ASSESSMENT OF LOBSTER (*HOMARUS AMERICANUS*) IN LOBSTER FISHING AREA 41 (4X + 5Z) FOR 2016

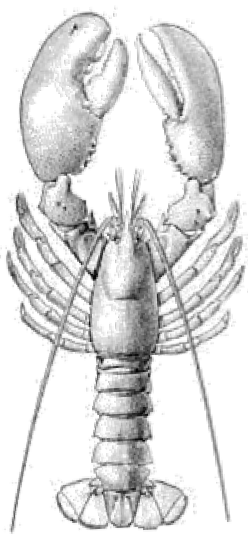

Image: Fishes of the Gulf of Marine; H.B. Bigelow and W.C. Schroeder 1953

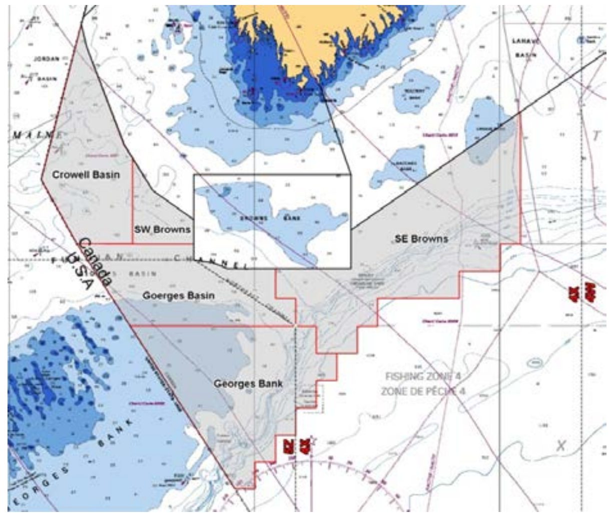

Figure 1. Map showing LFA 41 offshore subareas (4X - Crowell Basin, SW Browns, and SE Browns, and 5Z - Georges Basin and Georges Bank).

Context:

Lobsters (Homarus americanus) are found in coastal waters from southern Labrador to Maryland, with the major fisheries concentrated around the Gulf of St. Lawrence and the Gulf of Maine. Though lobster are most common in coastal waters, they are also found in deeper, warm water areas of the Gulf of Maine and along the outer edge of the continental shelf from Sable Island to off North Carolina.

The status of the Lobster Fishing Area (LFA) 41 offshore lobster resources in the Maritimes was last assessed in 2013. The fishery operates under the Offshore Lobster and Jonah Crab Integrated Fisheries Management Plan with 8 licences and a Total Allowable Catch (TAC) of 720t, and is authorized to fish in the NAFO Divs. 4X and 5Zc portions of LFA 41 (Figure 1). The fishery in LFA 41 is the only lobster fishery in Canada that is managed with a TAC. Indicators for lobster in LFA 41 are required to remain consistent with Fisheries and Oceans Canada's (DFO) precautionary approach and for the evaluation and monitoring of the fishery.

The objective was to apply the suite of indicators proposed during the 2017 framework to the stock status up to the end of the 2016 season.

This Science Advisory Report is from the September 27, 2017, Stock Assessment of American Lobster in Lobster Fishing Area (LFA) 41. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.

SUMMARY

- The Lobster Fishing Area (LFA) 41 fishery is the only lobster fishery in Canada managed with a total allowable catch (TAC), which has been set at 720 t since the mid-1980s.
- Primary indicators of stock status for the LFA 41 lobster stock show that the stock is currently in the Healthy Zone, with the commercial biomass for all four survey indices above their respective upper stock indicators.
- Reproductive potential is above the upper bounds, where defined, for all the survey indices with estimates of reproductive potential being at or near the highest values on record.
- The suite of contextual indicators show the current LFA 41 stock and ecosystem are characterized by higher survey abundances, smaller median body size with a lower maximum length, warmer bottom temperatures, expanding suitable lobster habitat, and decreased predator biomass compared to historic levels.
- The number of bycatch samples collected per year has been variable over time; since 2012 at-sea sampling has ranged from 12 to 17% of trips. The overall estimated non-lobster bycatch has declined from an average of 128.9 t (2008-2010) to an average of 21.6 t (2014-2016), which represented 3% of the total lobster landings.
- At the present time, the long-term TAC of 720 t poses minimal risk to the stock status falling into the Cautious Zone, as the stock has proven resilient to this level of removals across a broad range of biomasses.

BACKGROUND

Species Biology

The American Lobster (*Homarus americanus*) is a crustacean species that has been commercially fished since the early 1800s. This decapod has a complex life cycle characterized by several phases from eggs, larvae, juvenile, and adults, and relies on moulting its exoskeleton for an increase in size. Typically, the mature females mate after moulting in late summer, and extrude eggs the following summer. These eggs are attached to the underside of the tail to form a clutch. These are then carried for another 10-12 months and hatch in July or August. The eggs hatch into a pre-larvae or prezoea, and through a series of moults become motile larvae. These larvae spend 30-60 days feeding and moulting in the upper water column before the post-larvae settle to the bottom seeking shelter. For their first few years of life, juvenile lobsters remain in or near their shelter to avoid predation, spending more time outside of the shelter as they grow (Lavalli and Lawton 1996). Nova Scotia lobsters can take up to 8-10 years to reach a minimum commercial size of 82.5 mm Carapace Length (CL). Moulting frequency begins to decrease from 1 moult per year at about 0.45 kg to moulting every 2 or 3 years for lobsters above 1.4 kg (Aiken and Waddy 1980).

Lobsters mature at varying sizes depending upon local conditions (Aiken and Waddy 1980, Campbell and Robinson 1983, Comeau and Savoie 2002) with climatological factors such as temperature influencing the size-at-maturity. In LFA 41, the size (carapace length) at 50% maturity (SoM) has recently been estimated to be 92 mm CL (J. Gaudette and A.M. Cook, unpublished data). Decreases in size-at-maturity have been documented for many stocks and may be related to warming waters (Le Bris et al. 2017) and/or fisheries induced evolution (Haar et al. 2017) as observed in other LFAs where minimum legal sizes are smaller than the SoM.

In LFA 41, although the minimum legal size is below the SoM, the median size-at-capture is above this threshold, indicating a high proportion of the females caught have had the opportunity to breed. Female lobsters greater than 120 mm CL are able to spawn twice without an intervening moult (Waddy and Aiken 1986, Waddy and Aiken 1990), though this size may vary in nature (Comeau and Savoie 2002). This consecutive spawning strategy enables large lobsters to spawn more frequently over the long term than their smaller counterparts. This combined with the exponential relationship between body size and numbers of eggs produced (Campbell and Robinson 1983, Estrella and Cadrin 1995) means that very large lobsters have a much greater relative fecundity and are thus an important component to conservation. In the Gulf of Maine, the management plan and past assessments have looked at maintaining the high reproductive potential in this area by preserving its size structure dominated by mature animals, which has been a key component of stock assessments (Pezzack and Duggan 1987, Pezzack and Duggan 1995).

Fishery

The offshore fishery for American Lobster, which occurs in Lobster Fishing Area 41 (LFA 41), was established in 1971, although fishing had occurred prior to this time. The LFA 41 fishing area is delimited by the inshore/offshore 50 nautical mile line (92 km) off of Nova Scotia, and extends from Georges Bank to the Laurentian Channel off of Cape Breton (Figure 1, Cook et al. 2017). Traditionally, commercial fishing occurs on five major grounds: Georges Bank, Georges Basin, Crowell Basin, Southeast Browns Bank, and Southwest Browns Bank; all within the Northwest Atlantic Fishing Organization (NAFO) divisions 4X and 5Ze (Figure 1).

The Offshore Lobster Advisory Committee (OLAC) was formed in 1985, and served as a collaborative conservation strategy involving Fisheries and Oceans Canada (DFO) and the offshore lobster fleet. This decision body identified and adopted effort control measures that benefited both the biological and economical sustainability of the offshore fishery. Landings increased accordingly with the removal of American effort from Canadian fishing grounds and an introduction of the 720 t TAC.

The LFA 41 fishery has a total of 8 licenses currently issued to one company, Clearwater Seafoods Limited Partnership, and is the only lobster fishery in Canada managed with a TAC, which has been set at 720 t since the mid-1980s. In 1979, an area was closed to lobster fishing on Browns Bank, known as LFA 40. This closure was to protect lobster broodstock, and continues to remain in effect today. There has been a steady reduction of the number of vessels within LFA 41, and since 2011 one vessel has been used to catch the TAC. The status of LFA 41 offshore lobster was last assessed in 2013 (Pezzack et al. 2015).

Current management measures in LFA 41 include:

- **Fishing Season:** Year-round quota year (January 1 to December 31)
- **Minimum Legal Size:** 82.5 mm CL
- **Landing of berried and or v-notched females:** Prohibited
- **Trap Limit:** None
- **Number of licenses:** 8
- **Lobster TAC:** 720 t

Surveys

Fishery independent information is available from several ecosystem surveys conducted by DFO and Northeast Fisheries Science Center (NEFSC). The DFO Summer Research Vessel Survey covers the offshore portions on the Scotian Shelf (Figure 3 in Cook et al. 2017). The DFO Spring Research Vessel Survey covers the offshore portions on Georges Bank. The NEFSC surveys cover the Gulf of Maine and Georges Bank in the spring and autumn. Both DFO and NEFSC surveys have survey strata boundaries that do not conform to stock boundaries of LFA 41 (Figures 3 and 8 in Cook et al. 2017). As such, the survey strata were pruned to match the stock boundaries of LFA 41. For each abundance or biomass index, smoothed trends were shown using a running median. A running median was chosen over the more commonly used running mean as it is more resistant to influential data points.

ASSESSMENT

This stock assessment follows the Framework Assessment of 2017 (Cook et al. 2017) applying the methods and agreed upon primary and contextual indicators from that work. Upper Stock and Limit Reference indicators (USIs and LRIs, respectively) were developed for the biomass-based primary indicators to assess stock status. A reproductive potential primary indicator was developed, along with boundaries, to provide information on stock productivity. A suite of contextual indicators is also provided to encapsulate broad trends and ecosystem changes.

Primary Indicators and Stock Status

Primary indicators of stock status for the LFA 41 lobster show the stock is currently in the Healthy Zone, and has been since 2002. For the stock to be considered in the Healthy Zone, the commercial biomass indices for three of four surveys must be above their respective USIs (Figure 2). Currently, all four surveys are above their respective USIs. It is important to note that the stock status of LFA 41 has never been considered in the Critical Zone.

The coherence of biomass trends across surveys provides support to their value as stock status indicators as the surveys were performed in different seasons and under the direction of two different national agencies. Although the survey trends are showing the same general patterns, it is valuable to define reference indicators and maintain the separate analyses for each survey as indicators of stock status.

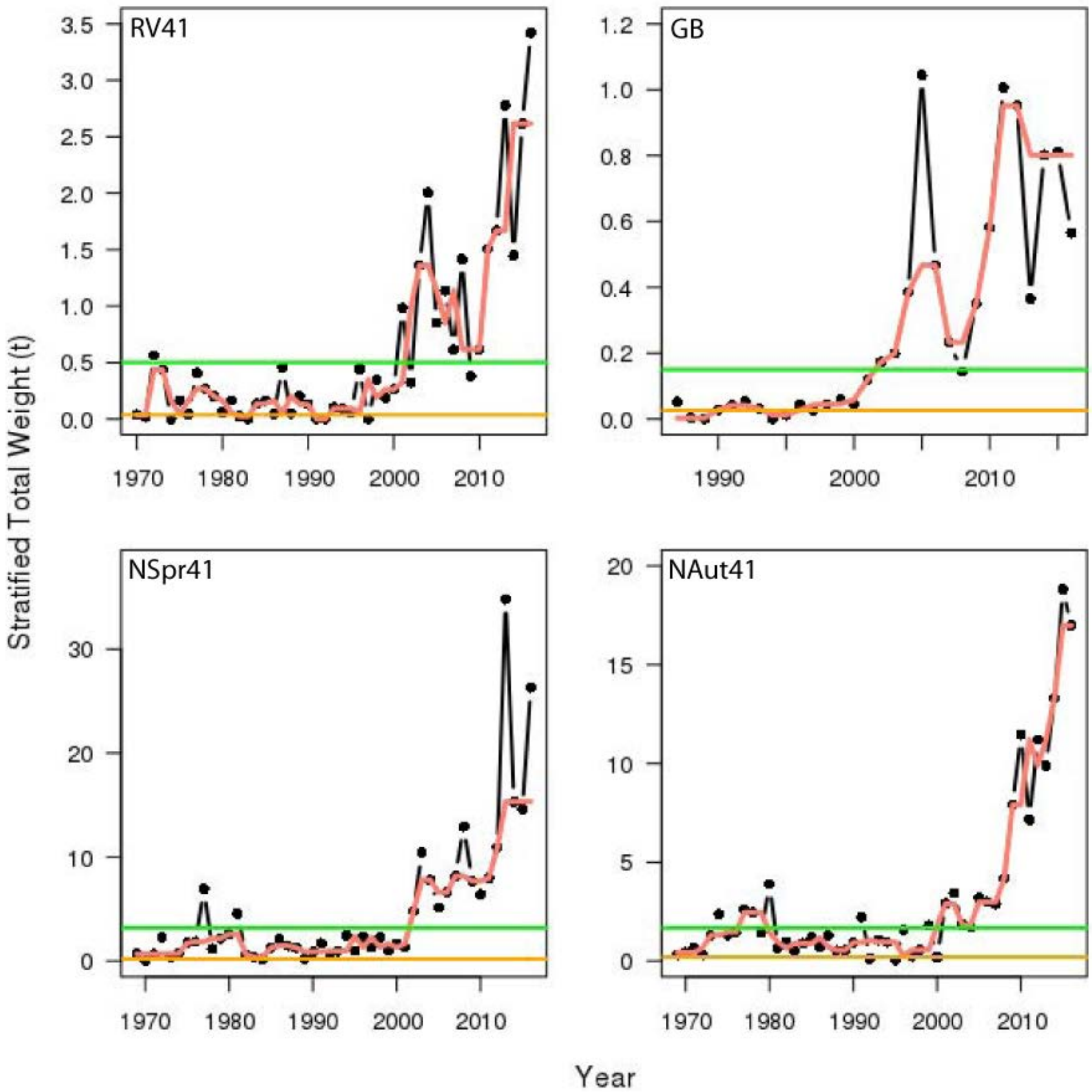

Figure 2. Commercial biomass time series along with the 3-year running median (red line), the median of the five lowest non zero biomasses (LRI; orange line), and 40% of the median of the higher productivity period (2000-2015;USI, green line). Top row: left - RV41, right - GB. Bottom row: left - NSpr41, right – NAut41. Note: Different scales used for y-axis.

Reproductive Potential

Reproductive potential is above the long-term average and above the respective Upper Bounds (UBs) (where there are sufficient data to define) in all survey indices. Estimates of reproductive potential are at or near the highest values on record (Figure 3) with one exception in NSpr41, where it has decreased from an extreme high in 2014, but remains within the top five estimates recorded.

The increase in overall abundance was the main driver of the increase in reproductive potential despite a decrease in median size of the lobsters observed in the at-sea samples.

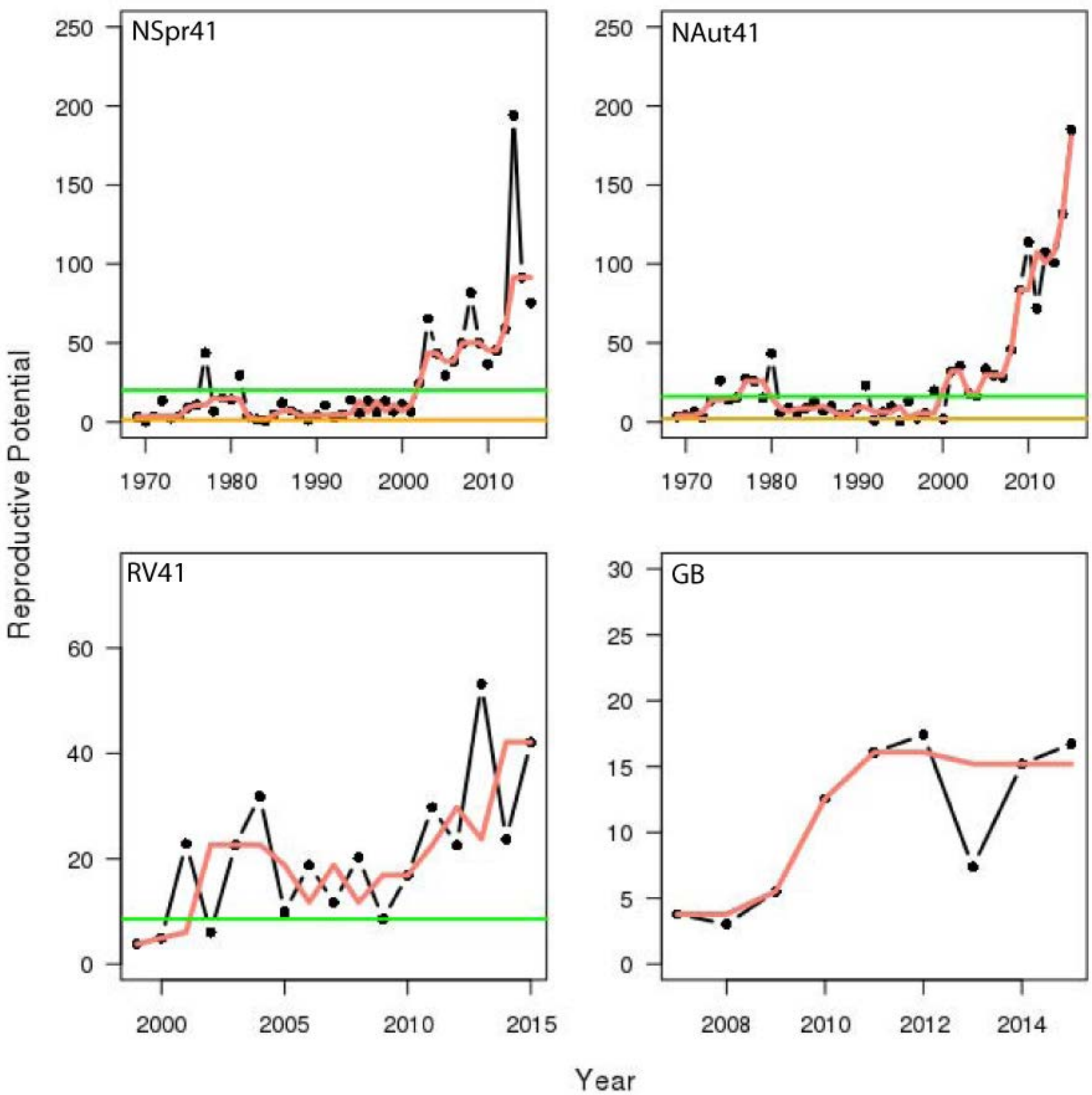

Figure 3. Reproductive potential in millions of eggs estimated from the four surveys covering LFA 41. Top row: left - NSpr41, right -NAut41. Bottom row: left - RV41, right - GB. Within panels reproductive potential time series along with the 3-year running median (red line). Where appropriate, the median of the five lowest non zero biomasses (lower boundary; orange line) and 40% of the median of the higher productivity period (upper boundary; green line) are shown. Note: Different scales on y-axis.

Contextual Indicators

The indicators described throughout this section were made directly comparable through statistical standardization (z-scores) after log transformations to normalize the appropriate indicators (e.g. abundance or biomass) and evaluated with a principal component analysis (Figure 4).

The changes over time were predominated by the decreasing body size metrics and increasing abundance trends and distribution (Figure 4). A decrease in both median size and maximum carapace length was observed in at-sea sampling of fishing activities. The body sizes recorded during surveys showed similar decreases although not to the same extent. The reduction in the patchiness (Gini) index was also present in the decreasing trends of indicators; however, a decreasing Gini index indicates a more evenly distributed stock, which is therefore considered a positive sign for stock status in LFA 41.

There was coherence between increasing abundance, biomass, and distribution of lobsters with increasing temperature and Atlantic Multi-decadal Oscillation (AMO) such that production and environmental characteristics have been changing at similar time periods. Long-term changes in the ecosystem structure and increases in habitat suitability have likely contributed to the increase in lobster productivity.

The suite of contextual indicators show the current LFA 41 stock and ecosystem are characterized by higher survey abundances, warmer bottom temperatures, smaller median body size with a lower maximum length, decreased predator biomass, and expanding suitable lobster habitat compared to historic levels.

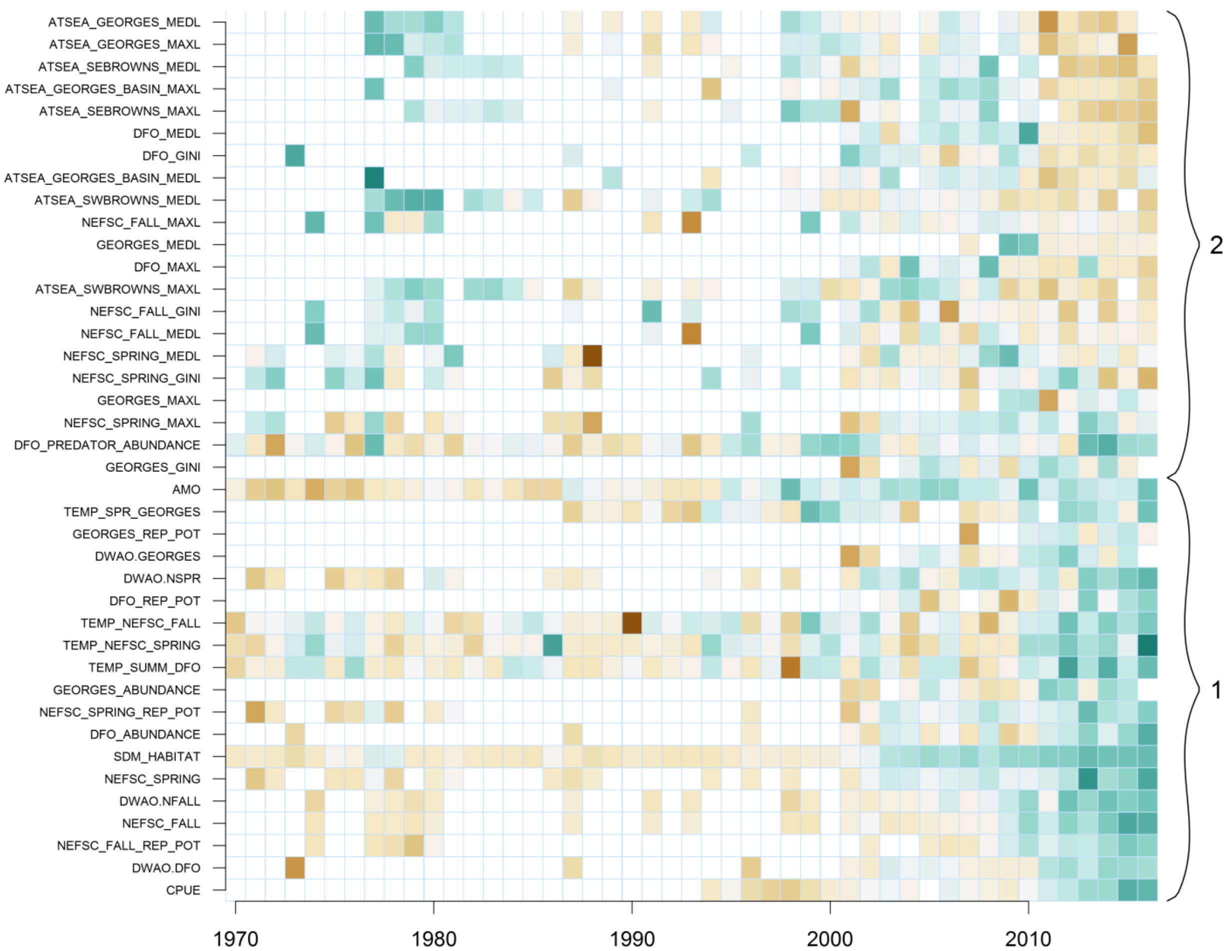

Figure 4. Time series of sorted anomalies from biological and ecosystem indicators associated with LFA 41. The green blocks indicate levels above the mean, whereas brown blocks indicate levels below the mean. White blocks indicate <20 observations were available for that indicator and time period. The sorting revealed common trends by type where abundance, habitat, and temperature based indicators were positive in recent years (1); and size and patchiness based indicators were negative (2).

Ecosystem Considerations

Significant ecosystem considerations are included explicitly in this assessment in the suite of indicators. Specific examples include the predator index, bottom temperature, and habitat index from a species distribution model. These indices are regularly updated to account for changes in the ecosystem that potentially affect the lobster population. Current trends in ecosystem indicators show warmer bottom temperatures, decreased predator biomass, and expanding suitable lobster habitat.

Bycatch

The number of bycatch samples collected per year has been variable over time; since 2012 at-sea sampling has ranged from 12 to 17% of trips.

Since 2012, the bycatch species that occurred most frequently in the LFA 41 lobster fishery were Jonah Crab, Cusk, Atlantic Cod, Red and White Hake, and Sea Raven (Table 1). Survival of the non-retained crustaceans has not been reported for lobster trap fisheries; however, return rates from lobster tagging studies and knowledge of species biology suggest that it is high for most invertebrates.

The overall estimated non-lobster bycatch has declined from an average of 128.9 t (2008-2010) to an average of 21.6 t (2014-2016), which represented 3% of the total lobster landings (Table 1). The gradual decrease in number of vessels throughout the years, and increased focus on areas of highest lobster Catch Per Unit Effort (CPUE), likely contributed to the reduction in bycatch. Cusk represented the largest estimated bycatch from 2014-2016 at 5.8 t.

Non-retained lobster catch consists of undersized, berried, v-notched and potentially cull (one or zero claws), soft and jumbos (>=140 mm CL). Observer data catch summaries and size frequencies indicate 23% and 26%, respectively, of the lobster caught in 2016 were returned to the water. All measures that return lobsters to the water contribute to maintaining the high reproductive potential in this stock.

The at-sea observer data was aggregated by three year time blocks to smooth the bycatch rates (Table 1). The top three bycatch species, Jonah Crab, Cusk, and Atlantic Cod catch rates have declined consistently over the time.

Table 1. The 3-year averages for total estimated bycatch and non-retained lobster in kilograms (kg) for LFA 41. Only lobster and the top 8 bycatch species are presented representing 98% of the total bycatch by weight.

Species	2008-2010	2011-2013	2014-2016
American Lobster	166,910	132,607	158,222
Jonah Crab	73,326	24,030	5,431
Cusk	23,314	11,892	5,840
Atlantic Cod	10,866	4,778	4,133
White Hake	4,485	5,588	4,854
Atlantic Rock Crab	13,944	43	191
Red Hake	299	1,430	663
Sea Raven	139	1,107	300
Haddock	2,479	182	150

Qualitative Risk Analysis of Harvest Options

The TAC for the LFA 41 fishery has been set at 720 t since the mid-1980s. An index of exploitation, relative fishing mortality (*relF*), has decreased to low levels largely due to the increase in biomass in recent years. Removal references have not been adopted due to the uncertainty associated with the productivity regime shift in LFA 41 and the relevance of historic relF on the current stock (Pezzack et al. 2015). At the present time, fishing at the current TAC poses minimal risk of the stock falling into the Cautious Zone.

Assessment Frequency and Interim Updates

It was proposed and agreed that the Lobster stock in LFA 41 would be assessed every five years, with interim Science Response reports conducted annually. The Science Response Report will include updates to bycatch plots, the commercial biomass time series, reproductive potential, time series of anomalies from the biological and ecological indicators, and the status of those results in relation to reference points. An assessment can be triggered in an update year. An earlier stock assessment could be triggered if the stock status approached the Cautious Zone for 2 of the 4 survey indices, or if any unforeseen change in stock characteristics became a cause for concern. A new framework would be triggered if the current approach does not provide the required information to characterize the stock.

Sources of Uncertainty

The Lobster stock in LFA 41 is likely comprised of migrants from adjacent stocks and the closed LFA 40. The degree of connectedness is not currently known, but may constitute a considerable fraction of the incoming biomass. This assessment treats LFA 41 as a closed stock and uses survey indices and fishery catch rates from within the stock area only. It is thought that this is a precautionary or conservative estimate of the Offshore Lobster stock as some of the most productive lobster areas are adjacent to LFA 41.

CONCLUSIONS AND ADVICE

Primary indicators of stock status for the LFA 41 lobster stock show that the stock is currently in the Healthy Zone, with all four survey indices above their respective USIs. Additionally, where bounds were defined, reproductive potential was above the upper bounds for the surveys. At the present time, the long-term TAC of 720 t poses minimal risk to the stock status falling into the Cautious Zone, as the stock has proven resilient to this level of removals across a broad range of biomasses.

The suite of contextual indicators suggested coherent trends over time with both the median size and maximum size of lobsters from at-sea sampling observations decreasing. The abundance, biomass, and distribution of lobsters in all four surveys within LFA 41 have been increasing in recent years and are currently at levels among the highest on record.

Accompanying the increase in abundance, bottom temperature has been approaching the highest levels recorded in recent years with large scale environmental forcing factors (AMO) being in a positive state.

SOURCES OF INFORMATION

This Science Advisory Report is from the September 27, 2017, Stock Assessment of American Lobster in Lobster Fishing Area (LFA) 41. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX

Description of contextual indicators used in Figure 4.

Indicators	Description
• ATSEA_GEORGES_MEDL • ATSEA_GEORGES_MAXL • ATSEA_GEORGES_BASIN_MEDL • ATSEA_ GEORGES_BASIN_MAXL • ATSEA_SWBROWNS_MEDL • ATSEA_SWBROWNS_MAXL • GEORGES_MEDL • GEORGES_MAXL • DFO_MEDL • DFO_MAXL • NEFSC_FALL_MEDL • NEFSC_FALL_MAXL • NEFSC_SPRING_MEDL • NEFSC_SPRING_MAXL	**Size – Median and Maximum** Broad size distribution provides an indication of the stability of populations. In populations that are heavily fished, size distributions skew toward smaller individuals as the increased total mortality (natural + fishing) decreases the probability of reaching old ages and/or large body sizes. Size distributions skewed toward small (or large) individuals may occur for a variety of reasons including the loss of large individuals or an increase in the abundance of small individuals. Using size frequency distributions from the surveys and at-sea samples collected during fishing operations the changes in the median and maximum were documented. The maximum of the size distribution was used to track changes in the large animals to provide context to the estimates of the median. Data collected at-sea was separated by fishing area within LFA 41 but not by fishing season, as differences in the size distribution was predominantly affected by area.
• GEORGES_GINI • DFO_GINI • NEFSC_FALL_GINI • NEFSC_SPRING_GINI	**Patchiness - Gini Index** The Gini index provides a measure of patchiness from data provided where 0 is a perfectly even distribution and 1 is maximum pachiness. Specifically, the Gini index quantifies the areal difference between Lorenz curves of the sorted cumulative proportion of total area to the cumulative proportion of total catch.
• AMO	**Atlantic Multidecadal Oscillation** The Atlantic multidecadal oscillation is alternating warm and cold periods of the North Atlantic which has been recently recognized to have occurred over the last 150 years.
• DWAO.GEORGES • DWAO.NFALL • DWAO.NSPR • DWAO.GEORGES	**Design Weighted Area Occupied** Changes in distribution through the total area occupied were considered important to document, as they provide information on the breadth of the habitat usage for the stock as well as their susceptibility to localized depletion, through anthropogenic or ecological events.

Indicators	Description
• NEFSC_SPRING • NEFSC_FALL • DFO_ABUNDANCE • GEORGES_ABUNDANCE • CPUE	**Abundance** Annual trends in abundance of lobster captured in the trawl surveys and CPUE from the fisher and CPUE from the fishery.
• TEMP_SPR_GEORGES • TEMP_SUMM_DFO • TEMP_NEFSC_SPRING • TEMP_NEFSC_FALL	**Bottom Temperature** Biological processes such as molting, growth, gonadal development, and egg development are influenced by water temperatures. The trends in bottom temperature obtained during the same surveys where lobster are being sampled were presented here.
• SDM_HABITAT	**Species Distribution Modelling** An integration of the temporal trends in species occurrence data with environmental data that allows for the identification of trends in the amount of suitable habitat.
• NEFSC_SPRING_REP_POT • NEFSC_FALL_REP_POT • DFO_REP_POT • GEORGES_REP_POT	**Reproductive Potential** Reproductive potential, expressed as an index of egg production, for each survey and year was estimated on a length basis using the annual stratified mean numbers of female at length incorporating fecundity and maturity at length relationships
• DFO_PREDATOR_ABUNDANCE	**Predator Index** Predator release has been suggested to be one contributing factor to the recent increase in lobster abundance. These are indices represent the combined abundance of lobster predators. includes Cunners, sculpins, skates, Cod, Spiny Dogfish, Sea ravens, Wolffish, Haddock, Hake, Plaice, Wolffish and crabs.

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