NCRL subject guide 2018-02
doi:10.7289/V5/SG-NCRL-18-02

Northeast Multispecies Fishery Management Plan Resource Guide: Atlantic Cod (Gadus Morhua)

Bibliography

Jamie Roberts, Librarian, NOAA Central Library

January 2018

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
NOAA Central Library – Silver Spring, Maryland

Table of Contents

Background & Scope

The Northeast Multispecies Fishery Management Plan (FMP) was implemented in 1986 to reduce fishing mortality of heavily fished groundfish stocks and to promote rebuilding to sustainable biomass levels. Thirteen species are managed through plan amendments and framework adjustments to the original plan, including: Atlantic cod, haddock, yellowtail flounder, American plaice, witch flounder (grey sole), winter flounder (black back), Acadian redfish, white hake, Pollock, windowpane flounder, ocean pout, Atlantic halibut, and the Atlantic wolffish. This bibliography focuses on Atlantic cod, and is intended as a primer and reference resource for staff of the National Marine Fisheries Service, Greater Atlantic Regional Fisheries office. It is organized into four sections: Biology (life history), Ecology (interaction with the environment), Fishery, and Management.

Section I - Biology

Section one is intended to provide an overview of the life history of Atlantic cod. The research in this area is a compilation of basic facts including diet, lifespan and habitat as well as current research on Atlantic cod Biology.

Section II – Ecology

Section two is intended to provide an overview of how Atlantic cod interacts with the environment. The citations in this area focus on how temperature, food resources, predation, and artificial sound impact wild Atlantic cod.

Section III – Fishery

Section three is intended to provide an overview of the Atlantic cod fishery. It is divided into two sections: Modern and Historical. The Modern section contains both news articles and scientific publications about the current state of the Atlantic cod fishery. The Historical section contains resources on the pre-1900s Atlantic cod fishery.

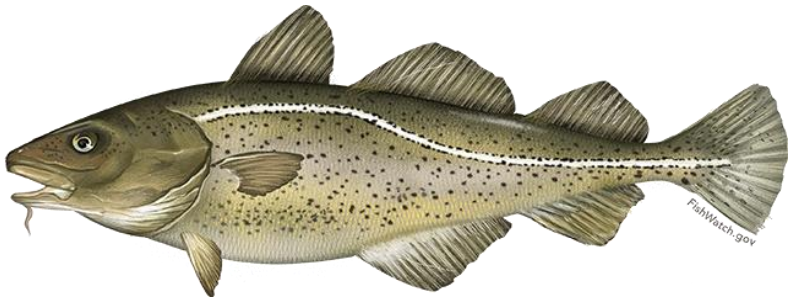
Section IV – Management

Section four is intended to provide an overview of the management of the Atlantic cod fishery. It includes news articles and research concerning plans and policies intended to protect and restore the Atlantic cod population.

Sources Reviewed

Along with a web search for news items and other relevant materials the following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded, Nexis.com, ProQuest's Science and Technology, and JSTOR. Only English language materials were included. There was no date range specification in order to cover any relevant research, although priority was given to publication in the last twenty years focusing on wild populations in the Atlantic region.

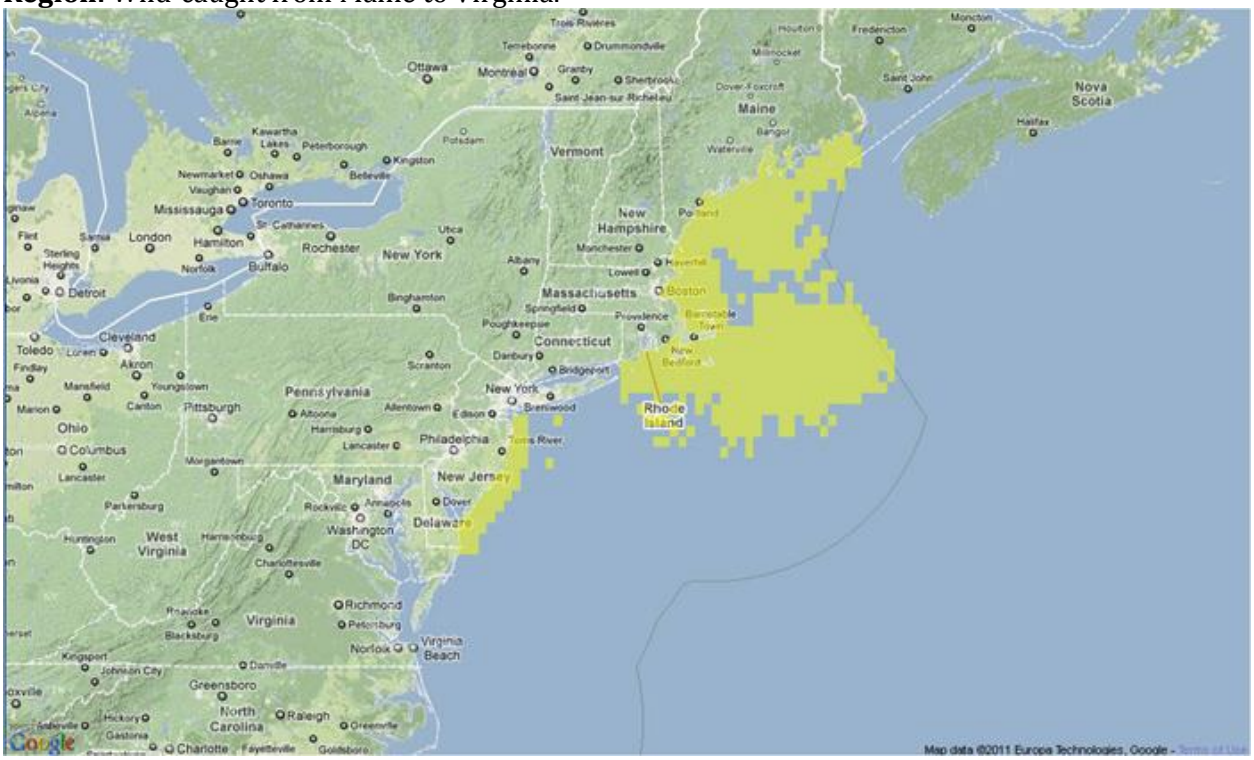
Section I: Biology



Images from http://www.fishwatch.gov/profiles/atlantic-cod

Also known as: Cod, Codling, Scrod cod, Markets, Steakers.

Region: Wild-caught from Maine to Virginia.



http://www.fishwatch.gov/profiles/atlantic-cod

Habitat: Atlantic cod live near the ocean floor along rocky slopes and ledges. They prefer to live in cold water, at depths of around 30 to 500 feet, on bottoms with coarse sediments, rather than on finer mud and silt.

Size: Atlantic cod can grow up to 51 inches and 77 pounds.

Physical Description: Atlantic cod are heavy-bodied with a large head, blunt snout, and a distinct barbel (a whisker-like organ, like on a catfish) under the lower jaw. Their coloring varies, ranging from light yellowish-green to red and olive, usually with darker speckles on the head, fins, tail, and body. The belly is light colored and usually spotless. Individuals can change color readily. Cod have an obvious lateral line (the faint line that runs lengthwise down each side of the fish).

Lifespan: Atlantic cod can live more than 20 years They are capable of reproducing at 2 to 3 years old, when they are between 12 and 16 inches long. Cod spawn near the ocean floor from winter to early spring. Larger females can produce 3 to 9 million eggs when they spawn.

Diet: They are top predators in the bottom ocean community, feeding on a variety of invertebrates and fish.

Source: NOAA. (10/20/2017). FishWatch U.S. seafood facts: Atlantic cod. Retrieved from http://www.fishwatch.gov/profiles/atlantic-cod

Von Krogh, K., Bjorndal, G. T., Nourizadeh-Lillabadi, R., Hodne, K., Ropstad, E., Haug, T. M., & Weltzien, F. A. (2017). Sex steroids differentially regulate fshb, lhb and gnrhr expression in Atlantic cod (Gadus morhua) pituitary. Reproduction, 154(5), 581-594. https://doi.org/10.1530/rep-17-0208

Depending on the stage of gonad maturation, as well as other factors, gonadal steroids can exert either a positive or negative feedback at the brain and pituitary level. While this has been demonstrated in many teleost species, little is known about the nature of steroid feedback in Gadiform fish. Using an optimized in vitro model system of the Atlantic cod pituitary, the present study investigated the potential effects of two physiologically relevant doses of estradiol, testosterone (TS) or dihydrotestosterone (DHTS) on cell viability and gene expression of gonadotropin subunits (fshb/lhb) and two suggested reproduction-relevant gonadotropin-releasing hormone receptors (gnrhr1b/gnrhr2a) during three stages of sexual maturity. In general, all steroids stimulated cell viability in terms of metabolic activity and membrane integrity. Furthermore, all steroids affected fshb expression, with the effect depending on both the specific steroid, dose and maturity status. Conversely, only DHTS exposure affected lhb levels, and this occurred only during the spawning season. Using single-cell qPCR, co-transcription of gnrhr1b and gnrhr2a was confirmed to both fshb- and lhb- expressing gonadotropes, with gnrhr2a being the most prominently expressed isoform. While steroid exposure had no effect on gnrhr1b expression, all steroids affected gnrhr2a transcript levels in at least one maturity stage. These and previous results from our group point to Gnrhr2a as the main modulator of gonadotropin regulation in cod and that regulation of its gene expression level might function as a direct mechanism for steroid feedback at the pituitary level.

Wilmot, C. (2005). "Gadus morhua" (On-line). *Animal Diversity Web.* Retrieved from http://animaldiversity.org/accounts/Gadus_morhua/

Basic cod biology, along with more information about diet/predation. “Atlantic cod populations respond differently to predators depending on what region of the Atlantic Ocean they occupy. Atlantic cod are susceptible to being consumed by large marine mammals (harp and harbor seals)

and sharks. In the northwest Atlantic Ocean most of the large predatory fish have been removed and cod (and similar species) act as dominant predators in this region. In other parts of the Atlantic Ocean with large harp seal populations the number of Atlantic cod has been greatly reduced due to consumption by seals. Cod larvae are vulnerable to smaller predators such as zooplankton. Juveniles are preyed on by species such as dogfish, squid, and halibut. Cannibalistic behavior becomes apparent as adult Atlantic cod readily consume juveniles. Although adult Atlantic cod have relatively few predators compared to their young, they still must be on the lookout for large marine animals. The greatest predatory threats to cod are those that lurk above the surface. Humans are responsible for drastically lowering Atlantic cod populations through well-developed fisheries. The economy of several regions is dependent upon these fisheries and the great demand for large numbers of Atlantic cod has resulted in overfishing and reduced cod stocks."

Lannig, G., Bock, C., Sartoris, F. J., & Portner, H. O. (2004). Oxygen limitation of thermal tolerance in cod, Gadus morhua L., studied by magnetic resonance imaging and on-line venous oxygen monitoring. American Journal of Physiology-Regulatory Integrative and Comparative Physiology, 287(4), R902-R910. https://doi.org/10.1152/ajpregu.00700.2003

The hypothesis of an oxygen-limited thermal tolerance due to restrictions in cardiovascular performance at extreme temperatures was tested in Atlantic cod, Gadus morhua (North Sea)... In conclusion, progressive cooling or warming brings cod from a temperature range of optimum cardiac performance into a pejus range, when aerobic scope falls before critical temperatures are reached. These patterns might cause a shift in the geographical distribution of cod with global warming.

Lough, R. G. (2004). *Essential Fish Habitat Source Document: Atlantic Cod, Gadus morhua, Life History and Habitat Characteristics* Retrieved from https://www.nefsc.noaa.gov/publications/tm/tm190/tm190.pdf

The initial series of EFH species source documents were published in 1999 in the NOAA Technical Memorandum NMFS-NE series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the Atlantic cod EFH source document is based on the original by Michael P. Fahay, Peter L. Berrien, Donna L. Johnson, and Wallace W. Morse, with a foreword by Jeffrey N. Cross (Fahay et al. 1999). Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA

Michael P. Fahay, P. L. B., Donna L. Johnson,, & Morse, a. W. W. (1999). *Essential Fish Habitat Source Document: Atlantic Cod, Gadus morhua, Life History and Habitat Characteristics*. Retrieved from https://www.nefsc.noaa.gov/publications/tm/tm124/tm124.pdf

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans….NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity. Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

Section II: Ecology

Guan, L., Chen, Y., Staples, K. W., Cao, J., & Li, B. (2017). The influence of complex structure on the spatial dynamics of Atlantic cod (Gadus morhua) in the Gulf of Maine. Ices Journal of Marine Science, 74(9), 2379-2388. https//:doi.org/10.1093/icesjms/fsx064

Atlantic cod (Gadus morhua) in the Gulf of Maine (GOM) is an iconic marine fishery stock that has experienced a substantial distributional shift since the mid-1990s. A geostatistical delta-generalized linear mixed model was utilized to hindcast yearly season-specific distributions of GOM cod. These distributions were calculated using the spring and fall bottom trawl survey data for the stock, along with cell-based bathymetry and bottom temperature data for the study area for the years 1982-2013. The centre of stock distribution (the centre of gravity), spatial extent in latitude and longitude, area occupied and median habitat temperature were estimated annually to quantify changes in the spatial dynamics of GOM cod. Time series of these distributional metrics were then used to evaluate the influences of climate change and density-dependent habitat selection on GOM cod's distribution. Results showed that the rapid southwestward shift in the stock distribution after the late 1990s could not simply be attributed to decreasing stock abundance or warming bottom temperatures. The observed shift in cod distribution requires further investigation on whether it is possibly a result of other factors, like fluctuating productivity among subpopulations

Stanley, J. A., Van Parijs, S. M., & Hatch, L. T. (2017). Underwater sound from vessel traffic reduces the effective communication range in Atlantic cod and haddock. Scientific Reports, 7. https://doi.org/10.1038/s41598-017-14743-9

Stellwagen Bank National Marine Sanctuary is located in Massachusetts Bay off the densely populated northeast coast of the United States; subsequently, the marine inhabitants of the area are exposed to elevated levels of anthropogenic underwater sound, particularly due to commercial shipping. The current study investigated the alteration of estimated effective communication spaces at three spawning locations for populations of the commercially and ecologically important fishes, Atlantic cod (Gadus morhua) and haddock (Melanogrammus aeglefinus). Both the ambient sound pressure levels and the estimated effective vocalization radii, estimated through spherical spreading models, fluctuated dramatically during the three-month recording periods. Increases in sound pressure level appeared to be largely driven by large vessel activity, and accordingly exhibited a significant positive correlation with the number of Automatic Identification System tracked vessels at the two of the three sites. The near constant high levels of low frequency sound and consequential reduction in the communication space observed at these recording sites during times of high vocalization activity raises significant concerns that communication between conspecifics may be compromised during critical biological periods. This study takes the first steps in evaluating these animals' communication spaces and alteration of these spaces due to anthropogenic underwater sound.

Dahlke, F. T., Politis, S. N., Butts, I. A. E., Trippel, E. A., & Peck, M. A. (2016). Fathers modify thermal reaction norms for hatching success in Atlantic cod, Gadus morhua. *Journal of Experimental Marine Biology and Ecology, 474*(Supplement C), 148-155.https://doi.org/10.1016/j.jembe.2015.10.008

Climate-driven warming is altering marine ecosystems at an unprecedented rate and evolutionary adaptation may represent the last resort for many ectothermic organisms to avoid local extinction...This study examined how males differ in their ability to sire viable offspring and whether the paternal contribution modified thermal reaction norms for hatching success in two replicated trials with cod Gadus morhua from the Northwest Atlantic (trial 1) and Baltic Sea (trial 2). Each trial included five temperature treatments (2.0, 4.0, 6.0, 8.0, 10.0°C in trial 1, and 6.5, 8.0, 9.5, 11.0, 12.5°C in trial 2) encompassing optimum conditions as well as the amount of warming projected in various future pathways for the year 2100. In both trials, mean hatching success significantly decreased towards thermal extremes...The observed magnitude of genetic variation underlying thermal reaction norms for embryo viability represents a relevant resource for adaptive responses (favorable selection) of cod populations exposed to environmental variability and/or directional changes, such as ongoing ocean warming.

Liboiron, M., Liboiron, F., Wells, E., Richárd, N., Zahara, A., Mather, C. . . . Murichi, J. (2016). Low plastic ingestion rate in Atlantic cod (Gadus morhua) from Newfoundland destined for human consumption collected through citizen science methods. *Marine Pollution Bulletin, 113*(1), 428-437. https://doi.org/10.1016/j.marpolbul.2016.10.043

Using citizen science during the Newfoundland recreational cod fishery, we sampled 205 Atlantic cod (Gadus morhua) destined for human consumption and found that 5 had eaten plastic, an ingestion prevalence rate of 2.4%. This ingestion rate for Atlantic cod is the second lowest recorded

rate in the reviewed published literature (the lowest is 1.4%), and the lowest for any fish in the North Atlantic.

Sierra-Flores, R., Atack, T., Migaud, H., & Davie, A. (2015). Stress response to anthropogenic noise in Atlantic cod Gadus morhua L. *Aquacultural Engineering, 67*(Supplement C), 67-76. https://doi.org/10.1016/j.aquaeng.2015.06.003

The potential effects of anthropogenic noise on the physiology of Atlantic cod have not been well described. The aim of the present study was to investigate the impact of anthropogenic noise on Atlantic cod stress response using cortisol as a biomarker as well as on broodstock spawning performance. Results showed that artificial noise consisting of a linear sweep from 100 to 1000Hz can induce a transient and mild cortisol elevation with a clear noise intensity dose response. In all cases plasma levels returned to baseline levels <1h post sound exposure. Daily exposure to a similar intensity and frequency noise range applied habitually to a broodstock population during the spawning window resulted in a significant reduction in total egg production and fertilisation rates thus reducing the total production of viable embryos by over 50%. In addition, a significant negative correlation between egg cortisol content and fertilisation rate was observed. These results confirm that cod can perceive noise generated within a frequency range of 100–1000Hz and display a heightened cortisol plasma level. In addition, anthropogenic noise can have negative impacts on cod spawning performances.

Lilley, R. J., & Unsworth, R. K. F. (2014). Atlantic Cod (Gadus morhua) benefits from the availability of seagrass (Zostera marina) nursery habitat. *Global Ecology and Conservation, 2*(Supplement C), 367-377. https://doi.org/10.1016/j.gecco.2014.10.002

This paper provides strong evidence that eelgrass meadows are of significant importance to contributing to Atlantic cod stocks.

Gurshin, C. W. D., Howell, W. H., & Jech, J. M. (2013). Synoptic acoustic and trawl surveys of spring spawning Atlantic cod in the Gulf of Maine cod spawning protection area. *Fisheries Research, 141*(Supplement C), 44-61. https://doi.org/10.1016/j.fishres.2012.09.018

Repeated acoustic and trawl surveys were performed in the Gulf of Maine cod spawning protection area (GOMCSPA) to: (a) describe the spatial and temporal distribution of spring-spawning Atlantic cod (Gadus morhua); (b) estimate their abundance and biomass; and (c) evaluate precision of the survey methods. A fishing vessel equipped with 38- and 120-kHz split-beam echo sounders surveyed once monthly from dusk to dawn along ten parallel transects that covered a 80.8km2 area during April–July 2011. During each survey, two bottom trawl vessels (one with a small mesh net and one with a large mesh net) each made ten tows in parallel behind the acoustic survey vessel. Cod abundance and biomass was derived from acoustic backscatter by a combination of methods: (1) species apportionment based on trawl catch vs. echo classification; (2) in situ vs. predicted target strength; (3) size of elementary distance sampling unit (EDSU) and statistical approach; and (4) with and without dead zone correction. The mean cod density based on echo classification and a 100-m EDSU resulted in a substantially lower coefficient of variation when the variance was estimated by geostatistics compared to any other method used. Based on echo classification, semivariogram modeling revealed that 67–77% of the variance in cod biomass density was explained by a spatial structural component at a range (correlation length) of 2.0–2.4km. Density

maps, produced by ordinary kriging, showed cod were relatively widespread in the survey area in May, but congregated at higher densities in areas adjacent to two elevated bathymetric features. Most cod converged to a single location in June, and were at a higher concentration compared to the highest densities observed in May. This congregation decreased in size and density in July. The survey estimates of cod biomass were 184–494 mt in May, 138–617 mt in June, and 39–135 mt in July. Based on echo classification, the biomass for the GOMCSPA, extrapolated from these survey estimates, were 260–466 mt in May, 196–513 mt in June, and 91–198 mt in July. These results provide some evidence that adult Atlantic cod in spawning condition congregated within the GOMCSPA during the seasonal fishing closure, and that the biomass being protected by the closure may have represented 4–5% of the GOM cod spawning stock biomass at the time of the study.

Hardie, D. C., & Hutchings, J. A. (2011). The Ecology of Atlantic Cod (Gadus morhua) in Canadian Arctic Lakes. *Arctic, 64*(2), 137-150. http://dx.doi.org/10.14430/arctic4095

The range of limnological conditions that support Atlantic cod populations in meromictic Arctic lakes is known to be relatively restricted. The degree to which differences in these features, particularly in the availability of allochthonous and autochthonous prey, affect the condition and growth of cod in these populations is unknown. We compared measures of condition among three Atlantic cod populations on Baffin Island, Nunavut, to assess their relationship to differences in potentially important habitat parameters. We also compared data spanning two decades (Ogac Lake) to five decades (Qasigialiminiq) to assess the degree to which natural and anthropogenic factors may have affected these populations. In general, growth rate and asymptotic length tend to be high under situations of intense cannibalism and when alternative prey species are relatively abundant.

Link, J. S., Bogstad, B., Sparholt, H., & Lilly, G. R. (2009). Trophic role of Atlantic cod in the ecosystem. *Fish and Fisheries, 10*(1), 58-87. https://doi.org/10.1111/j.1467-2979.2008.00295.x

As the world's oceans continue to undergo drastic changes, understanding the role of key species therein will become increasingly important. To explore the role of Atlantic cod (Gadus morhua Gadidae) in the ecosystem, we reviewed biological interactions between cod and its prey, predators and competitors within six ecosystems taken from a broad geographic range: three are cod-capelin (Mallotus villosus Osmeridae) systems towards cod's northern Atlantic limit (Barents Sea, Iceland and Newfoundland–Labrador), two are more diverse systems towards the southern end of the range (North Sea and Georges Bank–Gulf of Maine), and one is a species-poor system with an unusual physical and biotic environment (Baltic Sea). We attempt a synthesis of the role of cod in these six ecosystems and speculate on how it might change in response to a variety of influences, particularly climate change, in a fashion that may apply to a wide range of species. We find cod prey, predators and competitors functionally similar in all six ecosystems. Conversely, we estimate different magnitudes for the role of cod in an ecosystem, with consequently different effects on cod, their prey and predator populations. Fishing has generally diminished the ecological role of cod. What remains unclear is how additional climate variability will alter cod stocks, and thus its role in the ecosystem.

Palakovich Carr, J., & Kaufman, L. (2009). Estimating the importance of maternal age, size, and spawning experience to recruitment of Atlantic cod (Gadus morhua). *Biological Conservation, 142*(3), 477-487. https://doi.org/10.1016/j.biocon.2008.10.004

Empirical studies have demonstrated the importance of maternal characteristics to egg and larval viability in Atlantic cod (Gadus morhua) and other marine teleosts. The effects of these advantages on total reproductive output of individual fish have not yet been studied. A model of an Atlantic cod population was constructed to determine the contribution of offspring by spawners of different spawning experience. First-, second-, and third-time spawners consisted of cod ages 1–9 years old and experienced spawners consisted of ages 10 and 11. Experienced spawners contributed 10.1–12.4 times more offspring surviving to age 1 than did less experienced spawners. Reproductive efforts by first- and second-time spawners were relatively unimportant. These insights are at odds with traditional maximum sustainable yield based management and lax management, both of which favor a population dominated by young breeders and ignore the large per capita production of recruits by experienced spawners. To be managed for biological survival and commercial viability, northwest Atlantic cod will require legal protection to prevent the harvest of these oldest ages of cod.

Stellwagen Bank National Marine Sanctuary Web Group. Movement of Atlantic Cod Retrieved from https://stellwagen.noaa.gov/science/site_fidelity.html

This project used acoustic telemetry technology to quantify cod movement over different features of the landscape to inform management of the SBNMS and the greater Gulf of Maine region.

Beaugrand, G., Brander, K. M., Lindley, J. A., Souissi, S., & Reid, P. C. (2003). Plankton effect on cod recruitment in the North Sea. Nature, 426(6967), 661-664. https://doi.org/10.1038/nature02164

... in addition to the effects of overfishing(1), fluctuations in plankton have resulted in long- term changes in cod recruitment in the North Sea (bottom- up control). Survival of larval cod is shown to depend on three key biological parameters of their prey: the mean size of prey, seasonal timing and abundance. We suggest a mechanism, involving the match/ mismatch hypothesis(2), by which variability in temperature affects larval cod survival and conclude that rising temperature since the mid- 1980s has modified the plankton ecosystem in a way that reduces the survival of young cod.

Section III: Fisheries

Modern: There are two stocks of Atlantic cod in U.S. waters, the Gulf of Maine and Georges Bank stocks. NOAA Fisheries and the New England Fishery Management Council manage Gulf of Maine cod. NOAA Fisheries and the New England Fishery Management Council collaborate with Canada to jointly manage Georges Bank cod, because the stock spans the international boundary. Atlantic cod, along with other groundfish in New England waters, are managed under the Northeast Multispecies Fishery Management Plan, which includes:

- Permitting requirements for commercial vessels.
- Separate management measures for recreational vessels.
- Year-round and seasonal area closures to protect spawning fish and habitat.

- Minimum fish sizes to prevent harvest of juvenile fish.
- Annual catch limits, based on best available science.
- An optional sector (catch share) program can be used for cod and other groundfish species. The sector program allows fishermen to form harvesting cooperatives and work together to decide when, where, and how they harvest fish.

Source: NOAA. (10/20/2017). FishWatch U.S. seafood facts: Atlantic cod. Retrieved from http://www.fishwatch.gov/profiles/atlantic-cod

Anders, N., Ferno, A., Humborstad, O. B., Lokkeborg, S., Rieucau, G., & Utne-Palm, A. C. (2017). Size dependent social attraction and repulsion explains the decision of Atlantic cod Gadus morhua to enter baited pots. Journal of Fish Biology, 91(6), 1569-1581. https://doi.org10.1111/jfb.13453

The present study tested whether the presence of already retained fishes inside baited fish pots acted as a social attraction and affected the entrance probability of Atlantic cod Gadus morhua in a fjord in northern Norway. Video analysis revealed that the probability of an entrance initially increased with the presence of low numbers of fishes inside the pot, but subsequently decreased at a critical number of caught fishes. The critical number was dependent on the size of the G. morhua attempting to enter. This demonstrates that social attraction and repulsion play a role in G. morhua pot fishing and has important implications for the capture efficiency of fisheries executed with pots.

Eayrs, S., Pol, M., Caporossi, S. T., & Bouchard, C. (2017). Avoidance of Atlantic cod (Gadus morhua) with a topless trawl in the New England groundfish fishery. *Fisheries Research, 185*(Supplement C), 145-152. https://doi.org/10.1016/j.fishres.2016.09.014

Low quotas of Atlantic cod in the New England groundfish fishery may restrict fishing with trawls for mixed stocks of groundfish...Our results suggest that a topless trawl can be an effective method of cod avoidance for fishermen in the region, without substantial loss of landable flatfish.

Whittle, P. (03/24/2017). Cod Fishing Catches Plummet in Waters off New England. Retrieved from https://www.usnews.com/news/best-states/maine/articles/2017-03-24/maines-cod-fishermen-have-worst-year-in-history

“State records say 2016 was historically bad for cod fishing in Maine. Fishermen brought less than 170,000 pounds (77,110 kilograms) of the fish to land in the state last year. The haul was below the previous record low of about 250,000 pounds (113,398 kilograms) a year earlier. Maine's record year for cod was 1991, when fishermen brought more than 21 million pounds (9.5 million kilograms) of the bottom dweller to the docks, according to records that date to 1950”

Abel, D. (08/06/2016). After years of decline cod and community rebound in Newfoundland. *Boston Globe*. Retrieved from https://www.bostonglobe.com/metro/2016/08/06/after-years-decline-cod-and-community-rebound-newfoundland/oNxKF14RpE47yc65OOAy6O/story.html

Interviews with fishermen and scientists about the small but vital rebound in the cod population.

National Marine Fisheries Services. *Status of Stocks 2016*. Retrieved from http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/archive/2016/status-of-stocks-2016-web.pdf

At the end of 2016, the overfishing list included 30 stocks and the overfished list included 38 stocks. The number of stocks rebuilt since 2000 increased to 41. NOAA Fisheries tracks 474 stocks or stock complexes in 46 fishery management plans, or FMPs. Each year, assessments of various fish stocks and stock complexes are conducted to determine their status. These assessments include stocks of both known status and previously unknown status. Based on assessments conducted by the end of 2016, four stocks were removed from the overfishing list and six were added. There were no changes in the number of stocks on the overfished list. As required by the MSA management framework, the councils are developing management measures to end overfishing and rebuild all stocks added to the overfishing and overfished lists.

Lavelle, M. (2015, Oct. 29, 2015). Collapse of New England's iconic cod tied to climate change. *ScienceMag.org*. Retrieved from https://doi.org/10.1126/science.aad4793

"Using recent Gulf of Maine cod stock assessments, the researchers then tested a number of models for predicting the factors that affected cod reproduction. Warming was the best predictor, they reported: **When summer temperatures went up, the number of fish reaching maturity went down**. "The number of new cod for each year that appear in the population is strongly related to temperature," Pershing says. "And that's ultimately what you need to rebuild a population and sustain a fishery: new fish coming in.""

Historical: The story of the Northwestern Atlantic Cod fishery begins in June of 1497 when John Cabot found what he called "New Found Land" and claimed it for the British. While the Basques had been fishing for cod in this area secretly for years, most of the cod fishing occurred off the coast of Europe. After Cabot's discovery, the British brought fleets over to Newfoundland to sustain the growing European desire for cod as 60% of all fish eaten in Europe in 1550 was cod. Cod played a key role in the slave trade; Ships full of cod would sail from New England, Nova Scotia, and Newfoundland to West Africa, where high quality cod was traded for slaves. From there the ships would take slaves and the remaining low quality cod to the West Indies, where the slaves would be sold to plantations, whose managers valued low quality cod as a cheap protein source for their workforce. The ships would then return to Boston carrying rum, molasses, sugar, tobacco, and salt. However, this triangle trade collapsed in the 1840s when slavery was abolished in the West Indies. In the early 1900s, the combination of refrigeration, engine-power, and trawls morphed together to create the factory fleets, which could catch fish and process them on board for weeks without returning to port. The development of these ships caused a commercial increase in cod catches worldwide. In response to the influx of foreign Deep Water Fleets (DWFs), President Truman issued a proclamation stating that the United States had the right to control all resources on its continental shelf. This was later extended in the Magnuson Fisheries Conservation and Management Act of 1976, which created the 200 mile exclusive economic zone off the coast of the U.S. In the late 1980s cod started to periodically disappear off of Newfoundland and Nova Scotia. On July 2, 1992, John Crosbie, the Canadian Fisheries Minister, placed a moratorium on the northern stock of cod, causing 30,000 fishermen to go out of work. Two years later, Fisheries minister, Brian Tobin, extended the moratorium indefinitely and all the Canadian Atlantic cod fisheries, except for one in

southwestern Nova Scotia, were closed. The Georges Bank and New England stocks also witnessed the drop in cod populations. In 1994, the National Marine Fisheries Services found that the Gloucester fishing fleet was two times larger than the existing cod populations could sustain and the cod stock off of Georges Bank was 40% of the biomass it had been in 1990. Consequently, each fishing vessel was restricted to 139 days at sea and 15% of the total stock. However, in 1996, 50% of the stock was culled, and the policy was changed to 88 days at sea.
Source: Kurlansky, M. (1997). *Cod: A Biography of the Fish That Changed the World*. Toronto: A.A. Knopf Canada.

Murawski, S. A. (mid-1990s). Brief history of the groundfishing industry of New England. Retrieved from https://www.nefsc.noaa.gov/history/stories/groundfish/grndfsh1.html#art

"By 1930 there were clear signs that the fleet had grown too efficient in relation to the capacity of the stocks to sustain growth in landings. A new round of scientific investigation, begun in 1930 at Harvard University, showed just how powerful the new technology was. In 1930 the fishery landed 37 million haddock at Boston, with another 70-90 million baby haddock discarded dead at sea! The very small mesh size used in the nets was judged the culprit. Yet not until 1953 did the first regulations specifying the minimum mesh size for trawl nets come into force."

Section IV: Management

NOAA. (10/20/2017). FishWatch U.S. seafood facts: Atlantic cod. Retrieved from http://www.fishwatch.gov/profiles/atlantic-cod

Scientists at NOAA's Northeast Fisheries Science Center conduct research bottom trawl surveys throughout the Northeast continental shelf every year during the fall and spring. These surveys collect data on the environment as well as biological samples from fish caught during research trawling. The data from these and other sources are used by scientists in stock assessments to estimate population size and fishing pressure.

Abel, D. (2017, April 4) FISHERIES: State survey confirms historic low cod population. *Greenwire Natural Resources, 10*(9). Retrieved from https://www.eenews.net/greenwire/2017/04/04/stories/1060052564

Scientists in Massachusetts have come to the same conclusion the federal government did years ago: The cod population in the state is at a historic low. Fishermen have said the government used faulty science to assess the New England cod population's health, but the latest research bears out the finding that the population is 80 percent smaller than it was 10 years ago.

Abel, D. (2016, August 24, 2016) *Cod Willing: David Abel on the Cod's Resurgence*. Sea Change Radio, Newstex. Retrieved from http://3blmedia.com/Profiles/Sea-Change-Radio

Radio Interview: Since 1992, fish 'n chips fans may have noticed that there was no cod in their classic fried dish. That's the year that the Canadian government issued a moratorium on fishing the

popular, tasty species. It devastated the Newfoundland region's economy, but it had to be done. The cod population had dwindled to nearly nothing at that time due to over-fishing and changing water temperatures. Our guest today on Sea Change Radio is Pulitzer Prize-winning journalist David Abel, who recently wrote a piece for the Boston Globe about how the cod has actually rebounded in recent times. We talk about the region's historical relationship with cod, how science-informed policy can help reverse human-generated ecological damage, and Abel's upcoming film on the subject, Sacred Cod.

Abel, D. (2016). FISHERIES: Stock data could suffer with NOAA survey's delay. *Greenwire Natural Resources, 10*(9). Retrieved from https://www.eenews.net/greenwire/2016/05/13/stories/1060037215

A government research vessel is setting sail much later than it intended, a delay that could mean bad news for scientists trying to assess fish health. The Henry B. Bigelow's annual spring voyage allows researchers to look at the state of 52 fish stocks, from North Carolina to the Gulf of Maine. Fish migrate and shift their feeding schedules as waters warm. The delayed launch may complicate matters for National Oceanic and Atmospheric Administration scientists who want to compare this year's survey with previous years.

Taitano, E, & Cooner, J.P. (2015). The Atlantic Cod Fishery. Retrieved from http://www.atlanticcodfishery.com/

Atlanticcodfishery.com was created by students at a New England prep school as a class assignment; it's a thoroughly referenced source that pulls together key details from fishery management plans.

Morris, C. J., & Green, J. M. (2014). MPA regulations should incorporate adaptive management—The case of Gilbert Bay Labrador Atlantic cod (Gadus morhua). *Marine Policy, 49*(Supplement C), 20-28. https://doi.org/10.1016/j.marpol.2014.03.025

Although an important conservation tool, Marine Protected Areas sometimes fall short of intended goals; however, adaptive management can potentially improve their effectiveness. Efforts to develop an MPA in Gilbert Bay, Labrador, Canada, began in 1998 to protect the genetically distinct population of Atlantic cod (Gadus morhua) and its habitat. Population monitoring and research conducted in Gilbert Bay during 26 research trips over 14 years have documented significant population declines. The biomass declined by as much as 83% and research catch rates by 54% since Gilbert Bay became a MPA in 2005. Commercial fishing in adjacent waters was strongly correlated (Pearson correlation r=−0.87, p=0.002), with the declining trend in research catch rates. Tag recaptures from the commercial fishery (n=105) confirmed that fishing removed large adult Gilbert Bay cod that seasonally move outside the MPA. Evidence of the production of strong year classes even at low adult population levels indicate that the Gilbert Bay cod population has the potential to increase rapidly under appropriate adaptive management; thus improving MPA effectiveness. A relatively small change in the timing of commercial fishing in waters adjacent to the MPA would likely produce this result; however, inflexible MPA regulations, and poor co-ordination and agreement among differing fishery management processes and stakeholders has delayed the implementation of such a change.

Armstrong, M. P., Dean, M. J., Hoffman, W. S., Zemeckis, D. R., Nies, T. A., Pierce, D. E., McKiernan, D. J. (2013). The application of small scale fishery closures to protect Atlantic cod spawning aggregations in the inshore Gulf of Maine. *Fisheries Research, 141*(Supplement C), 62-69. https://doi.org/10.1016/j.fishres.2012.09.009

Atlantic cod form spawning aggregations in locations and seasons that are persistent from year to year and individual fish have been shown to exhibit spawning site fidelity and home to specific spawning grounds each season. In the Gulf of Maine, cod are known to have historically occupied a mosaic of spawning grounds but many of these spawning components have been extirpated, primarily through overfishing, with a near complete loss of spawning along mid-coast and eastern Maine. The remaining spawning aggregations in the western Gulf of Maine are particularly vulnerable to over-exploitation owing to their proximity to shore, the predictability of their timing, the fine-scales upon which they operate, and the high density of fish within each aggregation. Broad scale management actions that are currently being discussed may allow an increased harvest from these spawning aggregations. In this paper we describe the creation of three small-scale area closures that serve to eliminate the exploitation and disturbance of discrete spawning aggregations of Atlantic cod and prevent the potential extirpation of these spawning components. Each closure was unique in the circumstances that surrounded their creation, including differences in the amount of prior protection from commercial and recreational exploitation, the timing and duration of the closure, the size of the closure area, the management body that had authority to enact the closure, the amount of monitoring that has occurred, and the amount of spatial or temporal modifications that have occurred since enactment. We believe the case for spawning closures for Atlantic cod has already been made by several authors and the purpose of this paper is not to present new science, but rather to show the path that was followed to create these spawning closures within the complicated array of fisheries management.

Palmer, M. C., & Wigley, S. E. (2007). *Validating the stock apportionment of commercial fisheries landings using positional data from vessel monitoring systems (VMS)*. Retrieved from https://www.nefsc.noaa.gov/publications/crd/crd0722/crd0722.pdf

Vessel Monitoring System (VMS) positional data from northeast United States fisheries were used to validate the statistical area fished and stock allocation of commercial landings derived from mandatory Vessel Trip Reports (VTR). A gear-specific speed algorithm was applied to 2004–2006 VMS data from the otter trawl, scallop dredge, sink gillnet, and benthic longline fisheries to estimate the location of fishing activity. Estimated fishing locations were used to allocate the landings of 8 federally managed species to stock areas: **Atlantic cod (Gadus morhua),** haddock (Melanogrammus aeglefinus), yellowtail flounder (Limanda ferruginea), winter flounder (Pseudopleuronectes americanus), windowpane flounder (Scophthalmus aquosus), goosefish (Lophius americanus), silver hake (Merluccius bilinearis), and red hake (Urophycis chuss). Haul location and catch data from the Northeast Fisheries Observer Program (NEFOP) were used to assess the relative accuracy of both VMS and VTR allocation methods. Overall, the mean VMS-NEFOP agreement rate was 86.4 ± 7.6% compared to a mean VTRNEFOP agreement rate of 58.5 ± 4.9%. The VMS algorithm had a tendency (approx. 10% of all trips) to overestimate the number of statistical areas fished; when all fishing activity from a given trip occurred in a single statistical area, VTRs more accurately reflected the true fishing location. However, on trips where fishing

activity occurred in multiple statistical area, the VMS algorithm showed pronounced gains (77.2 ± 11.2% NEFOP agreement) relative to VTR reports (12.0 ± 5.9% NEFOP agreement). The VMS method achieved distributions of stock landings closer to NEFOP estimates in 18 out of 24 instances (8 species over 3 years). The stock allocations from both the VMS and VTR-based methods were within ± 5% for all stocks, suggesting that the impacts on total stock allocations are relatively minor. However, these small differences represent major relative differences for less abundant stocks such as southern New England/mid-Atlantic yellowtail flounder. In 2005 the VTR-based method allocated 61.9% more yellowtail flounder landings relative to the VMS-based method. The VMS-based method is not a replacement for the VTR-based method; however, it can, and should, be used as a tool to identify those vessels where targeted outreach activities would improve the accuracy of VTR statistical area reporting.

Fisheries and Oceans Canada. (2005). Management Strategies for Recovery of Atlantic Cod Stocks – Eastern Scotian Shelf (4VsW) Sydney Bight (4Vn May-October). Retrieved from http://www.dfo-mpo.gc.ca/fm-gp/initiatives/cod-morue/strategic-mar-eng.htm

The intention of this document is to identify what it is feasible to do to prevent further declines in cod abundance and indeed to encourage increases to historical levels.