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Northeast Multispecies Fishery Management Plan Resource Guide: Haddock (Melanogrammus aeglefinus)

Bibliography

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Office of Oceanic and Atmospheric Research
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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 haddock, 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 haddock. The research in this area is a compilation of basic facts including diet, lifespan and habitat; as well as current research on haddock biology.

Section II – Ecology

Section two is intended to provide an overview of how haddock interacts with the environment. The citations in this area focus on how temperature, food resources and predation affect haddock.

Section III – Fishery

Section three is intended to provide an overview of the haddock fishery. It is divided into two sections: Modern and Historical. The Historical section contains resources on the haddock fishery beginning and peak. The Modern section contains both news articles and scientific publications about the current state of the haddock fishery.

Section IV – Management

Section four is intended to provide an overview of the management of the haddock fishery. It includes news articles and research concerning plans and policies intended to protect and sustainably fish the haddock 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

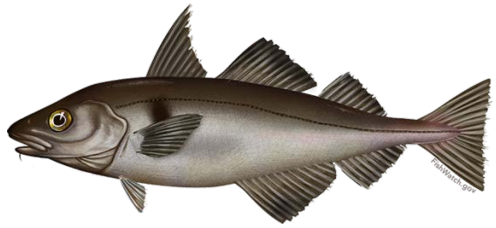


Image from: https://www.fishwatch.gov/profiles/haddock

Also known as: Scrod

Region: Haddock are found on both sides of the North Atlantic. In the western North Atlantic, they're found from Newfoundland to Cape May, New Jersey, and are most abundant on Georges Bank and in the Gulf of Maine.

Habitat: Haddock live near the bottom and prefer habitats of gravel, pebbles, clay, and smooth hard sand. Haddock are most common in waters approximately 130 to 500 feet deep and prefer temperatures below 45° F. Juveniles are found in shallower water on bank and shoal areas, while larger adults are more common in deeper water. Adults travel to shallower waters in the spring to spawn.

Size: Haddock are a fast-growing species that typically range between 1 and 3 feet long at maturity. They generally weigh between 2 and 7 pounds.

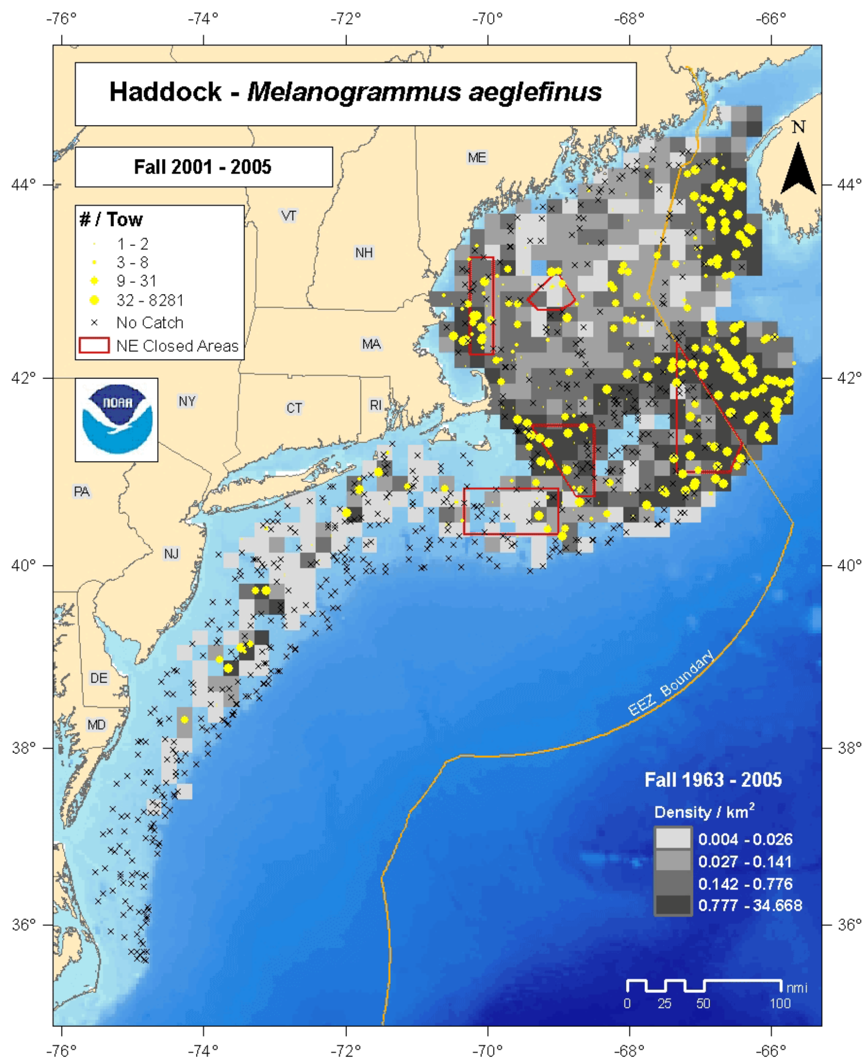
Physical description: Haddock are a member of the cod family, but they are smaller than Atlantic cod. They can be distinguished by a black "thumbprint" found on each side of their body. Their skin is also less mottled than cod.

Lifespan: They can live for 10 or more years, although NOAA Fisheries scientists typically catch haddock that are between 3 and 7 years old. Haddock begin to reproduce between the ages of 1 and 4 years old and at 10.5 to 11.7 inches long.

Diet: Haddock feed on a variety of bottom-dwelling animals, including mollusks, worms, crustaceans, sea stars, sea urchins, sand dollars, brittle stars, and occasional fish eggs. Adults sometimes eat small fish, especially herring. They spawn between January and June on eastern Georges Bank, to the east of Nantucket Shoals and along the Maine coast over rock, gravel, sand, or mud bottoms and are very productive.

Predators: Spiny dogfish, skates, and many groundfish species (cod, pollock, cusk, hake, monkfish, halibut, and sea raven) prey on juvenile haddock. Gray seals also prey on haddock.

Sources: NOAA (3/28/2018) FishWatch U.S. seafood facts: Acadian redfish. Retrieved from https://www.fishwatch.gov/profiles/haddock



Relative species abundance and distribution from NEFSC bottom trawl survey by time block and relative species density for the full time series.

Image from: https://www.nefsc.noaa.gov/sos/spsyn/pg/haddock/animation/fall/

Karlsson-Drangsholt, A., Svalheim, R. A., Aas-Hansen, O., Olsen, S. H., Midling, K., Breen, M., Johnsen, H. K. (2018). Recovery from exhaustive swimming and its effect on fillet quality in haddock (Melanogrammus aeglefinus). *Fisheries Research, 197*, 96-104. https://doi.org/10.1016/j.fishres.2017.09.006

Wild haddock (Melanogrammus aeglefinus) of commercial size (0.8-2.49 kg, 45-60 cm) were swum to exhaustion in a large swim tunnel and then allowed to recuperate for 0, 3 or 6 h, to investigate the effects of exhaustive swimming on blood glucose, blood lactate and post mortem development of fillet quality. There was a positive linear relationship between critical (aerobic) swimming speed (U-crit) and body length (BL). The average U-crit was 1.25 +/- 0.29 (SD) BL s(-1), which is close to that reported by others for haddock. Swimming to exhaustion resulted in reduced time to reach maximum muscle stiffness of the fillet (no recuperation vs unswum control), but the effect was remedied by recuperation for 3 h or more. Blood glucose and blood lactate increased during exercise and remained elevated throughout the entire 6-h resting period, indicating that complete recovery of these parameters may take more than 6 h. There was no significant effect of exhaustive swimming on muscle pH or colouration of the fillet. Taken together, the data suggest that swimming to exhaustion may have moderate and reversible negative effects on fillet quality in haddock. The effects observed in the present study are consistent with a recent study on exhaustive swimming in Atlantic cod, but less severe than that reported for haddock caught by trawl. This suggests that other factors (e.g. crowding/packing in the codend, barotrauma or suffocation) are contributing to the deterioration of fillet quality seen frequently in haddock caught by trawl.

Burchard, K. A., Juanes, F., & Rountree, R. A. (2014). Diel Reproductive Periodicity of Haddock in the Southwestern Gulf of Maine. *Transactions of the American Fisheries Society, 143*(2), 451-466. https://dx.doi.org/10.1080/00028487.2013.864704

We studied a population of Haddock Melanogrammus aeglefinus in the Gulf of Maine to determine whether it exhibits diel spawning periodicity. Commercial fishing vessels were chartered for 25 dedicated long-lining trips to collect sexually mature Haddock in the Stellwagen Bank National Marine Sanctuary at locations identified by commercial fishers as having spawning aggregations. In order to examine diel effects on Haddock reproduction, the changes in CPUE and percentages of male and female Haddock of all reproductive maturity stages, as well as gonadosomatic index (GSI), were observed across a 24-h diel cycle. The comparison of diel patterns among different maturation stages was used to differentiate diel periodicity due to spawning from feeding behavior. Diel periodicity was observed for the proportion of males and females in the catch, the proportion and CPUE of male and female maturation stages most indicative of imminent spawning, and for female GSI. Although spawning occurred throughout the diel cycle, peak spawning of females occurred during the evening hours (1700-2100 hours) and gradually declined to low values during the day at 0900 hours. In an apparent contradiction male spawning stages were uniformly high except for lows during the night between 2100 and 0100 hours. We hypothesize that this pattern is consistent with lekking behavior where strong competition among spawning-ready males during courtship would reduce their feeding activity during the peak spawning hours. Strong annual differences in diel periodicity may have resulted from different temporal patterns in the spawning season or density dependence, or both.

Petrik, C. M., Ji, R., & Davis, C. S. (2014). Interannual differences in larval haddock survival: hypothesis testing with a 3D biophysical model of Georges Bank. Fisheries *Oceanography, 23*(6), 521-553. http://dx.doi.org/10.1111/fog.12087

The ultimate goal of early life studies of fish over the past century has been to better understand recruitment variability. As evident in the Georges Bank haddock (Melanogrammus aeglefinus) population, there is a strong relationship between recruitment success and processes occurring during the planktonic larval stage. This research sought new insights into the mechanisms controlling the recruitment process in fish populations using biological-physical modeling methods together with laboratory and field data sets. We created the first three-dimensional model of larval haddock on Georges Bank by coupling models of hydrodynamics, lower trophic levels, a single copepod species, and larval haddock. Interactions between feeding, metabolism, growth, vertical behavior, advection, predation, and the physical environment of larval haddock were quantitatively investigated using the coupled models. Particularly, the model was used to compare survival over the larval period and the sources of mortality in 1995 and 1998, 2 years of disparate haddock recruitment. The results of model simulations suggest that the increased egg hatching rates and higher food availability, which reduced starvation and predation, in 1998 contributed to its larger year-class. Additionally, the inclusion of temperature-dependent predation rates produced model results that better agreed with observations of the mean hatch date of survivors. The results from this biophysical model imply that food limitation and its related losses to starvation and predation, especially from hatch to 7 mm, may be responsible for interannual variability in recruitment and larval survival outside of the years studied.

Dingsor G. E., Ciannelli, L., Chan, K.-S., Ottersen, G., & Stenseth, N. C. (2007). Density Dependence and Density Independence during the Early Life Stages of Four Marine Fish Stocks. *Ecology, 88*(3), 625-634. http://www.jstor.org/stable/27651146

Recruitment variability caused by density-dependent and density-independent processes is an important area within the study of fish dynamics. These processes can exhibit nonlinearities and nonadditive properties that may have profound dynamic effects. We investigate the importance of population density (i.e., density dependence) and environmental forcing (i.e., density independence) on the age-0 and age-1 abundance of capelin (Mallotus villosus), northeast Arctic cod (Gadus morhua), northeast Arctic haddock (Melanogrammus aeglefinus), and Norwegian spring spawning herring (Clupea harengus) in the Barents Sea. We use statistical methods that explicity account for nonlinearities and nonadditive interactions between internal and external variables in the abundance of these two pre-recruitment stages. Our results indicate that, during their first five months of life, cod, haddock, and herring experience higher density-dependent survival than capelin. The abundance of age-0 cod depends on the mean age and biomass of the spawning stock, a result which has implications for the management of the entire cod stock. Temperature is another important factor influencing the abundance at age-0 and age-1 of all four species, except herring at age-1. Between age-0 and age-1, there is an attenuation of density-dependent survival for cod and herring, while haddock and capelin experience density dependence at high and low temperatures, respectively. Predation by subadult cod is important for both capelin and cod at age-1. We found strong indications for interactions among the studied species, pointing to the importance of viewing the problem of species recruitment variability as a community, rather than as a population phenomenon.

Brodziak, J., & Traver, M. (2006). Status of Fishery Resources off the Northeastern US: Haddock. https://www.nefsc.noaa.gov/sos/spsyn/pg/haddock/

The haddock, Melanogrammus aeglefinus, is a commercially-exploited groundfish found in the northwest and northeast Atlantic Ocean. This demersal gadoid species is distributed from Cape May, New Jersey to the Strait of Belle Isle, Newfoundland in the northwest Atlantic, where a total of six distinct haddock stocks have been identified. Two of these haddock stocks are found in U.S. waters: Georges Bank and Gulf of Maine. The Georges Bank haddock stock is found in the shallow productive waters of Georges Bank while the Gulf of Maine stock inhabits waters of the southwestern Gulf of Maine. Both stocks support important commercial fisheries. Commercial fishing for haddock occurs year round in U.S. waters. Otter trawl fishing gear produces the majority of haddock landings, while the remainder of the catch is taken with longlines or gill nets. Recreational catches are relatively minor and amount to roughly 1%-2% of commercial catches in recent years. Most of the recreational haddock catch is taken with hook and line gear in the Gulf of Maine region during spring to late-autumn.

Roy, P. K., & Lall, S. P. (2006). Mineral nutrition of haddock Melanogrammus aeglefinus(L.): a comparison of wild and cultured stock. *Journal of Fish Biology, 68*(5), 1460-1472. http://dx.doi.org/10.1111/j.0022-1112.2006.001031.x

The macro and trace mineral composition of vertebrae and muscle in wild and cultured haddock Melanogrammus aeglefinus was determined. Results indicated that haddock deposit c. 10% higher amounts of mineral than salmonids. Based on distribution between the analysed tissues as well as concentration differences, the minerals in wild and cultured haddock were divided into four categories: (1) As, Mn, Na, S and Zn concentration did not show any significant ($P > 0.05$) variation in both muscle and vertebrae; (2) Cr, Co, Mg, Mo and Si concentrations in wild and culture stocks muscle did not vary but vertebrae concentration showed significant differences ($P < 0.05$); (3) Ca and Cu concentration varied in muscle while remaining the same in vertebrae; (4) Al, Ba, Fe, P, K and Sr concentration showed a significant difference in both muscle and vertebrae. Vertebrae P content of cultured haddock was lower than that of wild fish whereas muscle P content was relatively high in cultured fish. Vertebrae and muscle Fe content of cultured haddock was significantly higher than in wild fish. The Mg, K, Co and Cr concentrations in vertebrae were significantly higher in wild haddock than in cultured fish, whereas Mo and Al levels were low. These differences in trace element composition of wild and cultured haddock were probably related to differences in food source and therefore the mineral composition of the diet. The nutritional significance of these findings is discussed.

Hiddink, J. G., Jennings, S., & Kaiser, M. J. (2005). Do haddock select habitats to maximize condition? *Journal of Fish Biology, 67*, 111-124. http://dx.doi.org/10.1111/j.0022-1112.2005.00912.x

Haddock *Melanogrammus aeglefinus* in the North sea increased their distributional range when more abundant, but this density dependent habitat selection (DDHS) explained only a small part of the year-on-year variation in distribution patterns. The condition of haddock was examined at 24 sites in the North Sea in August and September 2004 and related to their abundance, to examine if the ideal free distribution theory (IFD), which assumes that organisms select habitats that maximize their rate of food intake, can be used to explain this variation in large scale distribution patterns. At a given temperature, condition (hepato-somatic index, I sub(H)) was better at stations where haddock were most abundant. Therefore, haddock were not distributed perfectly according to the IFD in 2004. The positive correlation between abundance and I sub(H), however, indicated there was some habitat selection by haddock, as in the total absence of habitat selection no correlation between I sub(H) and abundance, and no spatial variation in abundance was expected. DDHS may only explain a small part of the yearly variation in the distribution because haddock did not equalize and maximize their fitness at the scale of the North Sea. In addition, stable isotope analysis of muscle samples showed that haddock did not avoid competition for food when at high abundance by feeding at a lower or wider range of trophic levels.

Wright, P. J., & Gibb, F. M. (2005). Selection for Birth Date in North Sea Haddock and Its Relation to Maternal Age. *Journal of Animal Ecology, 74*(2), 303-312. http://www.jstor.org/stable/3505619

1. Birth date can be important to lifetime reproductive success. However, selection for birth date has rarely been addressed in fish, despite the opportunity provided by otolith microstructure. 2. This study examined the relationship between maternal age, spawning time and early survivorship in the North Sea haddock stock. Temporal changes in egg production were compared with the birth date distribution of progeny surviving to the demersal phase in 1994, 1996 and 1999 when the age structure of the spawning stock differed. 3. Estimates of intra-annual variation in stock egg production indicated that first-time spawning 2-year-olds began spawning much later than older age-classes. 4. The form and magnitude of selection on birth date varied between years, indicating that the production of multiple batches of eggs over an extended period has some adaptive significance to progeny survival. 5. Survivorship was consistently poor from the late spawning period when age 2 females contributed most to stock egg production. This persistent selection against late hatched offspring could reflect either low parental investment, as age 2 females produce smaller eggs, or the short length of the growing season prior to settlement. 6. Variability in birth date selection, particularly with respect to first vs. subsequent years of spawning, implies a strong selection pressure for a long reproductive lifespan. As such, reproductive potential in this and other exploited fish species with a similar reproductive trait may have been affected adversely by the general decline in repeat spawning females in recent years.

Begg, G. A., Overholtz, W. J., & Munroe, N. J. (2001). The use of internal otolith morphometrics for identification of haddock (Melanogrammus aeglefinus) stocks on Georges Bank. *Fishery Bulletin, 99*(1), 1-14. https://www.st.nmfs.noaa.gov/spo/FishBull/991/1.pdf

Internal otolith morphometrics, coupled with image analysis procedures and multivariate statistical analyses, were examined to investigate stock structure of haddock (Melanogrammus aeglefinus) on Georges Bank in the northwest Atlantic. Samples were collected during spring 1995-97 from the Northeast Peak (eastern Georges Bank) and the Great South Channel (western Georges Bank) spawning components. The structure of transverse sagittal otolith sections were described for individual haddock samples from each spawning component by using a combination of linear morphometrics, shape characteristics, and growth increments. Analyses were structured to account for the effects of size, sex, age, and year class. Significant differences in internal otolith structure were found between eastern and western Georges Bank haddock, providing phenotypic evidence of stock separation between the two spawning components. Eastern Georges Bank haddock tended to have smaller internal otolith dimensions than western Georges Bank haddock; these differences appeared to be related to growth rates. Total classification success for each spawning component varied from 61% to 83% for the different age and year-class combinations. Results from this study may be helpful in forming consistent stock definitions that can be used by both U.S. and Canadian fishery management agencies for rebuilding stocks of haddock on Georges Bank.

Cargnelli LM, et al. (1999). Essential Fish Habitat Source Document: Haddock, Melanogrammus aeglefinus, Life History and Habitat Characteristics. *NOAA Technical Memorandum NMFS-ME-128*. https://www.nefsc.noaa.gov/nefsc/publications/tm/tm128/tm128.pdf

NOAA Technical Memorandum on Haddock: In brief: A demersal gadoid species found on both sides of the North Atlantic, two haddock stocks are recognized at Georges Bank and the Gulf of Maine. Haddock spawn over pebble gravel substrate and the egg and larval stages occur in the water column at depths of 10-50 m below the surface. The oldest adult haddock was recorded at 14 years old, but it is uncommon to find haddock over 9 years old. Juveniles can be found more abundantly inshore and adult haddock primarily offshore. Haddock commercial landings on Georges Bank peaked in 1965 with nearly 150,000 mt.

Purcell, M. K., Kornfield, I., Fogarty, M., & Parker, A. (1996). Interdecadal heterogeneity in mitochondrial DNA of Atlantic haddock (Melanogrammus aeglefinus) from Georges Bank. *Molecular Marine Biology and Biotechnology, 5*(3), 185-192. Retrieved from ProQuest Earth, Atmospheric & Aquatic Science Database.

Atlantic haddock (Melanogrammus aeglefinus), of Georges Bank are characterized by large fluctuations in population size and a recent collapse of the commercial fishery. DNA extracted from dried scales of Georges Bank haddock, archived by the U.S. National Marine Fisheries Service (NMFS), reveals significant heterogeneity in frequencies of four mitochondrial DNA control region haplotypes between 1975 and 1985 cohorts. Several processes may be responsible for this temporal variation, the most attractive hypothesis being that haddock from other geographic regions episodically contribute to the Georges Bank gene pool. Thus, the population of haddock spawning on Georges Bank may not be genetically discrete and, with respect to Atlantic haddock, Georges Bank may not be viewed as a closed system.

Schwarz, A. (1971). Swimbladder development and function in haddock, melanogrammus-aeglefinus l. *Biological Bulletin, 141*(1), 176-188. https://doi.org/10.2307/1540002

This study is early research into the functioning and origination of haddock swimbladders and its role in the larval pelagic stage; especial interest is paid to how the swimbladder is inflated.

Section II: Ecology

Richardson, D. E., Hare, J. A., Fogarty, M. J., & Link, J. S. (2011). Role of egg predation by haddock in the decline of an Atlantic herring population. *Proceedings of the National Academy of Sciences of the United States of America, 108*(33), 13606-13611. http://www.jstor.org/stable/27979245

Theoretical studies suggest that the abrupt and substantial changes in the productivity of some fisheries species may be explained by predation-driven alternate stable states in their population levels. With this hypothesis, an increase in fishing or a natural perturbation can drive a population from an upper to a lower stable-equilibrium population level. After fishing is reduced or the perturbation ended, this low population level can persist due to the regulatory effect of the predator. Although established in theoretical studies, there is limited empirical support for predation-driven alternate stable states in exploited marine fish populations. We present evidence that egg predation by haddock (Melanogrammus aeglefinus) can cause alternate stable population levels in Georges Bank Atlantic herring (Clupea harengus). Egg predation by haddock explains a substantial decoupling of herring spawning stock biomass (an index of egg production) from observed larval herring abundance (an index of egg hatching). Estimated egg survival rates ranged from <2–70% from 1971 to 2005. A population model incorporating egg predation and herring fishing explains the major population trends of Georges Bank herring over four decades and predicts that, when the haddock population is high, seemingly conservative levels of fishing can still precipitate a severe decline in the herring population. These findings illustrate how efforts to rebuild fisheries can be undermined by not incorporating ecological interactions into fisheries models and management plans.

Martinez, I., Jones, E. G., Davie, S. L., Neat, F. C., Wigham, B. D., & Priede, I. G. (2011). Variability in behaviour of four fish species attracted to baited underwater cameras in the North Sea. *Hydrobiologia, 670*(1), 23-34. http://dx.doi.org/10.1007/s10750-011-0672-x

Baited underwater camera (BUC) systems to estimate demersal fish abundance are becoming increasingly considered as an alternative to traditional survey methods, particularly in environments that contain sensitive habitats or protected species. Based on 27 replicate deployments of BUCs at 100 m depth in the northern North Sea, in rank order of abundance, hagfish (Myxine glutinosa), flatfish mainly dabs (Limanda limanda), whiting (Merlangius merlangus) and haddock (Melanogramus aeglefinus) were observed consistently at baits. Higher maximum numbers (N ^sub max^) occurred during daytime in all species with the most significant effect in flatfish, 18 in daytime and 5 at night-time. Bottom current had no significant effect on numbers of whiting, flatfish or haddock. The N ^sub max^ of hagfish was strongly related to current speed in a non-linear way with an increase in numbers up to 10 cm s^sup -1^ and then decrease in N ^sub max^ at higher water speeds. Understanding and accounting for such species-specific influences is important in the design of long term monitoring surveys using baited cameras.

Bisagni, J. J., Georgianna, D., & Mountain, D. G. (2010). Climate-Related Ecosystem Variability and Its Potential Effects on Management of Atlantic Cod and Haddock on Georges Bank: *Proceedings from the 2010 AGU Ocean Sciences Meeting*, American Geophysical Union, 2000 Florida Ave., N.W. Washington DC 20009 USA. [Poster] Retrieved from ProQuest Earth, Atmospheric & Aquatic Science Database.

We seek to understand the role of a changing ocean environment in controlling the important uppermost trophic level within the Georges Bank (GB) ecosystem through an analysis of oceanographic and fish recruitment data. Results from earlier studies show strong relationships between year-to-year and decadal changes in the physical and biological characteristics of the GB ecosystem, including co-varying regime shifts in salinity, zooplankton community structure, and first year survival of haddock (Melanogrammus aeglefinus) and cod (Gadus morhua) populations. Earlier studies identified at least two different regimes on GB that contain differing zooplankton communities that had a significant impact on recruitment of haddock and cod. Specifically, we are working to provide and evaluate realistic tools based upon existing linkages between easily-observable hydrographic parameters, including salinity and the position of the shelf-slope front, measured within waters located off the eastern seaboard of the United States and Canada and observed recruitment success of haddock and cod. Furthermore, this work is unique in that we are examining the additional effect of out-of-phase management, due to delays by management in recognizing given shifts in biomass between GB haddock and cod, due at least in part to the changing ocean environment caused by a strong regime shift that began during the early 1990s.

Buckley, L. J., Lough, R. G., & Mountain, D. (2010). Seasonal trends in mortality and growth of cod and haddock larvae result in an optimal window for survival. *Marine Ecology Progress Series, 405*, 57-69. https://dx.doi.org/10.3354/meps08503

Changing climate and global depletion of fish stocks have added urgency to the century- old quest to understand the factors controlling fish production. The leading hypotheses advanced to explain the large (orders of magnitude) inter-annual variability in recruitment of young fish emphasize rapid growth and a match to prey production in the first weeks after hatching, although avoiding predators may be of equal or greater importance. Here we show for 2 important North Atlantic groundfish (Atlantic cod Gadus morhua and haddock Melanogrammus aeglefinus) that seasonal patterns in growth (G) and mortality (M) rates of young larvae combine in some years to yield a window of opportunity when M falls below G within days after hatching and cohort biomass increases rapidly possibly leading to high recruitment. Contrary to expectations, this window occurs early in the seasonal production cycle (February to March) when temperatures are near their annual minimum, fish larvae and their prey are relatively scarce, and G is low. In most cases examined, later, faster-growing cohorts appear to be rapidly lost to a suite of vertebrate and invertebrate predators whose abundance, metabolism, and consumption increase through the spring with increasing water temperature. In this seasonally varying environment, size on year day may be critical to minimizing M/G. Our data demonstrate the importance of rapid growth throughout the season cycle, but particularly early in the season when temperatures, potential prey, and predators are at seasonal low levels. These findings reinforce the importance of management practices protecting larger, older females that begin spawning earlier in the season and produce larger, more viable eggs and larvae.

Horwood, J. (1995). Plankton-generated chaos in the modelled dynamics of haddock. *Philosophical Transactions of the Royal Society B-Biological Sciences, 350*(1332), 109-118. https://doi.org/10.1098/rstb.1995.0145

This study illustrates the feasibility of regimes of chaotic dynamics in gadoid populations. A previously developed plankton model related fish larval survival to larval density and their copepod food supply. This model is extended to a full-population model, incorporating age structure, fishing and a stock-recruitment relation implicit in the plankton model. Parameterization is based upon the Georges' Bank haddock. It is shown that regions of stability, aperiodic and chaotic-like dynamics exist as both the copepod food-supply and fishing rates are varied. The deterministic aperiodic dynamics are significantly complicated by additional stochastic elements. The implications are that chaotic dynamics are plausible and that analyses of output data on stock and recruitment can reveal relatively little; field and laboratory studies are needed to elucidate the underlying mechanisms. Traditional fitting of stock and recruitment relations may give an overly optimistic interpretation for fisheries managers.

Boudreau, P. R. (1992). Acoustic observations of patterns of aggregation in haddock (Melanogrammus aeglefinus) and their significance to production and catch*. Canadian Journal of Fisheries and Aquatic Sciences, 49*(1), 23-31. https://doi.org/10.1139/f92-003

A dual-beam acoustic system was used to collect detailed information on density and body size over a 24-h period in an area of the Scotian Shelf occupied by a population of large spawning haddock (Melanogrammus aeglefinus). The acoustic sampling showed a persistent gradient of decreasing density with distance from bottom with 50% of the fish < 2.5 m off bottom. The differences in the degree of aggregation with time of day appear to be sufficient to explain diel changes in net catch rates. Haddock biomass density was also related to organism body size, suggesting that haddock population density is determined by trophic interactions similar to those that underlie production of other populations of organisms.

Hill, M. A. (1974). First record of Hemiurus levinseni Odhner (Trematoda:Hemiuridae) in haddock in the western North Atlantic Ocean. *J Parasitol, 60*(3), 544-545. https://doi.org/10.2307/3278387

This study looks at the first records of haddock infected with the *H. levinseni* parasite.

Colton, J. B., & Temple, R. F. (1961). The Enigma of Georges Bank Spawning. Limnology and *Oceanography, 6*(3), 280-291. http://www.jstor.org/stable/2832571

The drift of bottles and transponding drift buoys over the Georges Bank area show that, with the exception of midsummer when the Georges eddy is most pronounced and southerly winds predominate, surface drift is offshore in the direction of the slope water band. Indications are that the currents below the surface move at a slower rate than at the surface, but in a similar direction. The effects of offshore drift, time and location of spawning, vertical distribution of eggs and larvae, and length of pelagic life on the dispersal and survival of eggs, larvae, and juveniles of commercially important food fishes are discussed. It appears from observations on haddock and herring that under average conditions most fish eggs and larvae are carried away from Georges Bank and lost to the fishery, that only under unusual hydrographic conditions are the eggs and larvae retained in the area, and that the year class strength of the various species inhabiting Georges Bank is dependent in part upon non-tidal drift.

Section III: Fisheries

History: The Georges Bank haddock stock has been commercially exploited since the 19th century with reliable landings statistics available beginning in 1904. Since then, the fishery for Georges Bank haddock has gone through seven periods: (1) the initial expansion from 1904-1923 when annual landings averaged 17,400 mt; (2) the rapid expansion and decline during 1924-1930 when landings averaged 73,200 mt; (3) the thirty-year period of fishery stability during 1931-1960 when annual landings averaged 46,300 mt; (4) the rapid expansion and decline during 1961-1968 when landings averaged 73,000 mt and foreign distant water fleets began to harvest the resource; (5) the pre-Hague line fishery during 1969-1984 when landings averaged about 13,500 mt; (6) the fishery nadir during 1985-2000 when landings averaged only 5,600 mt; and (7) the nascent recovery from 2001-2005 when annual landings have increased to average 15,000 mt per year. Landings have generally increased each year since 1995 as the stock has been rebuilding under restrictive management measures. The commercial fishery landings of Georges Bank haddock has been primarily composed of age-3 and older fish. During the 1960s, the exceptional 1963 and strong 1962 year classes dominated the commercial fishery while the strong 1975 and 1978 year classes dominated catches in the late-1970s to early-1980s.

Modern: In recent years, the strong 1998 and 2000 year classes have produced the majority of the fishery yield in each subarea of Georges Bank. In 2005 total commercial landings were 20,597 mt, almost 9-fold larger than the lowest recorded landings in 1995. U.S. landings in 2005 were 6,107 mt, a 21% decrease from 7,746 mt in 2004. The U.S.

fishery accounted for approximately 30% of the total Georges Bank haddock landings in 2005.

Sources: Brodziak, J., & Traver, M. (2006). Status of Fishery Resources off the Northeastern US: Haddock. https://www.nefsc.noaa.gov/sos/spsyn/pg/haddock/

Pucci, J. (2018, March 9) Tracking haddock's route, from ocean to the plates of Upstate New Yorkers. *The Post Standard*. http://s.syracuse.com/scdwNZC

This article investigates the distribution and eventual sale of haddock in New York State. Surprisingly it mainly comes from Norway.

Lapinski, T. (2018, January 29) Spring GOM Haddock Closure Looming? A look at what might be on tap for spring haddock fishing in the Gulf of Maine. *The Fisherman.* https://www.thefisherman.com/index.cfm?fuseaction=feature.display&feature_ID=1959&ParentCat=19

News article on recent talks by the New England Fisheries Management Council pending new rules in 2018 and possible closure of haddock fishing in May for the Gulf of Maine stock.

Krag, L. A., Holst, R., Madsen, N., Hansen, K., & Frandsen, R. P. (2010). Selective haddock (Melanogrammus aeglefinus) trawling: Avoiding cod (Gadus morhua) bycatch. *Fisheries Research (Amsterdam), 101*(1-2), 20-26. http://dx.doi.org/10.1016/j.fishres.2009.09.001

The critical condition of the North Sea cod stocks has resulted in restrictions on not only cod, but also haddock and other species that are caught together with cod. Thus full exploitation of the haddock stock is unachievable unless cod can be excluded from the haddock catch. We designed a selective trawl based on the behavioral differences between haddock and cod as they enter a trawl, i.e., cod stay close to the seabed whereas haddock rise above it. The trawl's fishing line is raised 60cm above the seabed to allow cod to escape beneath the trawl while haddock are retained. To collect the escapees, three sampling bags were attached beneath the raised fishing line. The selective haddock trawl reduced the total catch of cod by 55% during the day and 82% at night, and 99% of the marketable haddock was caught during the day and 89% at night. Cod escape rates were highly length dependent: smaller cod escaped the trawl in greater numbers than did larger individuals. Whiting, saithe, lemon sole, and plaice were included in the analysis.

Becker, J. R., & Kanwit, J. K. (2010). Haddock (Melanogrammus aeglefinus) bycatch in the Northeast United States herring (Clupea harengus) fishery: results from the 2004-2006 portside bycatch survey of the Northeast United States herring fishery. Paper presented at the (2904) 96-97. Retrieved from ProQuest Earth, Atmospheric & Aquatic Science Database.

The Maine Department of Marine Resources (DMR) first secured funding in 2004 to support a portside bycatch survey of the Atlantic herring (Clupea harengus) fishery. This ongoing survey focuses on quantifying bycatch from herring landings sold to processing facilities throughout the northeastern United States. The herring fishery is a high volume industry that transfers catch by pumps minimizing opportunities to remove incidental catch and bycatch at-sea. The methods of this survey provide at a minimum, data on similar sized bycatch and non-target species. This paper presents results specific to haddock-herring interactions from 169 portside bycatch samples which were executed between January 2004 and December 2006. A total of 625 kilograms (kg) of haddock (Melanogrammus aeglefinus) were documented as bycatch from 5,275 metric tons (t) of herring evaluated. This ongoing portside bycatch survey offers valuable data on bycatch and incidental catch in the herring fishery and represents a novel approach for collecting bycatch data in a unique and cost effective manner.

Ford, J. S., Rudolph, T., & Fuller, S. D. (2008). Cod bycatch in otter trawls and in longlines with different bait types in the Georges Bank haddock fishery. *Fisheries Research (Amsterdam), 94*(2), 184-189. http://dx.doi.org/10.1016/j.fishres.2008.04.002

In the Northwest Atlantic, bycatch of depleted groundfish stocks in the haddock fishery on Georges Bank is an ongoing concern. In recent years, this fishery on the American side of Georges Bank has been limited by high bycatch rates of cod. Considerable conservation engineering work has been done to address the problem, including experiments with different longline baits and modifications to otter trawl gear. Fabricated baits have shown promise for increased selectivity when longlining, but it has sometimes been difficult to establish whether low cod catch rates with fabricated baits have resulted from bait selectivity or from a low abundance of cod in the area. In this study, we compare catch rates of cod and haddock between otter trawls and longline gear in experimental and commercial fishing on Georges Bank in the summer of 2005. We also compare cod bycatch rates among longlines baited with squid, herring, or fabricated baits (mainly Norbait 700E) in Georges Bank Closed Area 1, from October 2003 to June 2005. Records from the Northeast Fisheries Observer Program were combined with data collected by the Cape Cod Commercial Hook Fishermen's Association (CCCHFA), and compared using generalized linear models. In the Eastern US-Canada Resource Sharing Area (EUSCA) in the summer of 2005 catch of cod per haddock by weight was significantly lower when fishing with longline gear (0.008-0.045kg cod per kg haddock) than with otter trawl gear (0.059-0.826kg cod per kg haddock), in all months and areas. Cod bycatch rates were also significantly lower for longlines fishing for haddock than for otter trawls fishing for groundfish species other than haddock. In Closed Area 1, statistically significant differences in cod to haddock ratios were found between baits, with squid catching the highest amount of cod, fabricated baits catching the lowest amount, and herring at an intermediate level. The development of fishing methods that minimize cod bycatch is a high priority in many regions of the North Atlantic. These results indicate that longlines with fabricated bait have the potential to maintain a very low catch of cod while fishing for haddock.

Beutel, D., Skrobe, L., Castro, K., Ruhle, P., O'Grady, J., & Knight, J. (2008). Bycatch reduction in the Northeast USA directed haddock bottom trawl fishery. *Fisheries Research (Amsterdam), 94*(2), 190-198. http://dx.doi.org/10.1016/j.fishres.2008.08.008

We investigated the performance of a large mesh faced (upper and lower wings, side panels, first bottom belly) bottom trawl designed to capture haddock (Melanogrammus aeglefinus) while reducing the bycatch of cod (Gadus morhua) and other species. This experimental net, named the Eliminator Trawl(TM), was tested using two vessels, F/V Iron Horse and F/V Sea Breeze, in side-by-side catch comparison hauls with the currently regulated net. A total of 100 successful comparison tows were completed. All species captured were weighed for total weight. Haddock, cod, and the majority of the flounders were measured. The Eliminator Trawl(TM) significantly reduced the catch of stocks of concern including cod, yellowtail flounder (Limanda ferruginea), winter flounder (Pseudopleuronectes americanus), witch flounder (Glyptocephalus cynoglossus), and American plaice (Hippoglossoides platessoides). Other species such as monkfish (Lophius americanus) and skate (unclassified) also showed a significant decrease in catch in the Eliminator Trawl(TM). In addition, the catch of haddock, the target species, did not differ significantly between nets. The results of this study indicate that the Eliminator Trawl(TM) would be an efficient tool in gaining access to closed areas and used in recovery programs to exploit more abundant fish species. Examples in the Northeast USA include a B Days-at-Sea Program (DAS) as well as a Special Access Program (SAP) where the Eliminator Trawl(TM) appears to meet the minimum bycatch requirements to be considered for both these programs.

Greene, K. (2002). Bigger Populations Needed for Sustainable Harvests. *Science, 296*(5571), 1229-1230. https://doi.org/10.1126/science.296.5571.1229

This article discusses sustainable harvests and rebuilding of stocks in New England with graphics on Georges Banks haddock.

Lage, C., Purcell, M., Fogarty, M., & Kornfield, I. (2001). Microsatellite evaluation of haddock (Melanogrammus aeglefinus) stocks in the Northwest Atlantic Ocean. *Canadian Journal of Fisheries and Aquatic Sciences, 58*(5), 982-990. https://doi.org/10.1139/f01-052

The goal of this study was to gain insight about the impact of intensive fishing on a single haddock (Melanogrammus aeglefinus) stock, and examine the genetic structuring of spatially discrete spawning aggregations in the Northwest Atlantic. We analyzed genetic change at four microsatellite loci for Georges Bank haddock over a 40-year time span in which significant changes in demographics and abundances have occurred in the population. Allelic diversities have changed little, indicating that, although the commercial fishery has collapsed, stock sizes have remained large enough to insulate against major reductions in genetic variation due to drift. Results indicate significant genetic divergence among decadally separated samples. Potential causes for these differences include admixture from other spawning regions, fluctuations in the effective number of spawners contributing to a single spawning event, drift, or a combination of these. Examination of discrete spawning aggregations from Georges Bank, Browns Bank, the Scotian Shelf, and Nantucket Shoals indicated significant differences among stocks. Genetic distance based measures supported the clustering of Scotian Shelf, Browns Bank, and Georges Bank haddock to the exclusion of Nantucket Shoals haddock. Haddock spawning on Nantucket Shoals may be genetically discrete from other haddock populations in the northwest Atlantic.

Stern, H., Jr., & Hennemuth, R. C. (1975). A two-way model for estimating standardized fishing effort applied to the U.S. haddock fleet. *Rapports et Proces-Verbaux des Reunions - Conseil International pour l'Exploration de la Mer, 168*, 44-49. Retrieved from ProQuest Earth, Atmospheric & Aquatic Science Database.

Catches of haddock made on Georges Bank in each of the 28 calender quarters between 1962 and 1968 were classified by vessel gross tonnage and depth zone. In 10 of the 28 sets interaction between vessel class and depth zone was observed. Details of fishing power coeffs obtained are given. Adjusted effort is calculated by summing the product of fishing power coeff and the observed effort associated with it. From this an estimate of abundance may be obtained. These results were found to give a comparable but higher value of abundance than was obtained using individual study vessels. During quarters of low abundance the largest discrepancies between the whole fleet and individual vessel estimates were obtained. It is considered that further multi-factor analysis is required to study the relation of quarters, fishing depth and vessel class.

Schuck, H. A. (1949). Relationship of Catch to Changes in Population Size of New England Haddock. *Biometrics, 5*(3), 213-231. https://doi.org/10.2307/3001937

This study is an early look into determining haddock stock size and recommendations for future management practice. In summary the paper acknowledges that fishing practices thus far had indeed made a significant impact on the haddock population at Georges Bank. It also provided facts on number of fish present on the bank, mortality rates, growth rates, indices of the recruitment of young, the effect of various factors upon recruitment, and predictions as to the future abundance.

Wm, C. H. (1947). The Role of Intraspecific Competition and Other Factors in Determining the Population Level of a Major Marine Species. *Ecological Monographs, 17*(3), 317-323. https://doi.org/10.2307/1948662

This study looked into theories concerning the factors controlling marine populations in respect to haddock. Using commercial and sport fishing effort and catch statistics the study looks into reasons for declines in catch and population levels after the Second World War. Touching on the otter trawl controversies of the day the paper declines to definitely point at habitat destruction and decreased bottom productivity by trawl netting practices as the cause, but offers more research into the matter as being conducted.

Section IV: Management

Fisheries of the Northeastern United States; Northeast Multispecies Fishery; Fishing Year 2018 Recreational Management Measures; Federal Register Extracts, 50 CFR Part 648 (2018). https://www.federalregister.gov/d/2018-05811

These are the proposed management measures for 2018 for cod and haddock.

Gulf of Maine Atlantic Cod 2014 Assessment Update Report. (2014). NOAA. https://www.nefsc.noaa.gov/saw/cod/pdfs/GoM_cod_2014_update_20140822.pdf

This update of the Gulf of Maine cod stock assessment is a streamlined document that focuses on the primary assessment information required for management. The update incorporates recent commercial and recreational landings and discard data (2012 and 2013), and recent survey information (2012-2014 spring surveys; 2012-2013 autumn surveys) into the previously approved peer-reviewed model. This report is part of a larger effort to provide more timely information on stock status for all stocks in the Greater Atlantic Region.

Smith, B. E., Collie, J. S., & Lengyel, N. L. (2014). Fish trophic engineering: Ecological effects of the invasive ascidian Didemnum vexillum (Georges Bank, northwestern Atlantic*). Journal of Experimental Marine Biology and Ecology, 461*, 489-498. http://dx.doi.org/10.1016/j.jembe.2014.09.009

In the northwest Atlantic, concerns for the benthic communities of Georges Bank have evolved following the widespread detection of the invasive ascidian Didemnum vexillum in 2002. One question is whether D. vexillum affects the feeding of fishes, particularly commercially-important species. The major objectives were to examine the diets of five demersal fishes and the benthic epifauna (prey field) across contrasting levels of D. vexillum occurrence from 2004 to 2008 in and around northern Closed Area II of Georges Bank (42.0 degree N, 67.3 degree W). The fishes examined were winter skate (Leucoraja ocellata), little skate (Leucoraja erinacea), haddock (Melanogrammus aeglefinus), winter flounder (Pseudopleuronectes americanus), and longhorn sculpin (Myoxocephalus octodecemspinosus). Cumulative fish trophic diversity was often higher at sites where D. vexillum was present as measured by Shannon's H'. Diets were significantly different across levels of D. vexillum for the five fishes, and feeding by haddock was positively correlated with the benthic epifauna within rather than across sites, indicating site-specific feeding. For many fishes, prey that contributed to the diet dissimilarity between sites were benthic epifauna strongly associated with the presence of D. vexillum (Class Polychaeta: Nereis zonata, Harmothoe extenuata, and Lepidonotus squamatus; and Order Decapoda: Cancer irroratus) and absence of D. vexillum (Order Decapoda: Crangon septemspinosa). These feeding alterations are not necessarily negative, as fish diets in this region regularly contain prey positively associated with D. vexillum. However, with the momentum to incorporate habitat science into fish stock assessments, managers should not consider protected fish habitat to be static in the presence of habitat modifiers such as invasive ascidians. From influencing the trophic ecology of demersal fishes to driving substrate homogeneity, long-term monitoring and invasive ascidian management for this continental shelf region is recommended.

Casaretto, L., Picciulin, M., Olsen, K., & Hawkins, A. D. (2014). Locating spawning haddock (Melanogrammus aeglefinus, Linnaeus, 1758) at sea by means of sound. *Fisheries Research (Amsterdam), 154*, 127-134. http://dx.doi.org/10.1016/j.fishres.2014.02.010

The sites where haddock spawn and the factors that bring the fish together to spawn at particular locations are not well known. We have located haddock in the sea by listening for the sounds this species makes during its reproductive behaviour. The characteristics of the sounds made by haddock were first examined in the aquarium. Listening was then carried out in a Norwegian fjord, where fishers had reported spawning haddock. Long sequences of repeated knocks were heard in the fjord, similar to the display sounds recorded during stereotyped reproductive behaviour in the aquarium. Rapidly repeated knocks and humming were also heard, confirming that fish were engaging in courtship. At night the sounds merged into a continuous low frequency rumble, suggesting that many haddock were present, producing sounds simultaneously. Listening for haddock sounds provides a reliable, non-invasive way of locating aggregations of spawning haddock in the sea, allowing closer definition of the spawning areas. Both fishing and exposure of haddock to man-made noise at the critical time of spawning may have deleterious effects upon reproductive success.

Murawski, S., Methot, R., Tromble, G., Hilborn, R. W., Briggs, J. C., Worm, B., Watson, R. (2007). Biodiversity Loss in the Ocean: How Bad Is It? [with Response]. *Science, 316*(5829), 1281-1284. http://science.sciencemag.org/content/sci/316/5829/1281.2.full.pdf

This response to an article dissects the abundance of Georges Bank haddock and invokes the Magnuson Stevens Act as a preventative to overfishing and subsequent fishery collapse.

Safina, C., Rosenberg, A. A., Myers, R. A., Quinn, T. J., & Collie, J. S. (2005). U.S. Ocean Fish Recovery: Staying the Course. *Science, 309*(5735), 707-708. https://doi.org/0.1126/science.1113725

This article discusses sustainable fishing; urging appropriate federal regulations to prevent overfishing and includes haddock in graphic detailing the effectiveness of rebuilding stock measures.

Van Eeckhaute, L. A. M., Gavaris, S., & Trippel, E. A. (1999). Movements of haddock, Melanogrammus aeglefinus, on eastern Georges Bank determined from a population model incorporating temporal and spatial detail. *Fishery Bulletin, 97*(3), 661-679. https://www.st.nmfs.noaa.gov/spo/FishBull/21vaneec.pdf

A population model incorporating temporal and spatial detail revealed that the majority of eastern Georges Bank haddock, Melanogrammus aeglefinus, were found on the Canadian side of the Canada-U.S. boundary. During spring they were more wide-spread across the top of the bank and subsequently migrated eastward so that by fall almost all haddock were found in the deeper waters on the Canadian side. There is a return migration to the top of the bank during the winter. The seasonal distribution and migration of haddock has remained stable since 1985 and migration rates do not appear to be related to the observed range of abundance. The distribution pattern since 1985 appears similar to that observed between 1972 and 1984. In contrast, during 1963-71 haddock were more widespread throughout the area in both spring and fall. Abundance of haddock in the Georges Bank and Gulf of Maine area was exceptionally high in the earlier period, and haddock from the spawning component in the Great South Channel area may have accounted for a greater augmentation to the eastern Georges Bank population. In implementing strategies for managing this transboundary resource, scientists will need to evaluate the nature of haddock distributions in order, in turn, to evaluate the implications of their strategies.

Marshall, C. T., & Frank, K. T. (1999). Implications of density-dependent juvenile growth for compensatory recruitment regulation of haddock. *Canadian Journal of Fisheries and Aquatic Sciences, 56*(3), 356-363. http://dx.doi.org/10.1139/cjfas-56-3-356

Data from bottom trawl surveys conducted by Canada and the United States were used to describe temporal trends in the length of haddock ages 1-4 on the southwestern Scotian Shelf (SWSS) and Bay of Fundy. From 1970 to 1995, the length of juvenile (age-1) haddock on the SWSS was negatively correlated with the abundance of adults (age-4+). Within year-classes temporal trends in juvenile length persisted through to the adult stage such that year-classes that were small(large) at age-1 were small(large) at age-4. These two results were combined with the positive correlation observed between recruitment and the body size characteristics of haddock on the SWSS in a conceptual model of compensatory recruitment regulation. In the model high adult abundance decreases growth of juveniles leading to smaller-sized adults and subsequently lower recruitment.

Conversely, low adult abundance results in increased growth of juveniles leading to larger adults and higher recruitment. Density-dependent growth of juveniles, combined with the positive correlation between recruitment and adult body size, constitutes a compensatory mechanism for adjusting future haddock recruitment according to present adult abundance.

Wigley, S. E., Burnett, J. M., & Rago, P. J. (1998). An evaluation of maturity estimates derived from two different sampling schemes: Are the observed changes fact or artifact? *Journal of Northwest Atlantic Fishery Science 25*, 133-140. http://journal.nafo.int/Volumes/Articles/ID/313/categoryId/33/An-Evaluation-of-Maturity-Estimates-Derived-from-Two-Different-Sampling-Schemes-Are-Observed-Changes-Fact-or-Artifact

Biological sampling of fish during research vessel survey cruises is often conducted using length-stratified age sampling schemes. Maturity analyses may be affected by changes in sampling protocols, and may potentially result in biased estimates of maturation patterns. In such cases, these estimates may be artifacts of the sampling activities and not accurate estimators of stock dynamics. In 1992, the Northeast Fisheries Science Center modified the length-stratified age sampling protocol used during research vessel bottom trawl surveys conducted semi-annually since the 1960s. While demonstrating gains in the precision of age-length keys for many species have been obtained with the new protocols, no systematic evaluation of the effects of the sampling protocol change upon maturity analyses has been performed. In this study, potential effects of changes in sampling protocol were assessed for two groundfish species, haddock (Melanogrammus aeglefinus) and American plaice (Hippoglossoides platessoides). Over the critical size range of maturity for both species, significantly different length frequency sampling was obtained from each sampling scheme during the 10-year study period. Analyses for American plaice were further complicated by the dimorphic growth. Simulation techniques were employed to assess whether the observed changes in maturity estimates were a result of the changed sampling protocols. The simulation suggested that these changes were real phenomenon and not artifacts caused by changes in sampling.

Anthony, V. C. (1993). The state of groundfish resources off the northeastern United States. *Fisheries, 18*(3), 12-17. https://doi.org/10.1577/1548-8446(1993)018%3C0012:TSOGRO%3E2.0.CO;2

From the early 1960s to 1977, fishing vessels from 13 nations fished heavily off the northeastern United States. Landings of principal groundfish species rose to 780,000 tonnes in 1965 and abundance declined rapidly. Most species of groundfish were being underfished by the United States. With the passage of the Magnuson Fishery Conservation and Management Act in 1976, fishing by foreign nationals stopped and fishing effort by the United States increased. The number of days fished by otter trawlers steadily increased into the mid-1980s before tapering off. Fishing technology improved and the effective fishing effort continued to go up even though the number of days at sea did not. Landings rose with effort until 1983 and then fell dramatically. Groundfish abundance declined steadily after 1978 for the next decade. By 1990-1992, fishing mortality rates for the three major groundfish species (cod (Gadus morhua), haddock (Melanogrammus aeglefinus), yellowtail flounder (Pleuronectes ferrugineus)) were twice as great as the management targets. Overall groundfish landings were one-third the maximum sustainable yield (MSY). Landings for haddock and yellowtail flounder were one-tenth the MSY. If the abundance of groundfish were rebuilt to provide the MSY, the catch could increase by two to three times with one-half of the present effort.