion. The simple approach can be completed within a reasonable timeframe, while the complex approach requires significant time and effort to construct.

4.3 Discussion

After the presentation, the team asked 2 questions to motivate the discussion. The first question aimed to identify other modules to consider when building a simulation model. The second question aimed to identify the data available to estimate each module. For the first question, Alexa Dayton mentioned that the presentation did not consider the role of technical capacity. She stated that data suggest that technical capacity has increased without limits and that boat size has increased over time. An additional module could address the potential impacts that an increase in technical capacity may have on the amount of effective effort.

The discussion around the first question surrounded 2 topics: what motivates fishers to go fishing and the implications of developing a simulation model for the industry. Annie Tselikis commented that the harvest sector's profitability depends on the supply chain. Fishers are not motivated to fish to maximize their profits as postulated by economic theory, and anecdotal evidence suggests that fishers do not respond to changes in ex-vessel price. Instead, fishers fish hard regardless of the prevailing price conditions. Fishers' motivation to fish is to maintain their livelihood; prices do not play a role in participation or profitability.

Annie Tselikis stated that there is a lot of missing data to properly characterize the market module and its relationship to the harvest module. Patrice McCarron expressed her concerns about developing a simulation model, stating that results from past research from government agencies and other research institutions have negatively affected the industry. The team acknowledged the existence of many unknowns about the fishery dynamics and some known elements that are difficult to characterize. Allowing the industry stakeholders to provide early feedback will allow the team to account for known patterns and recognize unknown processes.

During the discussion around the second question, participants agreed on the lack of data to characterize the diversity of fishers. One of the sources of fishers' heterogeneity is fishers' participation behavior. Evidence suggests that some fishers fish year round while others fish for a few months. Kathleen Reardon suggested that one might consider the availability of alternative opportunities as a driver of fishing behavior and the expectation that the lobster fishery provides job opportunities. Reardon commented that modeling participation behavior could, to some extent, be informed by looking at data on the number of trips per vessel and compared across months within a season; however, the lack of data on alternative options does not allow to model participation behavior.

4.4 Collaboration route map

The workshops ended with participants discussing collaboration opportunities to build the different modules of the simulation. Patrice McCarron raised concerns about building models knowing that the existing data is insufficient to inform model parameters. Jeff Kipps mentioned that a simulation model could also be used to understand the data needs; thus, the lack of appropriate data may be, in fact, a motivation to develop a simulation model. Several participants agreed that there is a need for more data collection for the short and the long term. Alexa pointed out the need to repeat surveys carried out by GMRI in 2005 and 2010. Kanae Tokunaga and Alexa Dayton stated that they are currently working on a project to characterize fleet heterogeneity using GMRI data from 2010; a follow-up data will support this project. Kanae Tokunaga also mentioned the need to invite Keith Evan and Yong Chen to future conversations since they have a projection involving economics and have collected economic data using interviews with the fleets. The workshop was closed by participants agreeing to find venues to continue discussing individual models of the proposed simulation framework.

FIGURE

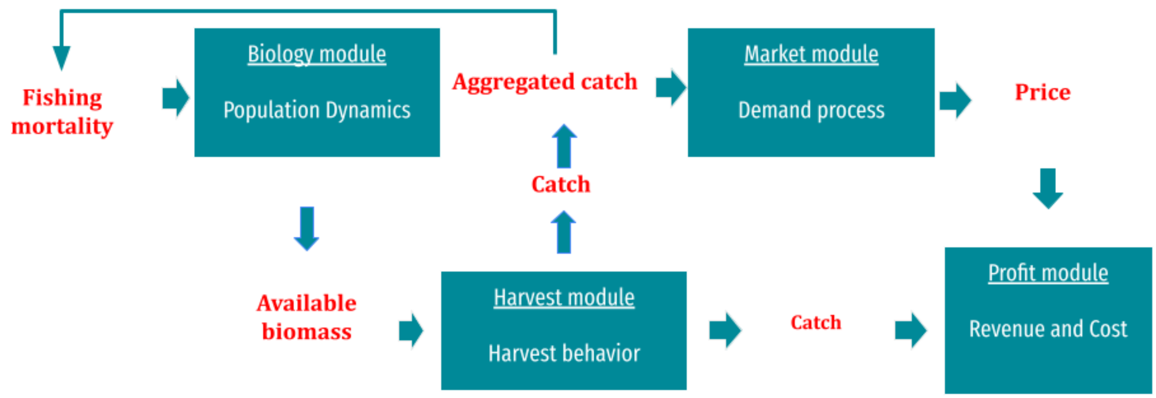

Figure 1. Conceptual framework for a basic bioeconomic simulation model of the American lobster (*Homerus americanus*) fishery.

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Richardson EJ and Gates JM. 1986. Economic benefits of American lobster fishery management regulations. Mar Res Econ. 2(4):353-382.

Thunberg E. 2007. Demographic and economic trends in the northeastern United States lobster (*Homarus americanus*) fishery, 1970-2005. US Dept Commer Northeast Fish Sci Cent Ref Doc. 07-17. Accessible at: https://repository.library.noaa.gov/view/noaa/5251

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APPENDIX A1. WORKSHOP PARTICIPANT LIST AND AFFILIATIONS

Participant Name	Affiliation	Attendance		
Adam Cook	Oceans and Fisheries (DFO) Canada	✓	✓	
Alexa Dayton	University of Maine	✓	✓	✓
Alicia Miller	NOAA	✓	✓	✓
Amalia Harrington	Sea Grant	✓		✓
Annie Tselikis	Maine Lobster Dealers Association		✓	✓
Burton Shank	NOAA	✓	✓	✓
Chao Zou	NOAA	✓	✓	✓
Courtenay Parlee	DFO Canada		✓	✓
Emily Fitting	Umaine			✓
Eric Thunberg	NOAA		✓	✓
Erin Summers	Maine Department of Marine Resources (DMR)	✓	✓	✓
Josh Stoll	Umaine	✓		
Jeff Kipp	Atlantic States Marine Fisheries Commission (ASMFC)			✓
Kanae Tokunaga	Gulf of Maine Research Institute (GMRI)	✓	✓	✓
Kathleen Reardon	Maine DMR	✓	✓	
Kathryn Bisack	NOAA	✓	✓	✓
Kathy Mills	GMRI	✓	✓	✓
Min-Yang Lee	NOAA	✓	✓	

Patrice McCarron	Maine Lobstermen's Association		✓	✓
Smit V. Caballero	NOAA	✓	✓	✓
Susan Arnold	Island Institute		✓	
Samantha Werner	NOAA		✓	
Theresa Johnson	Umaine			✓
Theresa Burnham	Umaine	✓		✓

APPENDIX A2: AGENDAS

Virtual workshop series: Lobster Economic Modeling
Workshop 1
Project overview and dynamics of the lobster harvesting sector
AGENDA

Wednesday, March 23, 2022
1:00 PM – 3:00 PM
Where: https://noaanmfs-meets.webex.com/noaanmfs-meets/j.php?MTID=m9e373256a48159888485f8f47530a7b6
Meeting number (access code): 2761 742 6950
Meeting password: kPNMAuu9w38
Join by phone: +1-415-527-5035

Meeting facilitator: Burton Shank
Notetaker: Alicia Miller
Ground rules: Use the raise hand feature. Be respectful of time constraints.
Goals for the day:

1. Introduce project and goals.
2. Describe existing modeling approaches that identify key economic dynamics affecting the performance of the lobster fishery.
3. Identify key elements that describe the harvesting sector.

1:00 PM – 1:15 PM	Welcome and introductions (Kathryn Bisack)
1:15 PM – 1:25 PM	Project overview (Kathryn Bisack) • Scope of project • Intended products
1:25 PM – 1:40 PM	Presentation 1: Previous lobster simulation models (Smit) • Overview of "Economic benefits of American lobster fishery management regulations" (Richardson and Gates, 1986)
1:40 PM – 2:00 PM	Discussion
2:00 PM – 2:20 PM	Presentation 2: Harvesting sector models (Smit) • Factors that affect catch • Determinants of revenue, costs, and profits • Data sources and availability
2:20 PM – 2:50 PM	Discussion
2:50 PM – 3:00 PM	Wrap-up

Discussion questions:
Presentation 1:
What are the foreseen challenges and opportunities likely to drive the performance of the fishery?
What sectors are necessary to characterize the dynamics of the fishery?
What are the data constraints that limit the possibility to build a simulation model for the fishery?
Presentation 2:
What are the fundamental inputs that determine vessel level landings and expenses?
What are some sources of heterogeneity across lobster fishers?

Suggested reading materials

Dayton, A. M., Sun, J., & Labaree, J. (2014). Understanding Opportunities and Barriers to Profitability in the New England Lobster Industry. GMRI. Link

Holland, D. S. (2011). Planning for changing productivity and catchability in the Maine lobster fishery. Fisheries Research, 110(1), 47–58. https://doi.org/10.1016/j.fishres.2011.03.011

Richardson, E. J., & Gates, J. M. (1986). Economic Benefits of American Lobster Fishery Management Regulations. Marine Resource Economics, 2(4), 353–382. https://doi.org/10.1086/mre.2.4.42628910

Virtual workshop series: Lobster Economic Modeling
Workshop 2
Lobster market dynamics and factors that affect lobster prices
AGENDA
Tuesday, March 29, 2022,
9:00 AM - 11:00 AM
Where: https://noaanmfs-meets.webex.com/noaanmfs-meets/j.php?MTID=m7364433f458376a918c5a57ca8466fdb
Meeting number (access code): 2761 449 2829
Meeting password: Bkyd5ynj2g2
Join by phone: +1-415-527-5035

Meeting facilitator: Burton Shank
Notetaker: Alicia Miller
Ground rules: Use the raise hand feature. Be respectful of time constraints.
Goals for the day:
1 Describe previous work that characterizes the market dynamics of the lobster fishery.
2 Identify key elements that affect the price and demand for lobster.
3 Identify uncertainties associated with the demand for lobster.

Agenda

9:00 AM – 9:10 AM	Welcome and introductions (Eric Thunberg)
9:10 AM – 9:15 AM	Workshop 1 recap (Smit)
9:15 AM – 9:30 AM	Lobster market models (Smit) • Models of ex-vessel price • Data sources • Models shortcomings
9:30 AM – 10:45 AM	Discussion
10:45 AM – 11:00 AM	Wrap-up

Discussion questions:
What are the main elements that determine ex-vessel and wholesale prices?
What are the key elements of the demand and supply?
What are key determinants of domestic and international demand for lobster?
What are key determinants of domestic and international supply for lobster?
What are the sources of uncertainty in the price determination for lobster?

Suggested reading materials

Cheng, H.-T., & Townsend, R. E. (1993). Potential Impact of Seasonal Closures in the U.S. Lobster Fishery. *Marine Resource Economics*, *8*(2), 101–117. https://doi.org/10.1086/mre.8.2.42629054

Dayton, A. M., Sun, J., & Labaree, J. (2014). *Understanding Opportunities and Barriers to Profitability in the New England Lobster Industry*. GMRI. Link

Holland, D. S. (2011). Planning for changing productivity and catchability in the Maine lobster fishery. *Fisheries Research*, *110*(1), 47–58. https://doi.org/10.1016/j.fishres.2011.03.011

Thunberg, E. (2007). *Demographic and economic trends in the northeastern United States lobster (Homarus americanus) fishery, 1970-2005* (No. 07–17; Northeast Fish Sci Cent Ref Doc). US Dept Commer. Link

Wang, S. D. H., & Kellogg, C. B. (1988). An Econometric Model for American Lobster. *Marine Resource Economics*, *5*(1), 61–70. https://doi.org/10.1086/mre.5.1.42871965

Virtual workshop series: Lobster Economic Modeling
Workshop 3
Conceptual economic simulation model
AGENDA
Friday, April 8, 2022
1:00 PM – 3:00 PM
where: https://noaanmfs-meets.webex.com/noaanmfs-meets/j.php?MTID=mf014ca22f60a583ef0f4e076e2ddca2c
Meeting number (access code): 2764 241 3886
Meeting password: PsVQtPqP772
Join by phone: +1-415-527-5035

Meeting facilitator: Burton Shank
Notetaker: Alicia Miller
Ground rules: Use the raise hand feature. Be respectful of time constraints.
Goals for the day:

1. Identify interdependencies among the lobster economic modules.
2. Relate biological and economic modules into a single simulation model.
3. Define the next steps for the development of the simulation tool.

1:00 PM – 1:10 PM	Project overview (Eric Thunberg and Kathryn Bisack)
1:10 PM – 1:15 PM	Lobster Economic Information for ASMFC (Jeff Kipp)
1:15 PM – 1:20 PM	Sea Grant and the American Lobster Initiative (Amalia Harrington)
1:20 PM – 1:40 PM	Overview of lobster economic modules (Smit) ● Richardson and Gates (1986) framework ● An alternative simulation framework ● Key modules and inputs of the simulation ● Potential modules interdependence
1:40 PM – 2:00 PM	Discussion
2:00 PM – 2:50 PM	Collaboration route map (Burton) ● Identify potential collaboration and synergies ● Identify potential sources of funding ● Possibly of a follow-up in-person workshop ● Next steps
2:50 PM – 3:00 PM	Wrap-up

Discussion questions:
What is the most simple model we can build given data constraints?
What critical processes are captured, and left out, in such a model?
How can we collaborate to build each module of the simulation model?

Suggested reading materials

Dayton, A. M., Sun, J., & Labaree, J. (2014). Understanding Opportunities and Barriers to Profitability in the New England Lobster Industry. GMRI. Link

Holland, D. S. (2011). Planning for changing productivity and catchability in the Maine lobster fishery. Fisheries Research, 110(1), 47–58. https://doi.org/10.1016/j.fishres.2011.03.011

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APPENDIX A3: OPENING PRESENTATION

Welcome and Introductions

Project Team

- Burton Shank - Population Dynamics Branch
- Eric Thunberg - OST Economic and Social Analysis Div
- Kathryn Bisack - Social Sciences Branch
- Smit Vasquez Caballero - SSB Contractor

NOAA FISHERIES 1

Workshop outline and Ground Rules

- Project overview and context
- Workshop 1 recap
- Lobster market models
- Discussion
- Wrap-up
- Ground rules
  - Use raise hand feature or use chat
  - Be respectful of time

NOAA FISHERIES

Overview

Virtual workshop series

Lobster Economic Modeling

March 23, 2022

NOAA FISHERIES 3

Context & Challenges

- **Shifting distribution of lobster stocks**
  - **Northward and into deeper waters**
- **Declining recruitment patterns**
- Overlap between lobster and NARW
- Offshore Wind
- Aquaculture

NOAA FISHERIES 4

Project Scope

Economic operating model to support MSE

- Simulation-based tool to explore robust management approaches
  - Not intended to predict or forecast
- Integration with biological models
- Key economic features of American lobster fishery
  - Harvest
  - Market
  - Spatial and time dimensions
- General approach
  - Simple to complex

NOAA FISHERIES 5

Project Approach

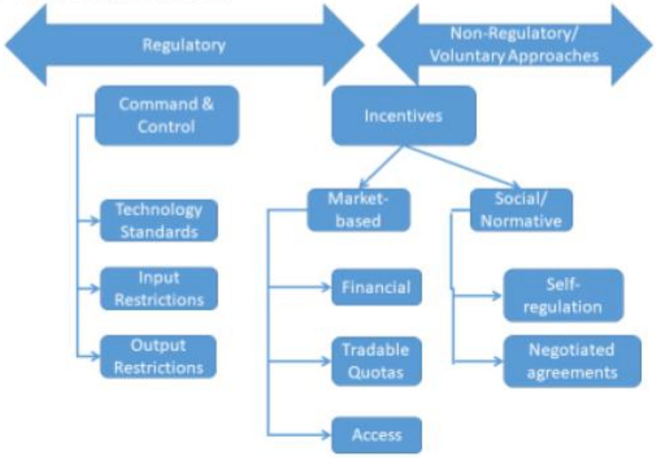
- Review previously developed lobster simulation models
- Review more recent bioeconomic models
- Recommend scope of economic operating model

We are here

- Review data availability
- Estimate empirical models

NOAA FISHERIES 6

Policy Instruments



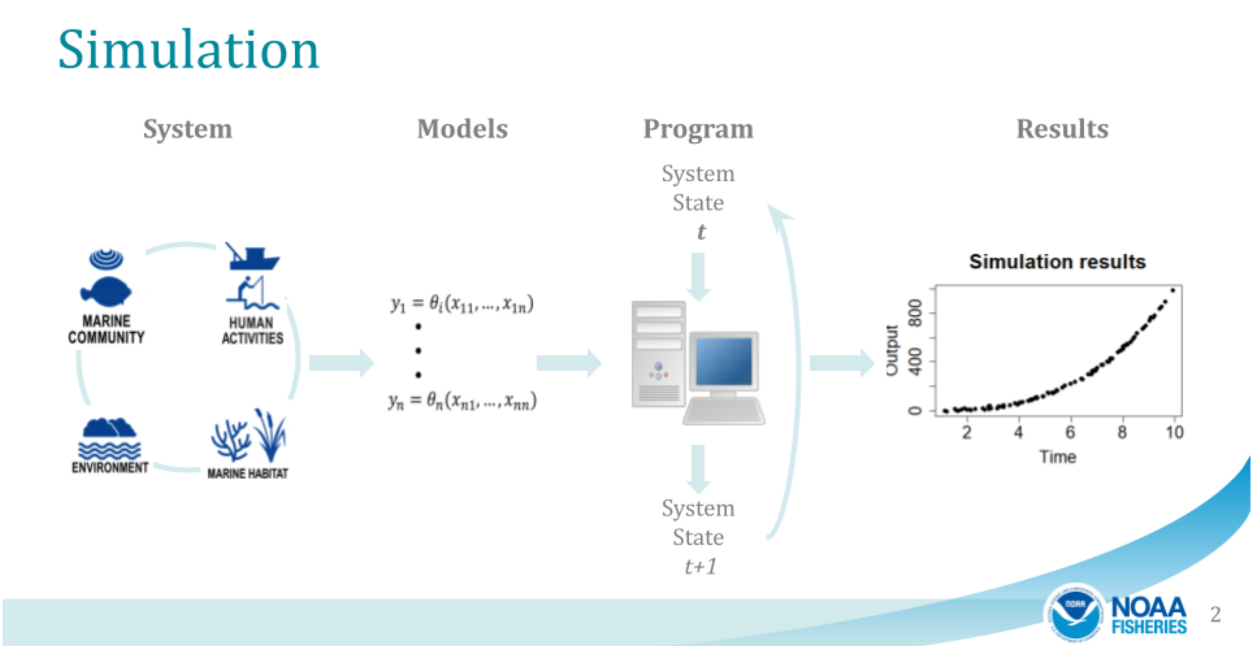
7

Management Menu

- Gauge size (minimum/maximum)
- Trap limits
- Closed seasons/areas
- Limited entry
- Hauling hours
- Male-only fishery
- Quota-based landing limits
- Tradeable Traps

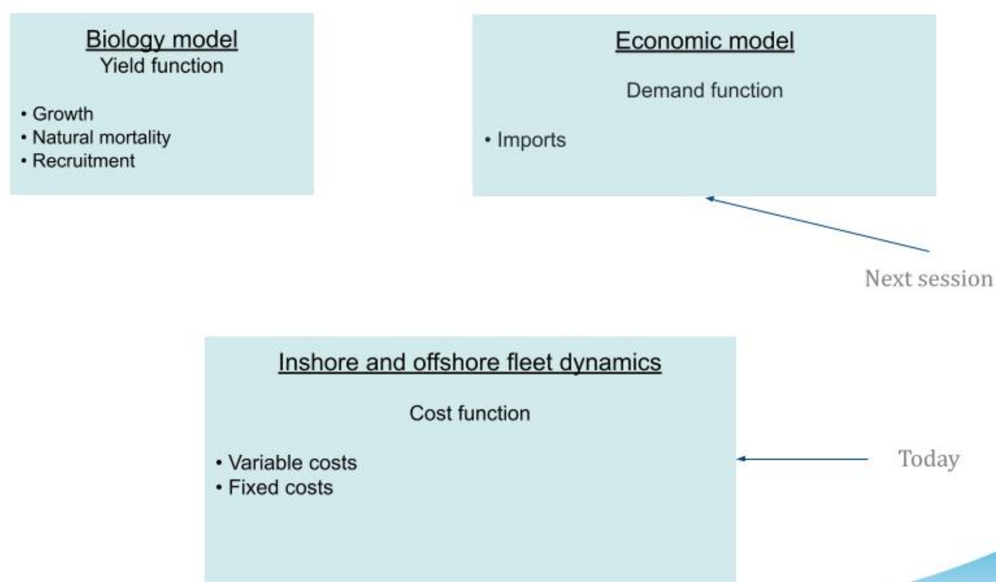
8

APPENDIX A4: PRESENTATION: PREVIOUS LOBSTER SIMULATION MODELS

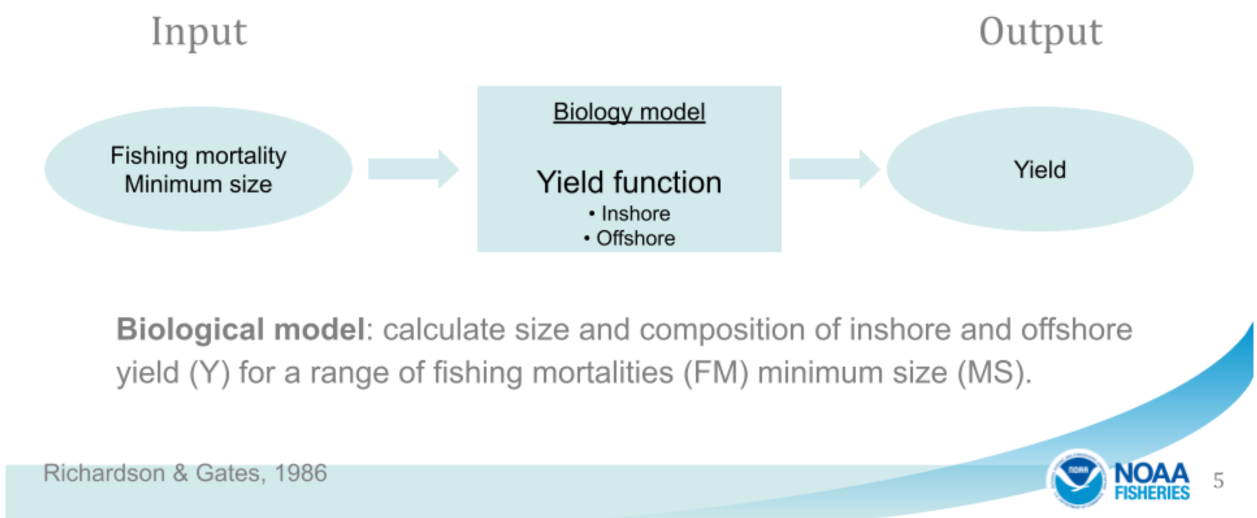


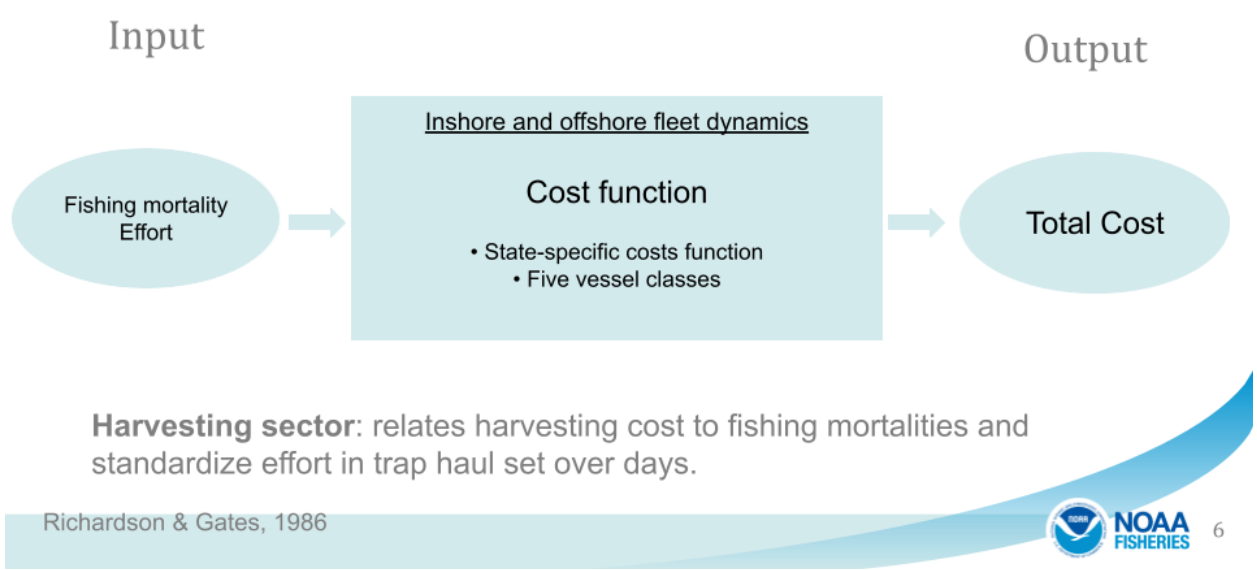
Lobster simulation models

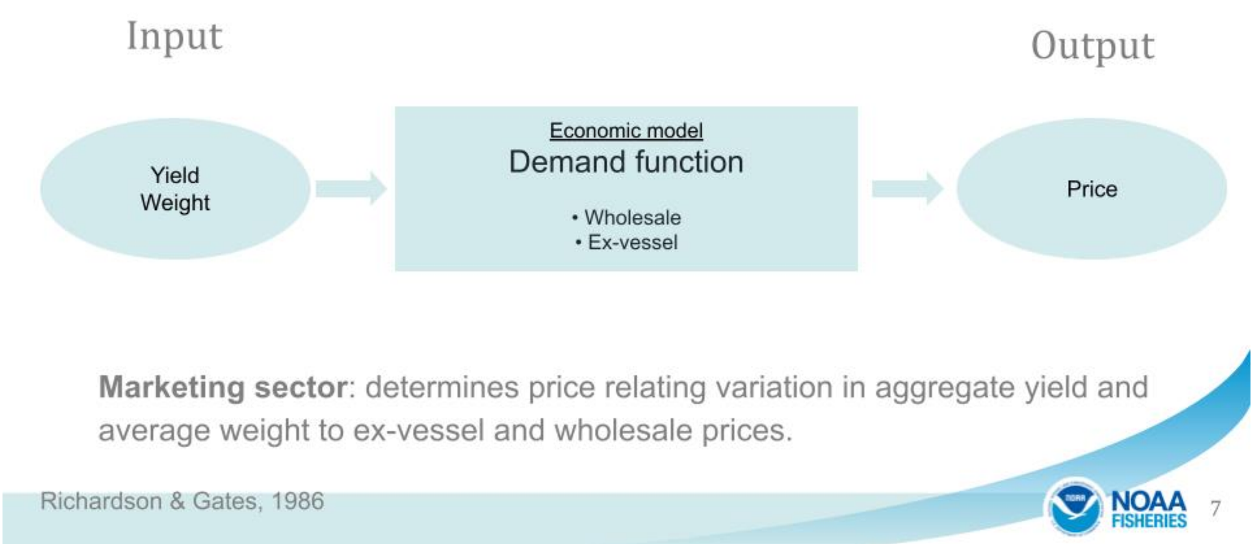
- Simulation to compare the distributional impacts of two alternative management regulations (Richardson and Gates, 1986).
  - Increase in minimum legal size
  - Reduction in aggregate fishing mortalities
- An updated version called SIMLOB (Gates and Sutinen,1995).

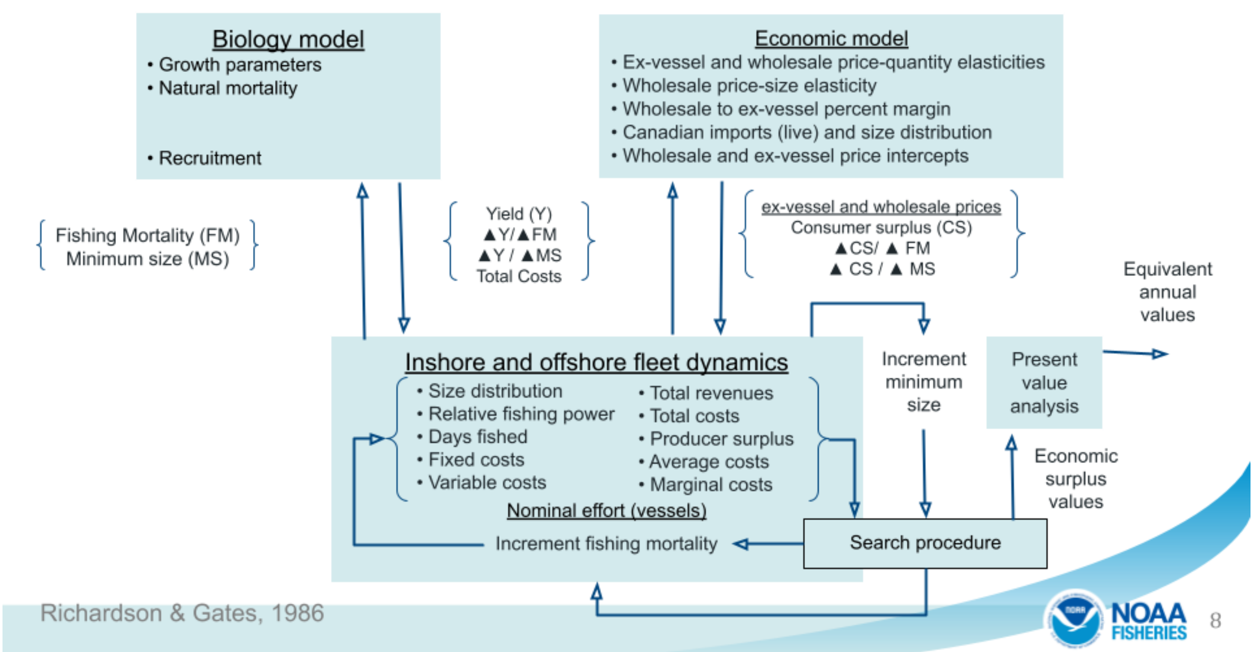


Richardson & Gates, 1986


Input
Output
Fishing mortality
Minimum size
Biology model
Yield function
• Inshore
• Offshore
Yield
Biological model: calculate size and composition of inshore and offshore yield (Y) for a range of fishing mortalities (FM) minimum size (MS).
Richardson & Gates, 1986
NOAA FISHERIES
5


Input
Output
Fishing mortality
Effort
Inshore and offshore fleet dynamics
Cost function
• State-specific costs function
• Five vessel classes
Total Cost
Harvesting sector: relates harvesting cost to fishing mortalities and standardize effort in trap haul set over days.
Richardson & Gates, 1986
NOAA FISHERIES
6


Input
Output
Yield
Weight
Economic model
Demand function
• Wholesale
• Ex-vessel
Price
Marketing sector: determines price relating variation in aggregate yield and average weight to ex-vessel and wholesale prices.
Richardson & Gates, 1986
NOAA FISHERIES
7


Biology model
• Growth parameters
• Natural mortality
• Recruitment
Economic model
• Ex-vessel and wholesale price-quantity elasticities
• Wholesale price-size elasticity
• Wholesale to ex-vessel percent margin
• Canadian imports (live) and size distribution
• Wholesale and ex-vessel price intercepts
Fishing Mortality (FM)
Minimum size (MS)
Yield (Y)
▲Y/▲FM
▲Y / ▲MS
Total Costs
ex-vessel and wholesale prices
Consumer surplus (CS)
▲CS/ ▲ FM
▲ CS / ▲ MS
Equivalent annual values
Inshore and offshore fleet dynamics
• Size distribution
• Relative fishing power
• Days fished
• Fixed costs
• Variable costs
• Total revenues
• Total costs
• Producer surplus
• Average costs
• Marginal costs
Nominal effort (vessels)
Increment fishing mortality
Increment minimum size
Present value analysis
Economic surplus values
Search procedure
Richardson & Gates, 1986
NOAA FISHERIES
8

Data Sources

- Yield function
  - Parameters cited in the literature
- Cost function
  - Vessel characteristics from socioeconomic surveys (Acheson et al., 1979)
  - Vessel cost from surveys (Richardson,1982)
- Demand function
  - Ex-vessel price from NMFS
  - Wholesale prices from Fulton Market database

NOAA FISHERIES 9

Simulation assumptions

- Yield function
  - Constant recruitment
  - Independent inshore and offshore simulation
- Cost function
  - Five classes of inshore vessel
  - One offshore fleet
  - Cost increase linearly in effort and fishing mortality
- Demand function
  - Imports from Canada remain unchanged

NOAA FISHERIES 10

Caveats

- Outdated model
- Lack of documentation
- Reproducibility
- Functions in the model are deterministic

NOAA FISHERIES 11

Discussion questions

- Question 1: What are the foreseen challenges and opportunities likely to drive the performance of the fishery?
- Question 2: What sectors are necessary to characterize the dynamics of the fishery?
- Question 3: What are the data constraints that limit the possibility to build a simulation model for the fishery?

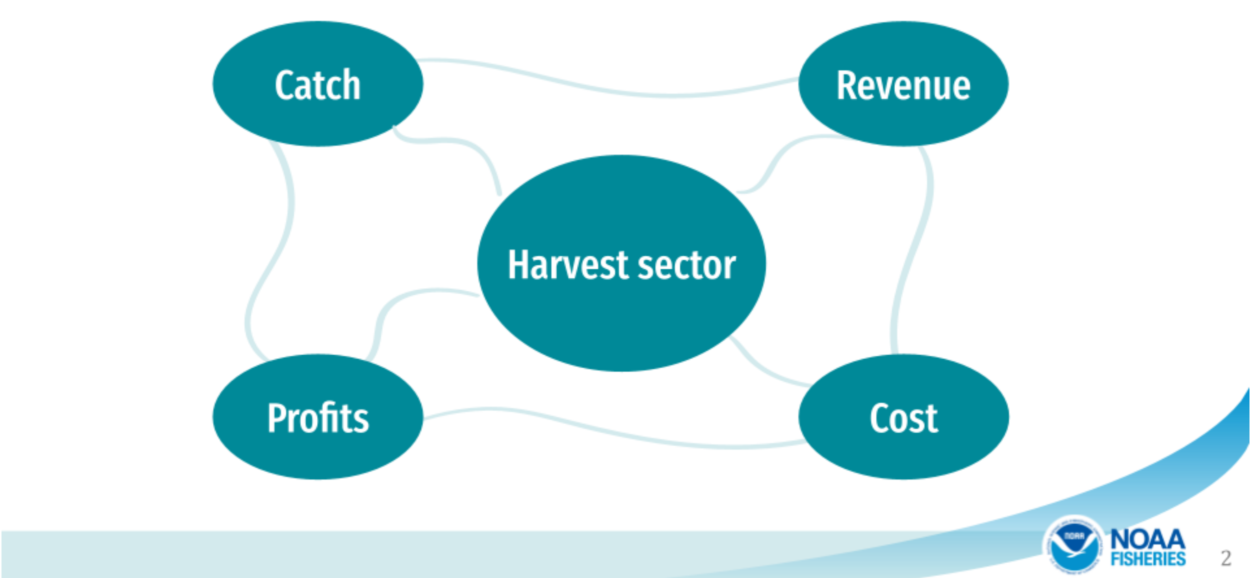
NOAA FISHERIES 12

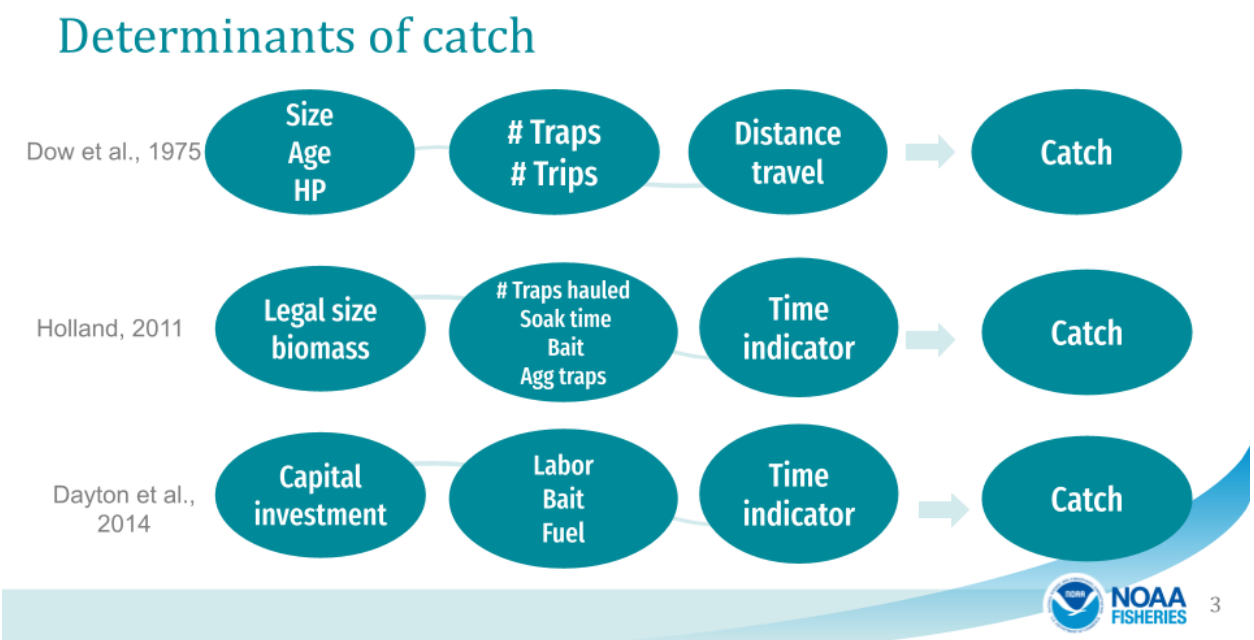
Work cited

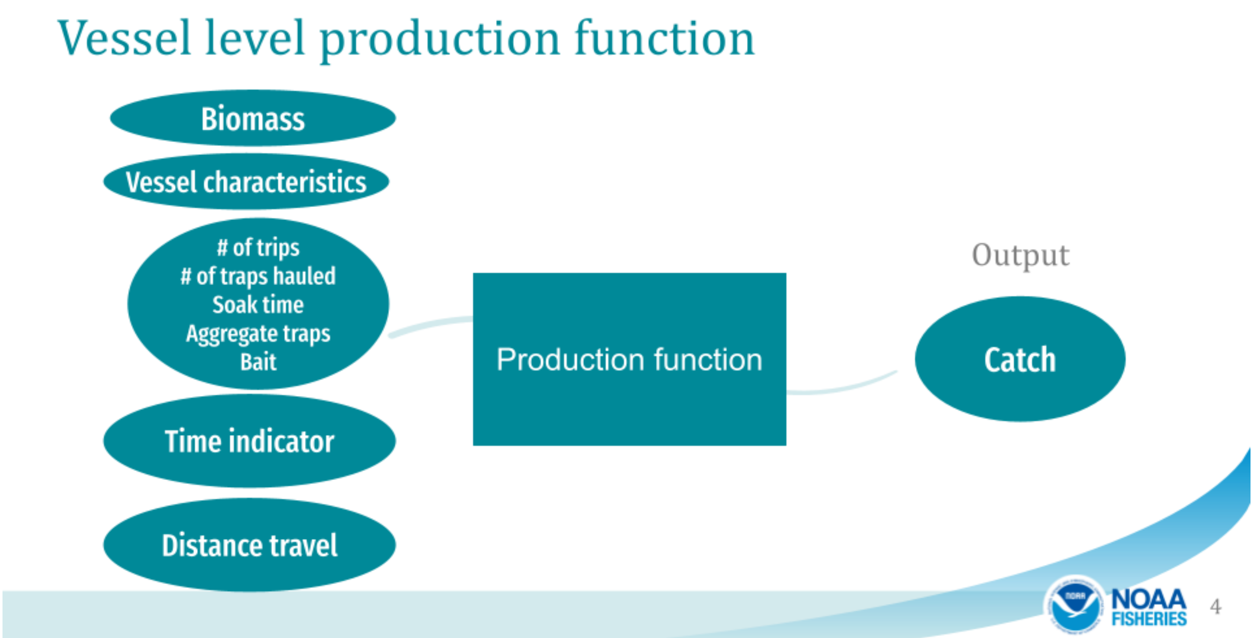
- Acheson, J. M. (1975). Fisheries Management and Social Context: The Case of the Maine Lobster Fishery. Transactions of the American Fisheries Society, 104(4), 653–668.
- Gates, J.M., and J.G. Sutinen (1995): SIMLOB: The Resource and Harvest Sector Components of the North American Lobster (Homarus americanus) Market Model Final report submitted to the National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA.
- Richardson, E. J. (1983). The Effect of a Change in the Size at First Capture in the Rhode Island Inshore Lobster Fishery: A Bioeconomic Analysis. Journal of the Northeastern Agricultural Economics Council, 12(2), 121–121.
- Richardson, E. J., & Gates, J. M. (1986). Economic Benefits of American Lobster Fishery Management Regulations. Marine Resource Economics, 2(4), 353–382.

NOAA FISHERIES 13

APPENDIX A5: PRESENTATION: HARVEST SECTOR MODELS



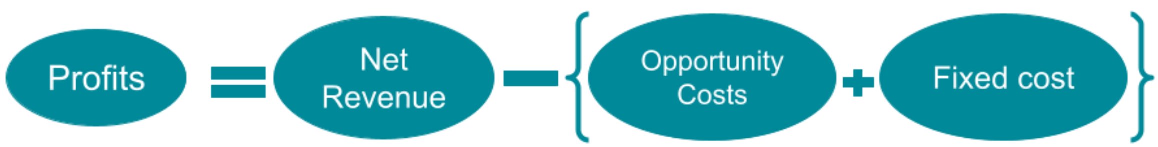

Determinants of catch
Dow et al., 1975
Size
Age
HP
Traps
Trips
Distance
travel
Catch
Holland, 2011
Legal size
biomass
Traps hauled
Soak time
Bait
Agg traps
Time
indicator
Catch
Dayton et al.,
2014
Capital
investment
Labor
Bait
Fuel
Time
indicator
Catch
NOAA
FISHERIES
3


Vessel level production function
Biomass
Vessel characteristics
# of trips
# of traps hauled
Soak time
Aggregate traps
Bait
Time indicator
Distance travel
Production function
Output
Catch
NOAA
FISHERIES
4

Revenue functions

5

Profit function



6

Cost function

Cost = Input quantities × Input prices

Cost structure

Operating Costs	Fixed Costs	Opportunity Costs
• Fuel • Bait • Repairs	• Insurance • Interest payment • License fees • Property taxes • Vessel depreciation • Dockage fees	• Capital • Capitan's labor

Data

Estimation of a production function and profitability at the vessel level requires information on the *catch*, *effort*, *cost*, and *vessel characteristics*.

- Holland (2011) uses a port sampling catch and effort survey running collected by the Maine DMR merged with a cost survey carried out by NMFS.
- Dayton (2014) uses survey responses on vessel characteristics, business financing and expenses, and effort, along with Federal dealer reported catch.

NOAA FISHERIES 9

Caveats

- The temporal dimension of the production function is determined by data availability.
- Lack of spatial considerations.
- Time and space are also inputs that determine catch.
- There is an underlying assumption that vessels are homogeneous.

NOAA FISHERIES 10

Discussion questions

- Question 4: What are the determinants of fishery participation?
- Question 5: What are the fundamental inputs that determine vessel level landings and expenses?
- Question 6: What are some sources of heterogeneity across lobster fishers?

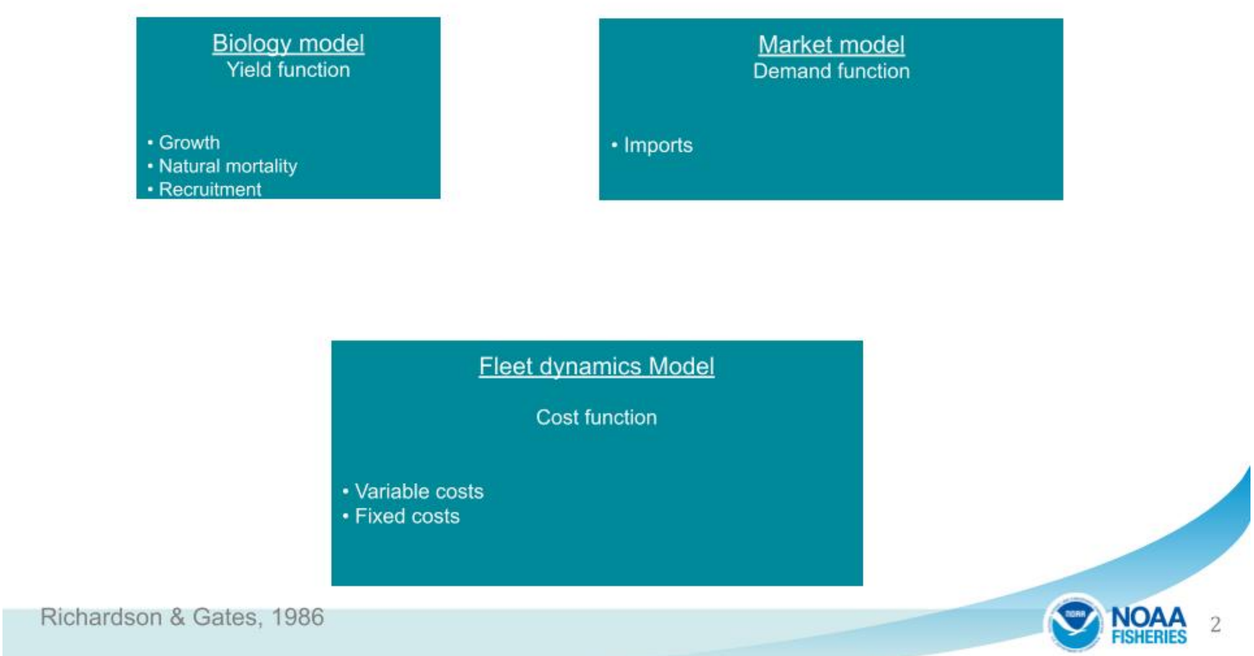
NOAA FISHERIES 11

Work cited

- Dayton, A. M., Sun, J., & Labaree, J. (2014). Understanding Opportunities and Barriers to Profitability in the New England Lobster Industry. GMRI.
- Dow, R. L., Bell, F. W., & Harriman, D. M. (1975). Bioeconomic Relationships for the Maine Lobster Fishery with Consideration of Alternative Management Scheme (Technical Report NMFS). NOAA.
- Holland, D. S. (2011). Planning for changing productivity and catchability in the Maine lobster fishery. Fisheries Research, 110(1), 47–58.

NOAA FISHERIES 12

APPENDIX A6: PRESENTATION: LOBSTER MARKET MODELS



NOAA FISHERIES 3

Biology model

Environmental conditions
Intra-annual volatility
Spatial distribution
Stock trajectory
Available biomass
Changes in CPUE

Market model

Fisheries certification
Overseas markets
Trade dynamics
Ex-vessel price
Holidays
Access to markets

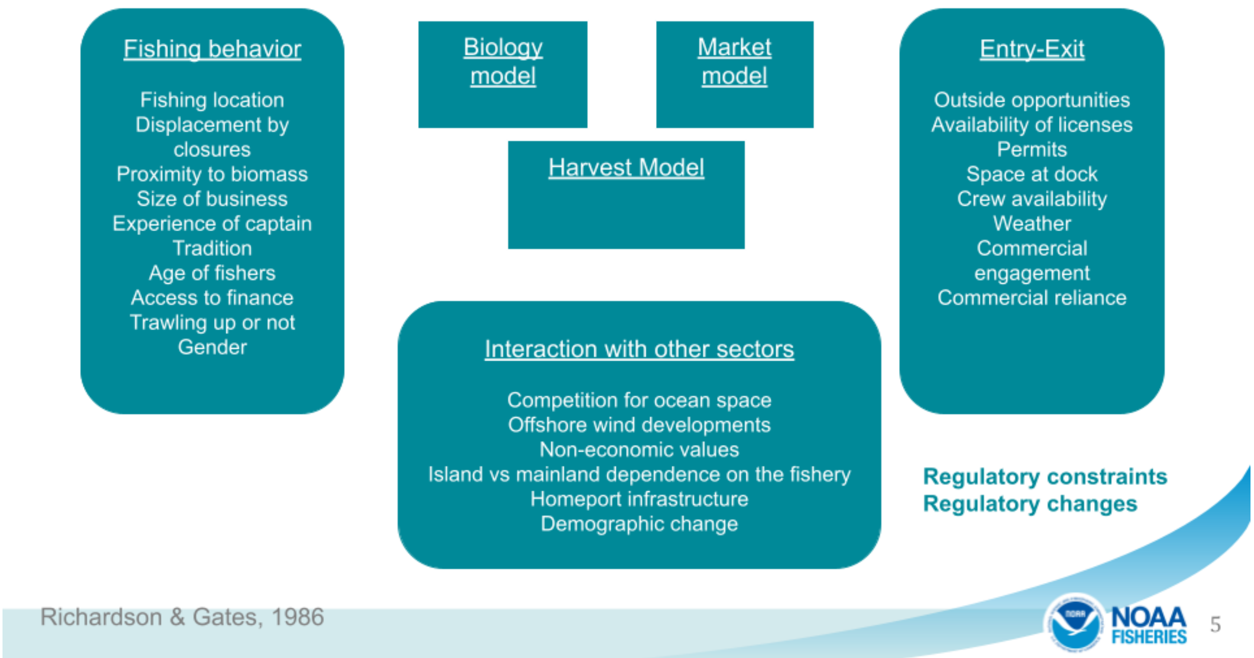
Harvest Model

Bait efficiency
Bait prices
Bait quality
Bait substitutes
Supply curve for bait
Fuel price volatility

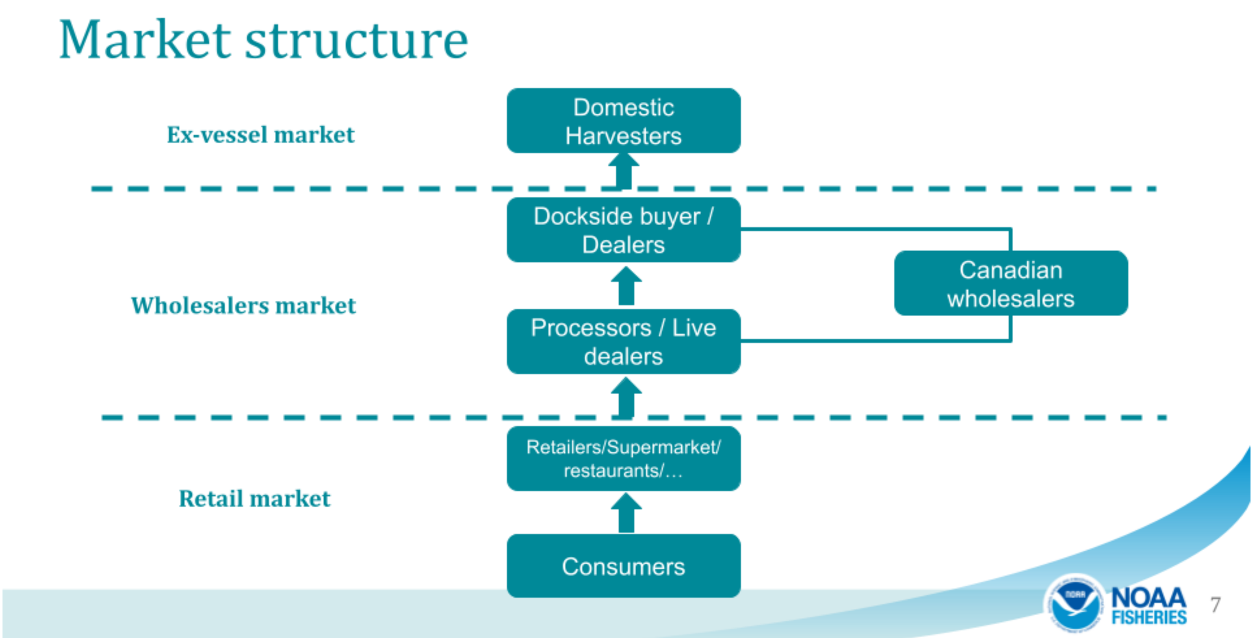
Inshore vs offshore
Soak time and adaptive to changes
Spatial dynamics
Trap density
Crew costs

Richardson & Gates, 1986

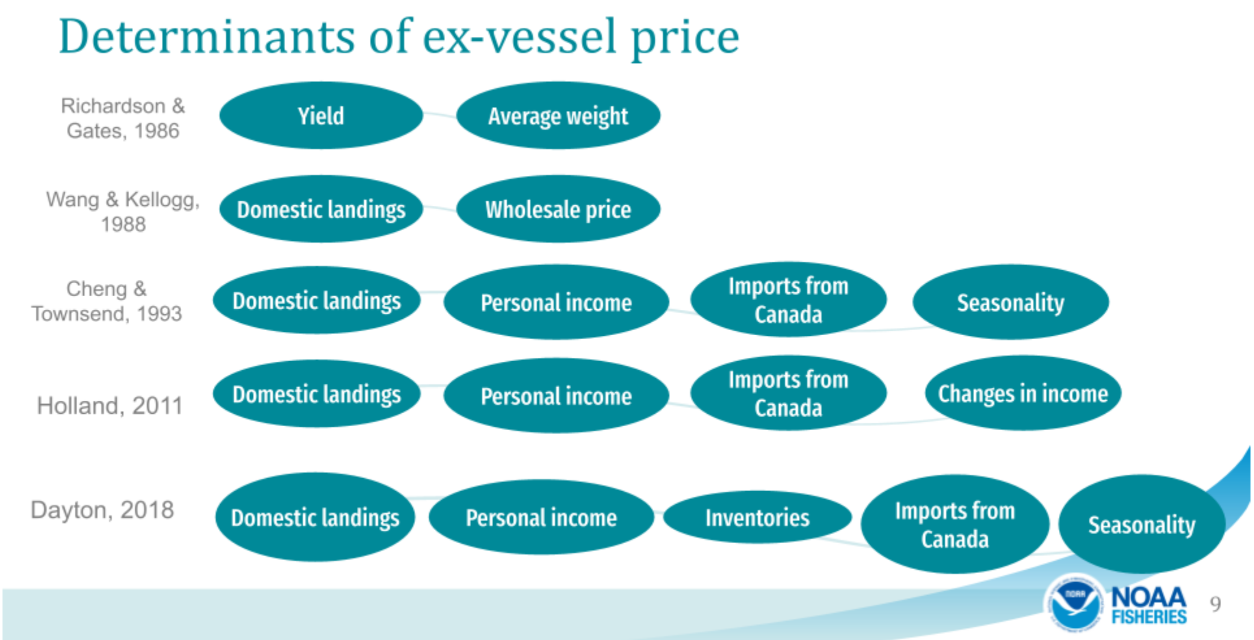
NOAA FISHERIES 4

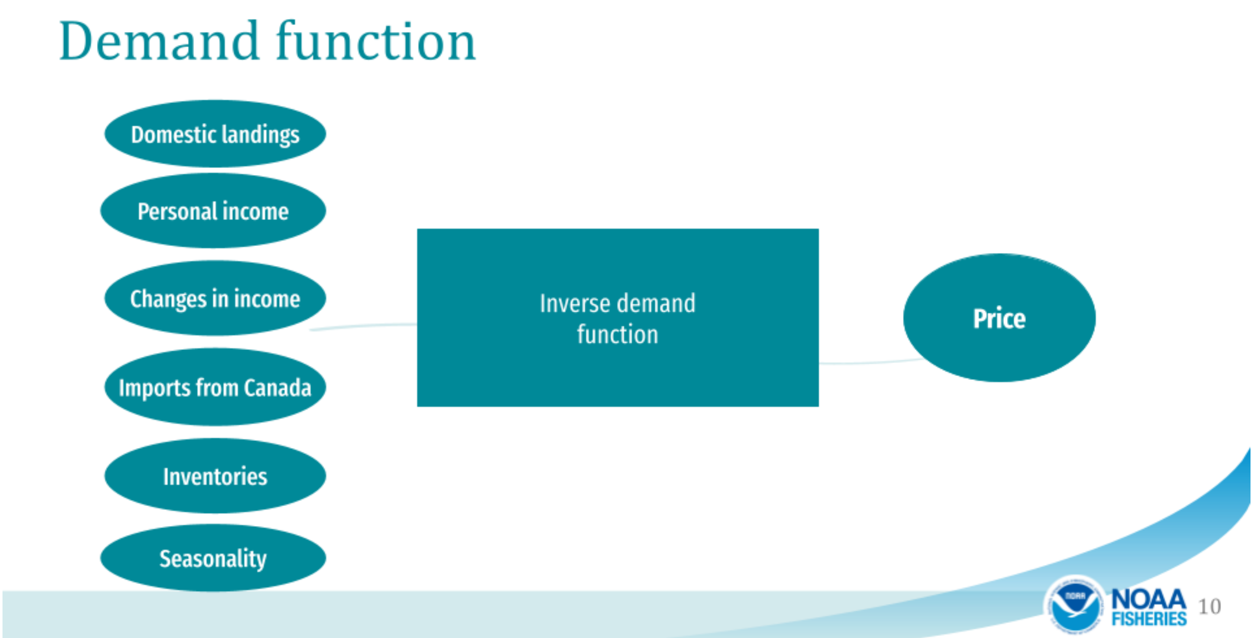

Fishing behavior
Fishing location
Displacement by closures
Proximity to biomass
Size of business
Experience of captain
Tradition
Age of fishers
Access to finance
Trawling up or not
Gender
Biology model
Market model
Harvest Model
Entry-Exit
Outside opportunities
Availability of licenses
Permits
Space at dock
Crew availability
Weather
Commercial engagement
Commercial reliance
Interaction with other sectors
Competition for ocean space
Offshore wind developments
Non-economic values
Island vs mainland dependence on the fishery
Homeport infrastructure
Demographic change
Regulatory constraints
Regulatory changes
Richardson & Gates, 1986
NOAA FISHERIES
5


Market Sector
Virtual workshop series
Lobster Economic Modeling
March 29, 2022
NOAA FISHERIES
6


Market structure
Ex-vessel market
Domestic Harvesters
Dockside buyer / Dealers
Canadian wholesalers
Wholesalers market
Processors / Live dealers
Retailers/Supermarket/ restaurants/…
Retail market
Consumers
NOAA FISHERIES
7


Determinants of wholesale price
Richardson & Gates, 1986
Yield
Average weight
Wang & Kellogg, 1988
Domestic landings
Imports from Canada
Seasonal demand
Inventories
Income
size
NOAA FISHERIES
8


Determinants of ex-vessel price
Richardson & Gates, 1986
Yield
Average weight
Wang & Kellogg, 1988
Domestic landings
Wholesale price
Cheng & Townsend, 1993
Domestic landings
Personal income
Imports from Canada
Seasonality
Holland, 2011
Domestic landings
Personal income
Imports from Canada
Changes in income
Dayton, 2018
Domestic landings
Personal income
Inventories
Imports from Canada
Seasonality
NOAA FISHERIES
9


Demand function
Domestic landings
Personal income
Changes in income
Imports from Canada
Inventories
Seasonality
Inverse demand function
Price
NOAA FISHERIES
10

Data

- Price and landing data from the NMFS dealer database.
- Import information from the National Fishery Statistics Program, NMFS.
  - Department of Oceans and Fisheries Canada.
- Exchange rates, per capita income, and changes in GDP from Macroeconomic statistics.

NOAA FISHERIES 11

Caveats

- The role of product differentiation
- International markets
- Spatial considerations

NOAA FISHERIES 12

Discussion questions

- What are the main elements that determine ex-vessel and wholesale prices?
- What are the key elements of the demand and supply?
- What are key determinants of domestic and international demand for lobster?
- What are key determinants of domestic and international supply for lobster?
- What are the sources of uncertainty in the price determination for lobster?

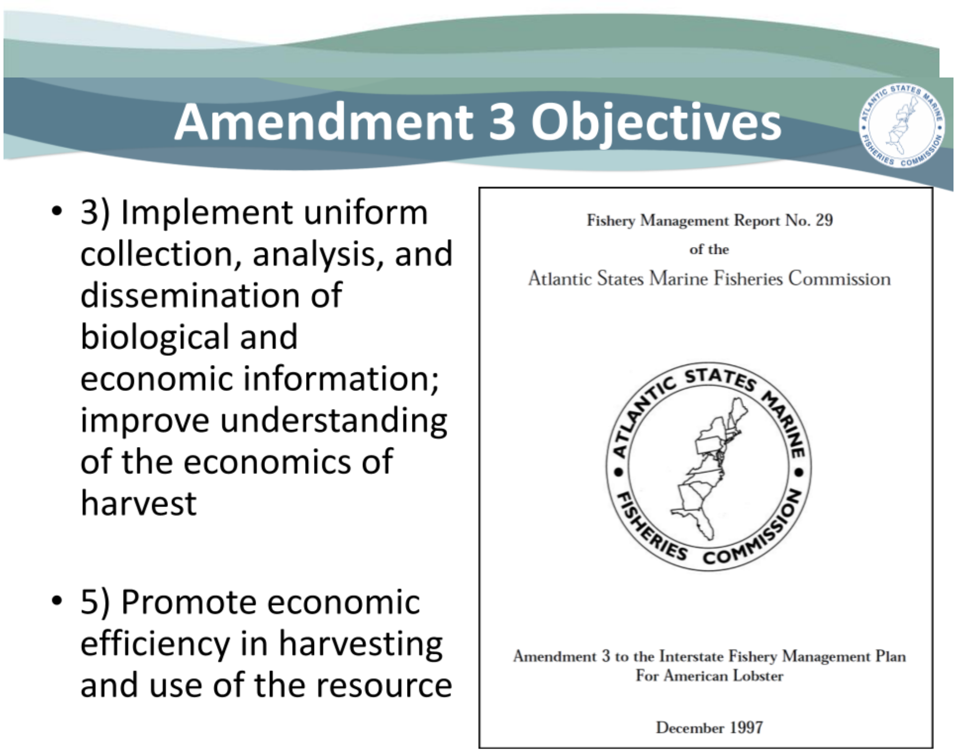
NOAA FISHERIES 13

Work cited

- Cheng, H.-T., & Townsend, R. E. (1993). Potential Impact of Seasonal Closures in the U.S. Lobster Fishery. *Marine Resource Economics*, 8(2), 101–117.
- Dayton, A. M. (2018). Assessing Economic Performance of Maine's Lobster Fleet Under Changing Ecosystem Conditions In the Gulf of Maine. University of Maine.
- Holland, D. S. (2011). Planning for changing productivity and catchability in the Maine lobster fishery. *Fisheries Research*, 110(1), 47–58.
- Richardson, E. J., & Gates, J. M. (1986). Economic Benefits of American Lobster Fishery Management Regulations. *Marine Resource Economics*, 2(4), 353–382.
- Wang, S. D. H., & Kellogg, C. B. (1988). An Econometric Model for American Lobster. *Marine Resource Economics*, 5(1), 61–70.

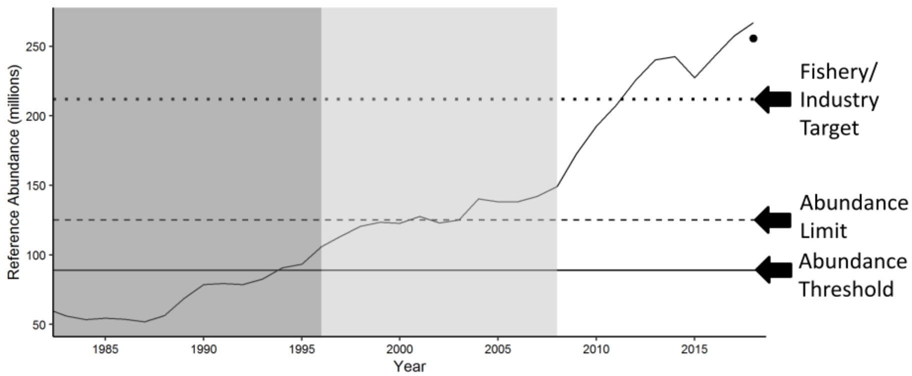
NOAA FISHERIES 14

APPENDIX A7: ASMFC PERSPECTIVE



2020 Stock Assessment

- a. ***Management Strategy Evaluation (High Priority)***
- b. ***Economic Reference Points (High Priority)***



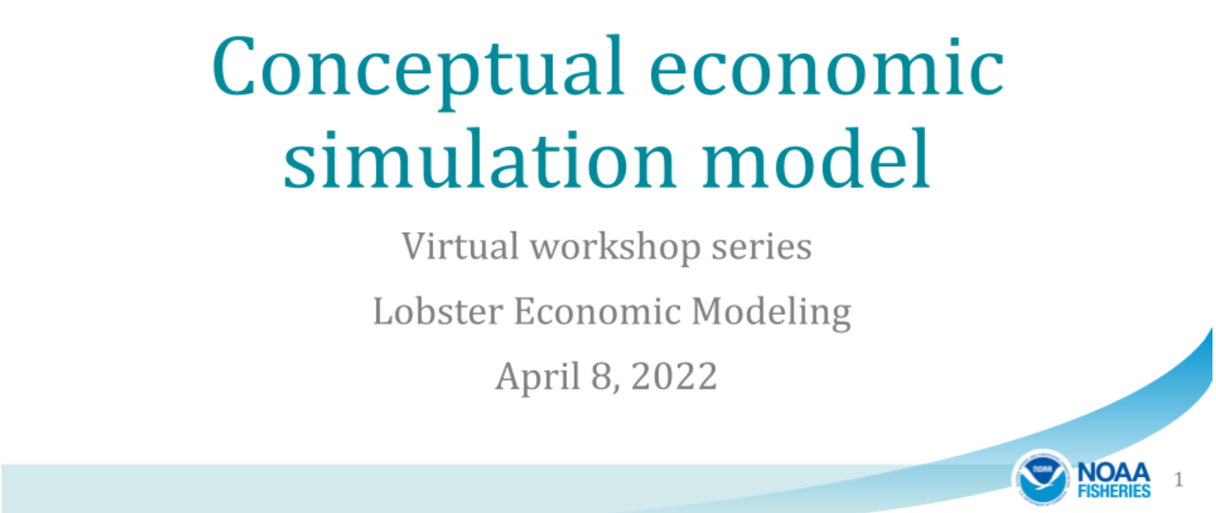
ASMFC Lobster MSE

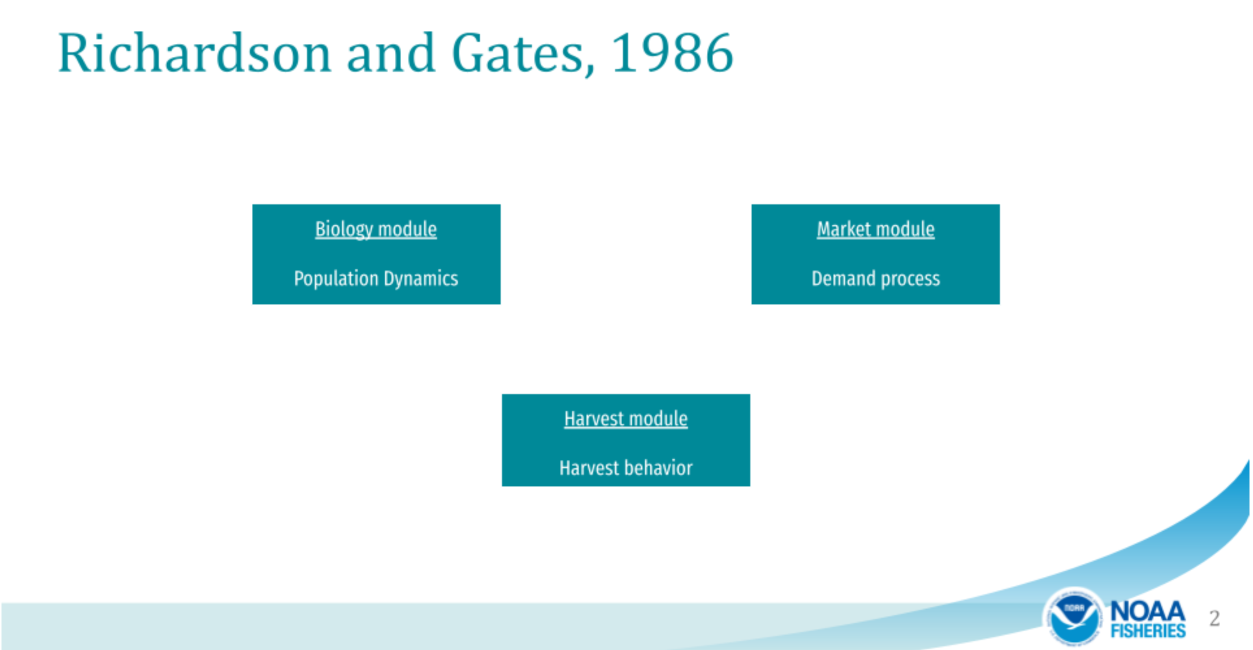
- Management and Science Committee identified lobster for potential MSE
- Lobster Technical Committee proposed MSE work plan
  - Economic considerations/models are essential to a successful lobster MSE for management advice
- Lobster Board prioritized current efforts on Draft Addenda XXVII and XXIX, as well as whale risk reduction and wind energy development
  - Postponed further discussion until Winter 2023 meeting

Questions?

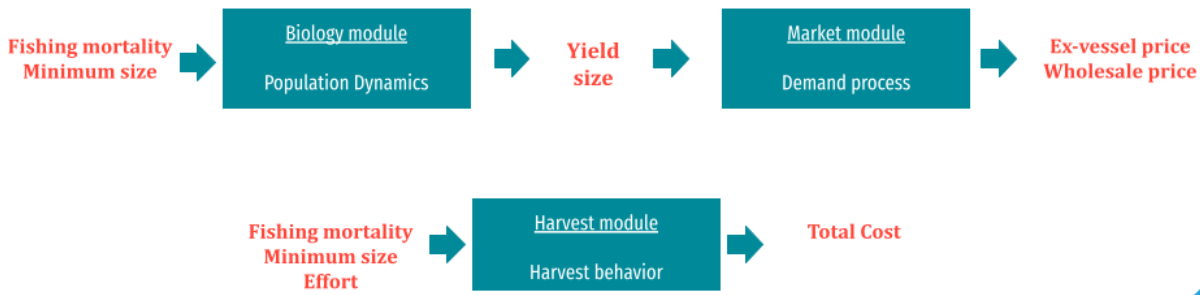
jkipp@asmfc.org

APPENDIX A8: CONCEPTUAL ECONOMIC SIMULATION MODEL





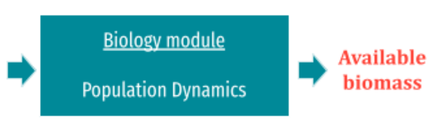
Richardson and Gates, 1986



3

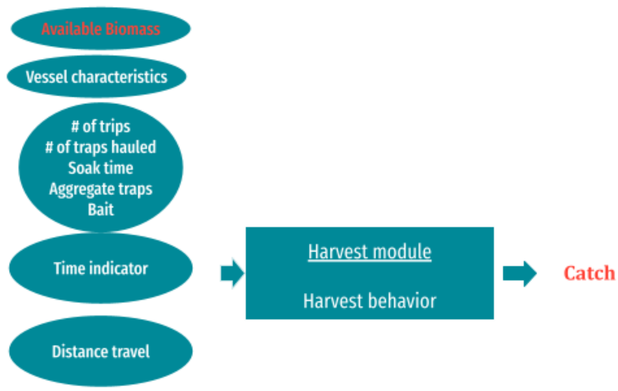
Inputs in the biological module

- Fishing mortality
- Natural mortality
- Growth
- Recruitment
- Environmental conditions
- Spatial distribution
- Intra-annual volatility



4

Inputs in the harvest models

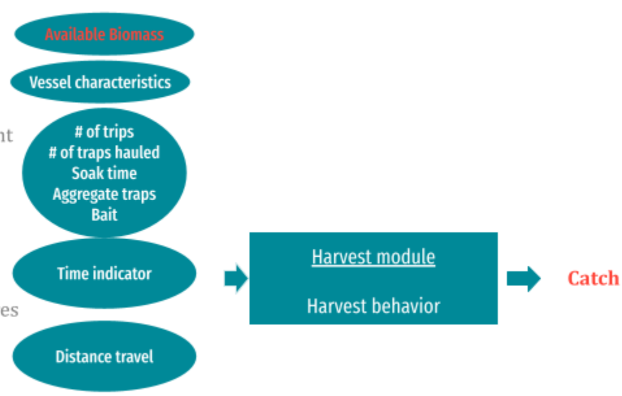


Dow et al.,1975; Holland, 2011; Dayton et al. 2014; Dayton, 2018

NOAA FISHERIES 5

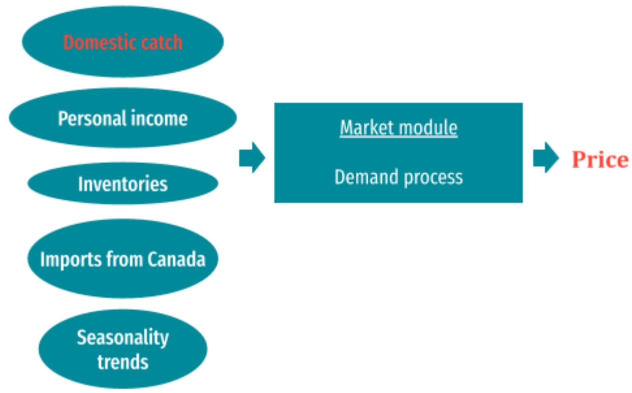
Inputs missing in the harvest models

- Outside opportunities
- Availability of licenses
- Permits
- Space at dock
- Crew availability
- Commercial engagement
- Commercial reliance
- Age of fishers
- Tradition
- Experience
- Fishing location
- Regulatory constraints
- Displacement by closures
- Proximity to biomass
- Size of business
- Experience of captain
- Weather



NOAA FISHERIES 6

Inputs in the demand models

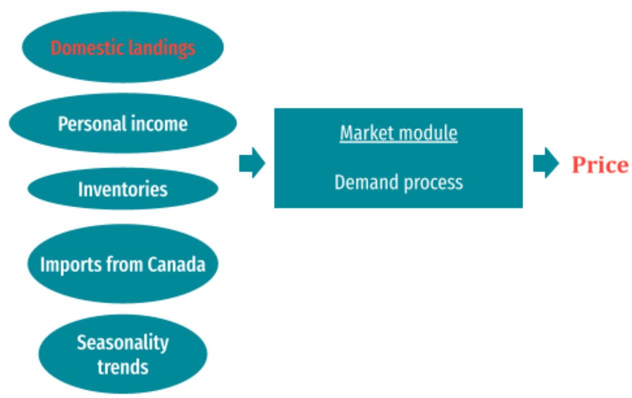


Richardson & Gates, 1986; Wang & Kellogg, 1988; Cheng & Townsend, 1993; Holland, 2011; Dayton, 2018

NOAA FISHERIES 7

Missing inputs in the demand models

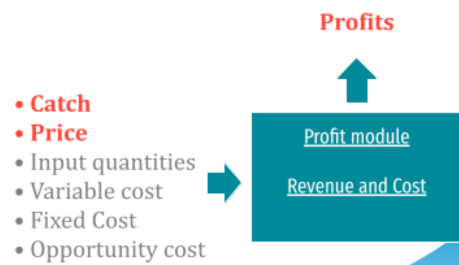
- Uncertainty
- Size and quality
- Domestic demand
- International demand
- International regulation



Richardson & Gates, 1986; Wang & Kellogg, 1988; Cheng & Townsend, 1993; Holland, 2011; Dayton, 2018

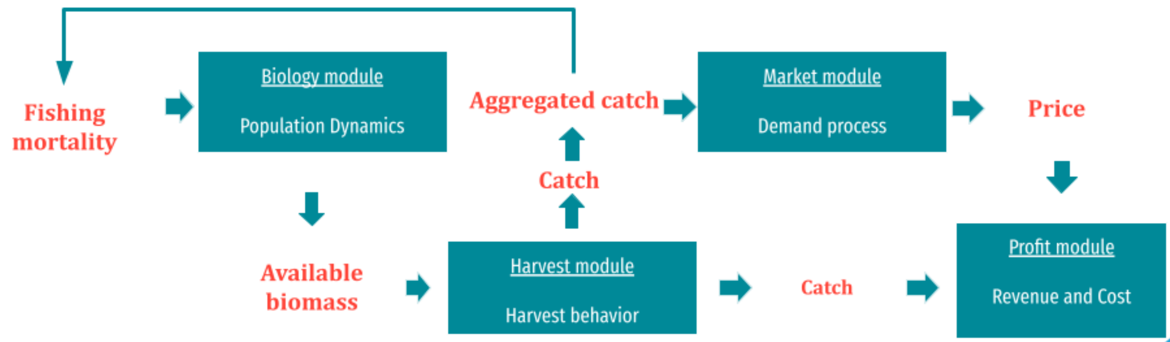
NOAA FISHERIES 8

Inputs in the profit models



Basic simulation

Basic simulation



Additional modules

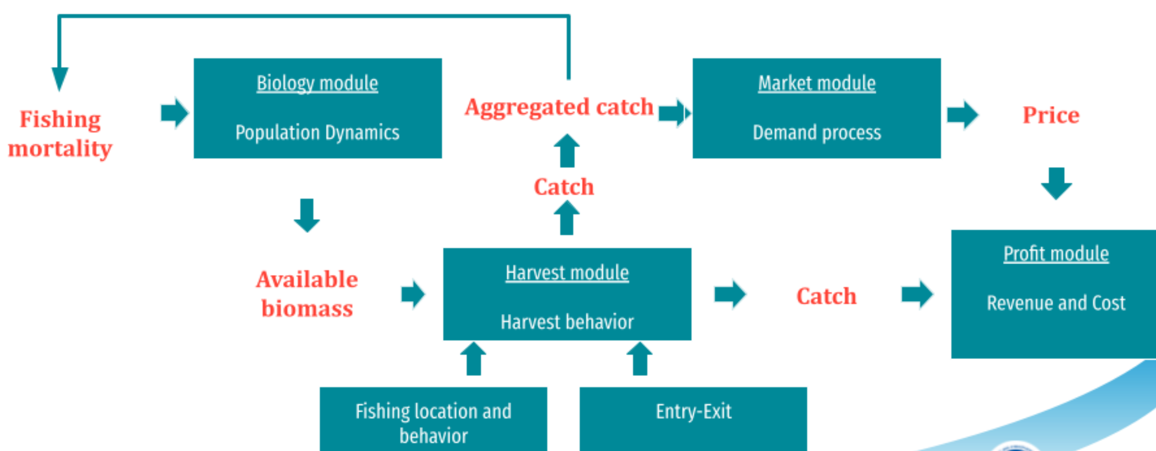
- Outside opportunities
- Availability of licenses
- Permits
- Space at dock
- Crew availability
- Commercial engagement
- Commercial reliance
- Age of fishers

Additional modules

- Proximity to biomass
- Size of business
- Experience of captain
- Tradition
- Weather
- Displacement by closures

NOAA FISHERIES 13

Augmented simulation



NOAA FISHERIES 14

Data availability for the harvest modules

- Annual operating and fixed costs surveys, of federally permitted vessels, conducted by the SSB-NEFSC in 2011, 2012, and 2015.
- Vessel-level survey of lobster business in 2005 and 2010 conducted by GMRI.
- Federal and State dealers reported catch and revenue
- Federal and State trip reports
- Federal and State permit data

NOAA FISHERIES 15

Additional factors

- Interaction with other sectors
- Competition for ocean space
- Offshore wind developments
- Non-economic values
- Island vs mainland dependence on the fishery
- Homeport infrastructure
- Demographic change

NOAA FISHERIES 16

Basics of currently existing Biological Module

- Written in R and structured to mirror the lobster length-based stock assessment model. Used for stock projections.
- Model tracks populations by sex in 5mm length bins in monthly time steps.
- No spatial structure, just aggregate numbers in the population.
- Model outputs catch numbers and mortality at size.

Time Invariant Inputs:

•Sizes at recruitment

•Recruitment seasonality

•Growth and seasonality of molting

•Size at maturity

•Length – weight relationship

Time variant inputs:

•Fishing mortality or catch

•Recruitment

•Natural Mortality

•Legal selectivity (legal size)

•Gear selectivity (availability to gear)

•Conservation selectivity (egg bearing, Vnotch, etc.)

NOAA FISHERIES 17

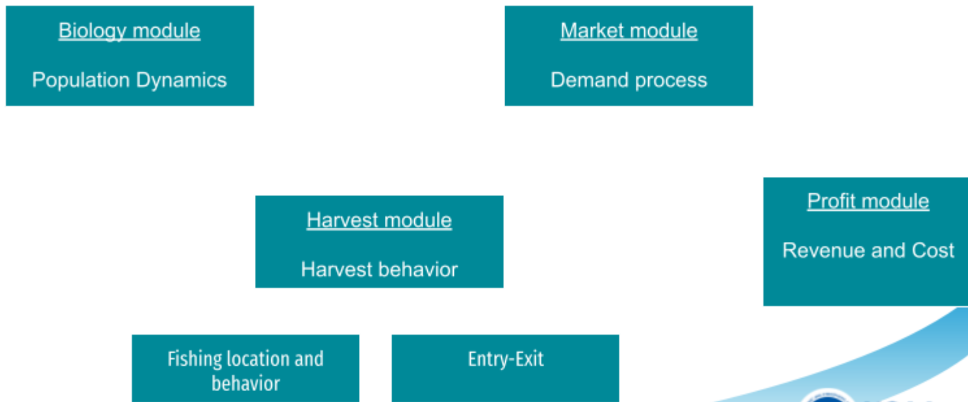
Envisioned Biological Model Intermediate-Complexity

- Biggest priority would be to model spatial distribution of stock, allowing for spatial economic processes.
- Not specifically done before but various ways this might be attempted with different levels of complexity.
    - Simple (relatively): Build a monthly climatology of lobster biomass based on surveys. Interpolate for unsampled months. Then spatially apply the aggregate biomass across the distribution map.
        - Could be implemented within a reasonable timeframe.
        - Would not be able to track spatial depletion.
    - Complex (really): Build a fully spatial population model with local dynamics and depletion.
        - Would require significant time and effort to construct.

NOAA FISHERIES 18

Whiteboard

Are we missing any modules?



19

Whiteboard:

What other data is available?

20

References

- Cheng, H.-T., & Townsend, R. E. (1993). *Potential Impact of Seasonal Closures in the U.S. Lobster Fishery*. Marine Resource Economics, 8(2), 101–117.
- Dow, R. L., Bell, F. W., & Harriman, D. M. (1975). *Bioeconomic Relationships for the Maine Lobster Fishery with Consideration of Alternative Management Scheme* (Technical Report NMFS). NOAA.
- Dayton, A. M., Sun, J., & Labaree, J. (2014). *Understanding Opportunities and Barriers to Profitability in the New England Lobster Industry*. GMRI.
- Dayton, A. M. (2018). *Assessing Economic Performance of Maine's Lobster Fleet Under Changing Ecosystem Conditions In the Gulf of Maine*. University of Maine.
- Holland, D. S. (2011). *Planning for changing productivity and catchability in the Maine lobster fishery*. Fisheries Research, 110(1), 47–58.
- Richardson, E. J., & Gates, J. M. (1986). *Economic Benefits of American Lobster Fishery Management Regulations*. Marine Resource Economics, 2(4), 353–382.
- Wang, S. D. H., & Kellogg, C. B. (1988). *An Econometric Model for American Lobster*. Marine Resource Economics, 5(1), 61–70.

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Procedures for Issuing Manuscripts
in the Northeast Fisheries Science Center Reference Document (CRD)
and the Technical Memorandum (TM) Series

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of the nation's ocean resources and their habitat." As the research arm of the NMFS's Greater Atlantic Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS's mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (e.g., anonymously peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own series.

NOAA Technical Memorandum NMFS-NE – This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review, and most issues receive technical and copy editing.

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