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A Guided Tour through the Yellowtail Flounder Literature for the 2014 Georges Bank Yellowtail Flounder Diagnostic Benchmark

Christopher M. Legault[1] and Steven X. Cadrin[2]

[1]National Marine Fisheries Service
Northeast Fisheries Science Center
166 Water Street, Woods Hole, MA 02543

[2]School for Marine Science and Technology
University of Massachusetts
200 Mill Road, Fairhaven, MA 02719

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ABSTRACT

Yellowtail flounder resources have supported productive fisheries off New England since 1935, and a long time series of research and monitoring are available to inform historical and recent patterns of productivity and exploitation. A brief summary of the most relevant studies from peer-reviewed and gray literature is provided as context for the empirical benchmark assessment of yellowtail on Georges Bank. Several periods of productivity changes in the past may help to inform the most appropriate approach to assessing and managing current yellowtail resources.

Introduction

Yellowtail flounder (*Limanda ferruginea*) have been extensively studied in waters off the northeast US since the fishery for this species began in 1935. During this time, there have been several periods of changing productivity that were difficult to understand, similar to the recent apparent changes that led to this Empirical Approach Diagnostic Benchmark Assessment. This assessment will continue a long series of studies and stock assessments. Reviewing the previous studies has been a benefit to us, and we think this summary and the source documents will similarly help other participants of the benchmark assessments for considering the large body of work. In order to better understand the current situation, this guided tour through the relevant literature provides a brief overview of some of the research done on this species and its fishery. Although this review was exhausting, it is not exhaustive, and we selected the studies on yellowtail flounder that we think are most relevant to the terms of reference of the benchmark assessment of Georges Bank yellowtail flounder.

The desire to provide a brief summary will invariably lead to some topics being described in less detail than would otherwise be preferred. We have tried to balance the need for brevity with the highlighting of important results that could shed light on the current situation. The full articles can be consulted by the interested reader for full details and to draw their own conclusions. Our intentions are to identify relevant papers, summarize their content and encourage participants to read source papers that they are interested in, which are also provided.

Summary of Important Papers in Chronological Order

1) Scott (1954) found yellowtail in the Southern New England stock (called Cape Cod region in the paper) grew faster and to smaller maximum size and younger oldest age than two regions off Nova Scotia (Middle Ground and Western Bank). Morphometric differences also suggested the Canadian fish were different stocks than the US fish. Georges Bank was not included in this study.

2) Royce et al. (1959) examined the yellowtail fishery during the period 1942 through 1949 when a large decline in landings of the Southern New England stock from 63 million pounds (29,000 mt) to 10 million pounds (5,000 mt) occurred. It is a seminal paper on the early development of the yellowtail flounder fishery and contains information on tagging studies, distribution, growth and aging, landings, maturity and spawning, egg and larval distribution, survival, and management. It contains information about four US stocks of yellowtail flounder: Southern New England, Georges Bank, Cape Cod, and Northern Gulf of Maine, but focuses on the Southern New England stock, because it was the most important at the time and the decreased landings in that region were a concern.

The fishery for this species had just begun in 1935 as the winter flounder fishery declined, and yellowtail served as a substitute for the flounder filet market. Catches from all stocks combined rapidly increased from 23 million pounds (10,000 mt) in 1938 to approximately 70 million pounds (32,000 mt) in 1942 but then followed a strong decline to 30 million pounds (14,000 mt) in 1949. The authors examined the possible role of prices in the decline and concluded that decline in production was not due to a decrease in demand. The authors found few old fish in the catch (6.1% were age 6 or older) and estimated the total mortality rate (Z) on fully selected yellowtail to average 0.86. However, the authors did not find symptoms of heavy fishing, such as a declining average size, an increasing proportion of young fish in the catch, or an increasing growth rate due to the thinning of the stock. Regressing the total mortality rate by year against fishing effort (in thousands of days fished) had a high correlation but a negative value for the y-intercept, an estimate of the natural mortality rate. Examination of short term and long term tag returns also found that fishing and total mortality rates were similar, implying low natural mortality. The authors did not believe the great decline in the catch of the southern New England stock was caused by catching too many yellowtail, too many small yellowtail, or too many spawning yellowtail.

3) Lux (1963) used tagging, meristics, and trematode parasites to identify three groups of yellowtail flounder in New England: southern New England, Cape Cod, and Georges Bank. Trematodes were found only in the Cape Cod yellowtail and fin ray counts did not differ among the three groups. Results corroborate and strengthen conclusions of Royce et al. (1959) regarding divisions of the New England yellowtail where each of the three principal fishing grounds supports a group which is essentially separate from the others, although a small amount of seasonal intermingling takes place between the groups. Seasonal movements within stock are generally toward the east in the summer months and toward the west in winter (also seen in Royce et al., 1959).

4) Lux (1964) computed commercial catch per unit effort for boats landing more than 50% yellowtail in the three regions to measure relative apparent abundance during the period 1943-1961. Effort was standardized to a 26-50 ton vessel in days fished. A profitable catch for a yellowtail trip consists of about 10 to 20 thousand pounds (4.5 to 9.1 metric tons) for small draggers carrying 4 or 5 man crews. For larger vessels, carrying 6 or 8 men, it varies from 25 to 50 thousand pounds (11.3 to 22.7 metric tons).Total effort for all three grounds averaged about 5,400 standard days per year. The patterns of relative apparent abundance were generally similar to the patterns of landings. A positive relationship between CPUE and average effort for Southern New England indicated the stock was not reduced by the amount of effort expanded, while the negative relationship for Georges Bank indicated fishing had a significant effect on the stock. Apparent abundance dropped to its lowest level at about the time when temperature reached its peak in the early 1950s, and apparent abundance subsequently increased during a period of decreasing temperature (surface temperature measured at Boothbay Harbor, Maine). The available evidence provided no evidence that overfishing occurred during this period.

5) Hennemuth (1968) presented results of mesh selection studies relative to expected yields in the commercial fishery. Increasing the mesh size would decrease discards and landings in the short-term, but increase landings in the long-term. No evidence that reducing the current level of effort (producing an F of 80%) would be beneficial in the long run.

6) Lux (1969a) reported on landings, catch per unit effort, and effort during years 1943 through 1966 for yellowtail flounder in the Southern New England and Georges Bank stocks. Typical otter trawl mesh size during this period was 114-mm, which retained yellowtail that were smaller than the minimum acceptable market size of about 30 cm. Undersized fish sometimes made up more than half of the total catch by weight, with about 25% surviving based on limited observations. Apparent abundance continued to vary widely. High recruitment from 1958, 1959, and 1960 year-classes led to high abundance in the early 1960s. Total mortality (Z) in both stocks averaged about 1.02. Insufficient data were available for a good estimate of the natural mortality rate; however it appeared that losses of adult flatfish from natural causes are small. Used average time at large from seven tagged fish of 22 months (range 5-56 months) to conclude natural mortality was 20% per year or less.

7) Lux (1969b) calculated length-weight relationships for six flatfish species, including yellowtail, using both commercial and survey data. Yellowtail relationships were calculated by sex and calendar quarter based on 1,748 measurements obtained during 1956 through 1961, mostly from the Southern New England stock but 249 fish were from Georges Bank. Female yellowtail are heavier than males at the same length. Yellowtail caught during the first half of the year are heavier than those caught during the second half of the year at the same length due to gonad development.

8) Lux and Nichy (1969) used scales to estimate von Bertalanffy growth equations for male, female, and sexes combined yellowtail flounder for the three New England stocks based on data collected during 1955-1965. Females grew faster than males beyond age 2 and were observed at older ages. The number of added rings for tagged fish aged at both release and recapture confirmed the aging. Southern New England yellowtail were slightly larger than those from Georges Bank at about 1 ½ to 2 ½ years of age, but Georges Bank yellowtail were larger at older ages. Cape Cod yellowtail grew slower than the other two stocks in early years and faster in later years, but sample size was low for this stock. The oldest fish encountered during the study was 14 years old, this fish was from the Cape Cod stock.

9) Efanov (1973a) estimated optimim fishing mortality to be 0.7 for yellowtail in southern New England and on Georges Bank based on yield-per-recruit analysis assuming natural mortality (M) of 0.6.

10) Efanov (1973b) estimated natural mortality (M) to be 0.6 based on catch-per-effort during two periods with different effort.

11) Sissenwine (1974) examined biotic and abiotic regulation of the Southern New England yellowtail flounder fishery using fishery data from Royce et al. (1959) and Lux (1969a) and temperature data from Block Island, Rhode Island. The abiotic factor of temperature was found to explain a significant amount of variation in equilibrium catch and recruitment during the period 1944-1965. The author concluded that the decline of the fishery during the late 1940s resulted from a general warming trend in the region.

12) Sissenwine (1977) developed a simulation model for the Southern New England yellowtail flounder stock which included fluctuating environmental conditions (temperature) in addition to the standard population dynamic equations. Temperature was found to explain a significant portion of recruitment variability, regardless of whether recruitment was modeled as a linear function of stock size or independent of stock size. Substantial increases in simulated yield resulted from concentrating fishing effort during the second half of the year and when fishing effort and discard mortality were reduced.

13) Sissenwine et al. (1978) reported the most recent (1977) commercial catch per unit effort and survey indices were all comparable to the lowest level ever observed for all three stocks of yellowtail flounder. A sharp reduction in the proportion of the yellowtail flounder catch discarded at sea in recent years. The commercial catch per standard day of fishing on Georges Bank has been less than two tons since 1975, compared to an average of 4.2 during 1943 through 1974. On Georges Bank, the pre-recruit indexes during the last two surveys averaged only 8% of the index during the previous 13 surveys. Fmax was estimated to be 0.5 and F0.1 to be 0.3 assuming M of 0.2 for the Georges Bank stock with associated projected catch of 4,400 mt and 3,000 mt, respectively. The relationship between autumn survey and subsequent year’s catch was used to predict next year’s catch under different fishing mortality rates.

14) McBride and Sissenwine (1979) reported a reduction in landings from 1977 (9,700 mt) to 1978 (4,600 mt) on Georges Bank, but the catch per unit effort and survey indices remained low, but perhaps stabilizing. Age 1 survey indices indicated improved recruitment in the most recent year. The reduction in landings on Georges Bank was partially due to reductions in the target yield implemented in 1978. The 1978 F shows a large reduction to approximately Fmax based on plotting the autumn survey against the subsequent year’s catch.

15) McBride et al. (1980) reported a change in methodology for estimating discards due to a decline in reporting of discards in vessel interviews. The new method relies on mesh selectivity studies and resulted in increased catch estimates due to greater discards than previously estimated. Misreporting of areas in the catch statistics were identified in which some of the catch reported in other areas may in fact have been taken from the Southern New England stock. On Georges Bank, catch per unit effort increased from 1978 to 1979, but remained low relative to earlier values. The age distribution of the commercial catch shifted from mostly ages 3 and 4 in the 1960s to mostly ages 2 and 3 in the late 1970s. The Georges Bank yellowtail flounder index from the 1979 autumn trawl survey declined. Survey catches were found to be higher at night than

during the day, but trends were similar among all time periods. The available evidence did not indicate significant recovery of the Georges Bank population.

16) Brown et al. (1980) examined a number of management strategies that could be used for yellowtail flounder based on the historical literature and recent stock assessments. They suggested that some of the reported catch in the late 1970s from Georges Bank and Cape Cod stocks actually came from Southern New England, about 1,500 to 4,000 mt are indicated as incorrectly attributed to stock. Maximum sustainable yield for the Georges Bank stock was estimated using a production model to be about 9,000 mt. Yield per recruit at a fishing mortality rate of 1.0 and the average year class during the 1960s produced about 10,000 mt.

17) Clark et al. (1981) reported that the implementation of catch quotas and landings restrictions under the Fisheries Conservation and Management Act of 1976 resulted in extensive misreporting by area. In many cases, landings were completely unreported. Consequently, data for 1977-1980 were not considered to be reliable. Commercial catch per unit effort indices were reported but were considered to be suspect due to management changes. Survey indices for the Georges Bank yellowtail stock showed sudden rapid increases in 1980 for both the spring and fall surveys, possibly due to increased availability. Total mortality estimates from the surveys were 1.44 and 1.19 for the spring and fall surveys, respectively. Cooperative surveys were conducted in the Southern New England region during 1980 and 1981 using commercial vessels. Equilibrium yield calculations indicated the potential for continued low levels of abundance and dependence of the fishery upon incoming recruitment if mortality remained high and recruitment was confirmed to be poor compared to previous years.

18) McBride and Clark (1983) report on management regulation changes for trawl gear on Georges Bank which increased minimum mesh size from the previous standard of 4 ½” to 5 1/8” in 1982 and to 5 ½” in 1983 as part of the Interim Plan (while the Atlantic Demersal Finfish Plan, ADF, was being developed). The large mesh regulations were thought to prevent the large increase in discards observed in the Southern New England stock, which did not have this mesh size increase. Easing of landings restrictions led to an increase in landings in 1982 (10,600 mt) relative to 1981 (6,400 mt) on Georges Bank. The cause of the landings increase could be either improved abundance or greater effort. The spring and fall surveys gave somewhat different signals, with the spring survey showing increases in abundance and biomass compared to the late 1970s, while the fall survey showed little or no increase. The cooperative industry-based survey was continued in 1983 and indicated a sharp increase from the 1980-1981 indices. Estimates of total mortality from the surveys were 1.05 and 1.33 for the spring and fall, respectively.

19) Clark et al. (1984) reported U.S. yellowtail landings during the first 10 months of 1984 were 47% below corresponding 1983 levels despite relaxation of landings restrictions under the Interim Plan beginning in 1982. Dominance of age 2 and age 3 in the 1982-1983 landings (90% of the total by number) and the magnitude of the current reduction in landings indicates that this fishery was almost completely dependent

upon incoming recruitment. Survey indices for Georges Bank were low and indicated poor incoming recruitment. Total mortality from surveys remains high for 1980-1983 at 1.30 and 1.05 for Southern New England and Georges Bank, respectively. Abundance appeared to have declined to such low levels that additional measures to control mortality were probably required if a significant degree of recovery was to be achieved.

20) Overholtz and Murawski (1985) simultaneously assessed cod, haddock, yellowtail flounder, and pollock on Georges Bank to account for mixed-species harvests (bycatch) under a range of possible management options; mesh increases, area closures, and effort reductions. The major driving variable in the model was fishing effort, but changes in vulnerability and availability of the stocks by area were also possible by changing partial recruitment vectors (age specific F) and closing particular areas. Results showed that haddock and yellowtail would continue their downward trends over the next several years under present patterns of effort and exploitation. The Georges Bank multispecies trawl fishery could generally be categorized as suffering from chronic overexploitation at this time. Fishing mortality was excessive and needed to be lowered if long-term recovery was to occur. Results suggested that mesh changes were not sufficient, but needed to be combined with effort reductions or area closures. These reductions would result in lower catches of all stocks.

21) Collie (1987) examined yellowtail flounder stomachs and benthic grab samples to estimate food selection on Georges Bank. Yellowtail flounder feed mainly on benthic macrofauna, mainly amphipods and polychaetes. The preferred prey size of a 3-year-old yellowtail flounder is 13 mg.

22) O'Brien and Mayo (1988) described the changes in the fishing fleet for yellowtail flounder and computed new standardized catch per unit effort series for the three yellowtail stocks. The traditional side trawlers had been almost entirely replaced by stern trawlers, many of which were larger in size than the previous fleet. ANOVA results demonstrated high variability in yellowtail catch per unit effort among vessel sizes and geographic regions with many significant interactions, leading to standardization of effort by stock. Despite annual differences between the revised and traditional catch per unit effort indices, both tracked the same general trends.

23) NEFSC (1989) is the report of the 7th NEFSC Stock Assessment Workshop (SAW) which presents update assessments of the Georges Bank and Southern New England yellowtail flounder stocks. The New England Fishery Management Council's technical monitoring group (TMG) also presented a report on recent management actions highlighting some of the issues faced by groundfish stocks in the region. A virtual population analysis (VPA) for Georges Bank yellowtail flounder was presented which shows high F in all years (0.83 in the terminal year 1986) and low current spawning stock biomass (an all time low of 2,500 mt in 1985). Given current resource conditions, no recovery of the Georges Bank yellowtail stock was expected unless fishing mortality was significantly reduced.

24) NEFSC (1991) is the report of the 12th SAW which presents update assessments of the Georges Bank and Southern New England yellowtail flounder stocks and associated management advice. Analytical assessments for the two yellowtail stocks were presented for years 1973-1990 using a VPA that was calibrated using survey trends (ADAPT). The current fishing mortality rate (0.82) was estimated to be 1.4 times the target of F20%MSP (0.58) and 3.3 times the F0.1 reference point (0.25). A revised estimate of discards was greater than previous estimates, and the fishing mortality rate associated with this source of removals also increased. The 1987 year class was large in the Southern New England stock and relatively large in the Georges Bank stock, but well below recruitment levels estimated for the 1970s. In both stocks, more recent year-classes were poor. Both stocks were expected to be near a record low level in 1991. If current F was maintained on Georges Bank, the SSB was expected to continue to fall, while if F was reduced to the reference level there should be some increase by 1993.

25) Ross and Nelson (1992) examined the influences of stock abundance and bottom-water temperature on growth dynamics of haddock and yellowtail flounder on Georges Bank. Growth rates for both species were highly correlated with stock abundance but not with temperature. Annual temperature fluctuations of the magnitude studied appeared to exert only modest influence on growth rates of the two species.

26) NEFSC (1994) is the report of the 18th SAW which presents an update assessment and advisory report for Georges Bank yellowtail flounder. The stock was at low biomass levels and was overexploited based on the updated and revised ADAPT VPA. Relative to historic biomass levels, the stock had collapsed. Management advice was that fishing mortality should be reduced to levels approaching zero.

27) Gavaris et al. (1996) updated and revised previous U.S. stock assessments of Georges Bank yellowtail flounder based on an ADAPT VPA by including catch from the recently developed Canadian fishery on eastern Georges Bank. Results confirmed the perception of a rapid stock decline from 1973 to 1985 associated with decreasing recruitment and high exploitation rates, with only modest decreases in exploitation rates and stock increases since 1985.

28) Helser and Brodziak (1996) examined the influence of temperature and depth on the distribution and catches of yellowtail flounder, cod, and haddock in NEFSC spring and fall bottom trawl surveys during 1963-1994. Catch weighted cumulative distribution functions for temperature and depth were computed for each species. Yellowtail were consistently caught in the lower 25th percentile of the survey depth distribution in both seasons (around 50 m). Yellowtail were caught in the lower 25th percentile of survey temperatures in the spring (3-6 degrees C) and in the upper 25th percentile of survey temperatures in the fall (9-13 degrees C). This suggested that depth was more important than temperature in influencing yellowtail flounder distribution patterns.

29) NEFSC (1997) is the report of the 24th SAW which presents update assessments and advisory reports for Georges Bank and Southern New England yellowtail flounder.

Although Georges Bank SSB had doubled in the last two years and is currently slightly above the biomass threshold (SSB1996=11,700 mt, SSBthreshold=10,000 mt), it remained low relative to historic levels, and this threshold was well below the level which would maximize potential yield. Fishing mortality dropped sharply in 1995 and declined further in 1996 to below the F0.1 reference level. The 1990-1994 cohorts were moderately abundant, but the 1995 cohort was the weakest since 1986. A surplus production model confirmed the trends in F and SSB from the VPA.

30) Cadrin et al. (1998) presented the results of the 24th Northeast Regional Stock Assessment Workshop (SAW) which conducted an assessment for Georges Bank yellowtail flounder. VPA was the main assessment model, but a surplus production model was also presented. Both models agreed the biomass was low but increasing and that recent fishing mortality rate had declined. The few samples available to characterize the commercial landings in recent years were highlighted as a source of uncertainty. Retrospective analysis of the VPA model found no pattern of positive or negative inconsistencies but some large annual differences.

31) Neilson and Cadrin (1998) present the 1998 assessment for Georges Bank yellowtail flounder as the first TRAC (Transboundary Resources Assessment Committee, a joint US-Canada scientific body) assessment of this stock. Both catch and surveys increased during the past three years. Fishery catch rates and survey size composition supported the view that the resource was recovering. Recent management measures by both countries had the desired effect of rebuilding the population.

32) Brodie et al. (1998) examined the range of yellowtail flounder on the Grand Bank of Newfoundland during 1975-1995. The area occupied by the stock was positively correlated with stock abundance from surveys, but not with bottom temperature. The area of distribution for this stock to the preferred habitat around the Southeast Shoal is primarily a function of low stock size, which resulted from increased fishing activity in the mid to late 1980s.

33) Johnson et al. (1999) documented essential fish habitat for yellowtail flounder. It summarizes life history, habitat characteristics, and geographic distribution of the species in waters off the northeastern US. Plots are provided that allow examination of changes in spatial distribution over time.

34) NDWG (2000) presents assessment results of eleven northeast groundfish stocks, including Georges Bank yellowtail flounder, through 1999. Catch increased to 3,100 mt in 1999 and all three surveys increased in 1999. Georges Bank yellowtail flounder was assessed using VPA, and a surplus production model (ASPIC) was used to set the reference points for the stock. The first section of this report details the reasons for using two different models for assessment and reference points. Both the age-based and surplus production model projections indicated that rebuilding to Bmsy (46,850 mt) would occur within a couple years if F remained low. Retrospective analysis

indicates a tendency toward underestimating F in the most recent years. Estimates of catch at age may not be reliable due to poor sampling intensity.

35) Cadrin et al. (2000) report the TRAC stock assessment for Georges Bank yellowtail flounder through 1999. The stock was recovering from an overfished state with mean 1999 biomass of 49,600 mt, 92% of Bmsy, and low 1999 F of 0.13, 30% of Fmsy. Recruitment was strong, with an outstanding 1997 yearclass and above average 1996 and 1998 cohorts. At the current exploitation rate the stock is expected to increase by more than 10% during 2000. Retrospective analysis indicated a strong tendency toward overestimating abundance of older ages since 1994 and as a result, fully-recruited fishing mortality had been underestimated by recent assessments. Surplus production model results were similar to the VPA results, although statistical problems were encountered in finding a stable solution.

36) Johnson (2000) examined the match-mismatch hypothesis relating prey of larval yellowtail flounder with subsequent recruitment in the Southern New England and Georges Bank stocks during 1977-1987. There was no clear demonstration of a match or mismatch for strong or weak year classes.

37) Stone et al. (2001) present the TRAC stock assessment for Georges Bank yellowtail flounder through 2000. Catch increased to 6,895 mt in 2000 and survey indices indicated the population was at high levels relative to the early 1990s. Population abundance estimated by the VPA had increased ten-fold since 1995. However, the age structure was truncated, and retrospective patterns indicated that VPA estimates of biomass and F may be overly optimistic. The surplus production model indicates similar trends as the VPA, with both models showing the stock responding to low mortality rates in last several years with substantial increases through growth and recruitment. Canadian commercial catch rates declined in 2000 for no apparent reason.

38) Tsou and Collie (2001) present a multispecies virtual population analysis (MSVPA) of nine species on Georges Bank during 1978-1992. Yellowtail flounder was modeled as a prey species of Atlantic cod and female spiny dogfish. Yellowtail flounder was not an important prey species. Predation mortality for yellowtail flounder was approximately 0.22 for age 1 and negligible for all other ages.

39) Walsh and Burnett, eds. (2001) summarized a workshop on age reading for yellowtail flounder. A comparison of age determination by scales (the current protocol for US stocks), whole otoliths and thin-section otoliths suggested that thin sections were the superior structure for age determination of older yellowtail, but scales are appropriate for the current age distribution. However, if stock rebuilding continues, the increase in abundance of old fish may necessitate the use of thin sections.

40) NEFSC (2002a) produced new biological reference points for all New England groundfish stocks. The goal was to improve upon the previous situation in which an age-based assessment was used to assess the stock but a surplus production model

was used to set the biological reference points. This was successful for Georges Bank yellowtail flounder and resulted in using F40%=0.248 as a proxy for Fmsy and the empirical approach to estimate the Bmsy proxy of 58,800 mt and MSY proxy of 12,900 mt. The parametric approach to estimating reference points was not accepted, but resulted in estimates of Fmsy=0.32 (approximately F34%), Bmsy=63,200 mt, and MSY=17,600 mt.

41) NEFSC (2002b) presents the results of the first GARM (Groundfish Assessment Review Meeting) which assessed 20 northeast groundfish stocks through 2001. This was a large undertaking to address a perception that the US bottom trawl surveys were biased due to offsets on the trawl warps (the so-called "Trawlgate" examination). No evidence was found for bias due to the trawl offsets. The Georges Bank yellowtail flounder assessment estimated low current F and high current SSB (approaching Bmsy proxy levels), but exhibited a strong retrospective pattern.

42) Stone and Legault (2003) present the TRAC assessment for Georges Bank yellowtail flounder through 2002. Catch declined from 7,800 mt in 2001 to 6,100 mt in 2002 and all three surveys declined but remained above levels seen in the early 1990s. The VPA estimated recent F that was less than Fref (0.25) and increasing biomass but exhibited a strong retrospective pattern. There were fewer fish in the oldest age classes in both the catch and surveys than would be expected given the perception of recent low exploitation. No confidence was expressed in projection results, so status quo catch was recommended.

43) Stone et al. (2004) provides an historical perspective on the collapse and recovery of Georges Bank yellowtail flounder. Past and present spatial distribution and abundance data from groundfish surveys and trends in exploitation, recruitment, biomass, and age composition from recent stock assessments, which were based on a VPA and a production model, were used to illustrate the changes over time. Exploitation was considered the dominant influence in the decline of this stock and the effectiveness of the current management strategy to rebuild the stock is demonstrated through deterministic simulations and yield per recruit analysis.

44) Legault and Stone (2004) present the TRAC assessment for Georges Bank yellowtail flounder through 2003. The retrospective pattern in the VPA continued to worsen with terminal year F above Fref for the first time since the mid 1990s. The surplus production model diverged from the VPA, suggesting a much more optimistic outlook than the VPA. Sensitivity analyses based on a statistical catch-at-age model, ASAP, were used to examine the hypothesis that Closed Area II was acting as a refuge for old yellowtail. These sensitivity analyses demonstrated that if this hypothesis was true, then yields could be increased by fishing in this area. In June 2004, a special access program for groundfish fishermen began in Closed Area II. Considering the trends in survey abundance and recruitment, status quo catch or lower was recommended as an appropriate management approach until the source of the retrospective pattern is identified.

45) Walsh and Morgan (2004) present observations of natural behavior of 29 yellowtail flounder derived from data storage tags in the Grand Banks region. Yellowtail flounder exhibited diel and seasonal variations in depth and temperature. During various times of the year yellowtail flounder make extensive off-bottom movements at night and can remain off bottom for several hours.

46) Cadrin and Westwood (2004) observed off-bottom movements using archival tags deployed on yellowtail tagged off New England. Off-bottom movements were associated with movement to different habitats.

47) Gavaris et al. (2005) present the proceedings of the 2005 TRAC benchmark for Georges Bank yellowtail flounder. These two meetings in January and April were planned specifically to address the retrospective pattern in the Georges Bank yellowtail flounder assessment through examination of the data and new modeling approaches. Canadian discards of yellowtail from their sea scallop fishery were included in the assessment for the first time. A wide range of models was examined, but no single approach was found sufficient to adequately address the retrospective problem. It was therefore recommended that management advice be formulated after considering the results from three approaches: 1. projections from a model that adopts assumptions towards reconciling the fishery and survey observations; 2. projections from a base case model with due consideration for the magnitude of the retrospective; and 3. trends in relative abundance and relative mortality rates derived from survey and fishery data. It was suggested that when the indications from these three approaches are not coherent, the conservation implications of taking action on the assumption that one is correct when another is closer to reality should be described.

48) Stone and Legault (2005) present the TRAC update assessment that applies the major features of the benchmark formulations (Gavaris et al., 2005) using one additional year of data. The Major Change model did not include all of the minor aspects of the benchmark method, but included the most influential feature of splitting the survey time series between 1994 and 1995 to remove the retrospective pattern (approach 1 from the benchmark). The Minor Change model was not accepted in this assessment, and instead the Base VPA, the same formulation as had been used previously (e.g., modeling surveys as single series with no split), was used for approach 2 from the benchmark. The relative F (fishery catch/survey biomass) and survey total mortality estimates were examined and found to disagree; relative F declined sharply in 1995 while survey Z remained high throughout the assessment time period (approach 3 from the benchmark). Adjusting the catch advice from the Base VPA to account for the retrospective pattern resulted in similar advice as from the Major Change model. Both models had problems: the Base VPA had poor fits to the survey indices and a strong retrospective pattern, while the Major Change had large increases in survey catchability that could not be explained. The large changes in survey catchability were considered an alias of unknown mechanisms which cause the retrospective pattern because no changes actually occurred in the surveys. Both models indicated that more stock rebuilding was necessary.

49) Mayo and Terceiro, eds. (2005) present the results of the second GARM (Groundfish Assessment Review Meeting) which assessed 19 northeast groundfish stocks through 2004. The Georges Bank yellowtail flounder assessment was the same as Stone and Legault (2005). The estimated SSB in 2002-2004 was well below (about one fifth) that which had been projected in the first GARM in 2002. The GARM II panel could not find a specific cause of the retrospective pattern and noted that none of the hypotheses were supported by information on the fishery or resource.

50) Cadrin and Silva (2005) examined morphometric variation in yellowtail flounder from US and Canadian waters. Significant variation was found between sexes and among eight geographic areas. The differences were consistent with differences in ontogentic rates among groups but not strong enough to delineate geographic stocks off the northeastern US.

51) Sullivan et al. (2005) present evidence for atmosphere-ocean forcing of Southern New England-Mid-Atlantic yellowtail flounder recruitment. The North Atlantic Oscillation and air temperature were correlated with recruitment, but recruitment and cold pool bottom temperature were only marginally correlated. Recent settlers and cold pool temperatures were related but the relationship was often modified by subsequent changes in cold pool stratification (fall overturn), underscoring the dynamic role of thermal habitat in early life history.

52) Legault et al. (2006) presents the TRAC update assessment for Georges Bank yellowtail flounder through 2005. Both the Base Case and Major Change VPA formulations were presented, but only the Major Change was accepted by the TRAC for providing catch advice. The Base Case continued to exhibit a strong retrospective pattern, and trends in age 3+ biomass did not display a decline in recent years as indicated by all three surveys. The Major Change model followed the recent declining trend in the surveys and did not exhibit a consistent retrospective pattern. The Major Change model estimated F had never been below Fref, and the current F was above 1.

53) Legault et al. (2007) presents the TRAC update assessment for Georges Bank yellowtail flounder through 2006. Indications of a strong 2005 year-class were seen in all the surveys. The Base VPA was again rejected by the TRAC and the Major Change model was used to provide stock status and catch advice. The model indicated that the 2005 year-class was as strong as some from the 1970s, F was decreasing but still about Fref, and SSB was increasing, with a projection of an increase in quota. A caveat was that the increase in quota was largely dependent on the strength of the 2005 year-class.

54) NEFSC (2008) presents the results of the third GARM (Groundfish Assessment Review Meeting) which assessed 19 northeast groundfish stocks through 2007. This meeting changed and standardized the method to estimate US landings (Area Allocation, AA tables) and discards (Standardized Bycatch Reporting Method, SBRM) for all groundfish stocks. These changes were minimal for Georges Bank yellowtail.

The biological reference points for all the stocks were estimated, resulting in a lowering of the Bmsy proxy for Georges Bank yellowtail to 43,200 mt and MSY proxy to 9,400 mt, but kept the Fmsy proxy (F40%) at 0.25. The 2008 DFO survey (used in the assessment to tune the terminal year plus one abundance at the start of the year) had one tow which caught 7.5 mt of yellowtail, which was much larger than any previous catch (<1 mt). The 2008 DFO survey value was not included in the reference case for this assessment, but sensitivity runs explored including the value either with or without the large tow. The Base VPA was again rejected due to a strong retrospective pattern. The Major Change model did not exhibit a strong retrospective (a small one was noted) and was used for stock status, which found that F continued to decrease towards Fref as catch continued to decline, and SSB continued to increase due to the large 2005 year-class.

55) Legault et al. (2009) presents the TRAC update assessment for Georges Bank yellowtail flounder through 2008. The 2009 DFO survey again had a single large tow of more than 5 mt, which had a large influence on the stratified mean. The vessel and gear used for the US survey was new and calibration coefficients were not yet available, so the 2009 US spring survey value could not be used. The Base VPA was again rejected by the TRAC due to a strong retrospective. The Major Change was used for stock status and catch advice under two formulations: including or excluding the large tows in the 2008 and 2009 DFO surveys. These formulations were suggested as bounds. The including and excluding Major Change runs both did not indicate a strong retrospective pattern and both resulted in current F below Fref as catch continued to decline and increasing SSB due to the strong 2005 year-class. However, recruitment subsequent to the 2005 year-class was estimated to be poor and the age structure of the population had not extended to older ages in either formulation.

56) Cowen et al. (2009) estimate exploitation rates, natural mortality, and movement rates of yellowtail flounder on Grand Banks using multistate mark-recapture methods incorporating tag loss and variable reporting rates. The tagging study occurred during 2000-2004 off Newfoundland, Canada. Exploitation rates were low, up to 0.047, and natural mortality was estimated to be 0.256. Movement rates were among study areas which contained a single stock.

57) Legault et al. (2010) presents the TRAC update assessment for Georges Bank yellowtail flounder through 2009. The 2005 year class did not appear strong in any of the recent surveys and did not dominate the catch, causing the assessment model to estimate the 2005 year class as only average abundance. Catch increased from 2008 (1,275 mt) to 2009 (1,778 mt). The 2008 and 2009 DFO survey values were downweighted in this assessment (which was not possible previously due to software limitations) to account for the greater uncertainty of these values. Length-based calibration coefficients for the US survey were used. The Base VPA was not considered due to previous poor performance. The Major Change model was renamed the Split Series model and exhibited a moderate retrospective pattern for SSB, but not for F. Model results indicated SSB was at its highest level since 1974,

but much lower than estimated the previous year due to the change in perception of the 2005 year-class and well below the US rebuilding target. Recent recruitment was poor but F was less than Fref. A retrospective adjustment for catch advice was included.

58) Brooks et al. (2010) present the length-based calibration factors for cod, haddock, and yellowtail flounder for US surveys. These calibration factors are needed due to the changes in vessel and gear used to conduct US bottom trawl surveys between 2008 and 2009. The calibrations are based on 636 side-by-side tows conducted by both vessels and gears during 2008, with 143 stations at which yellowtail was caught by both paired tows. The calibrations indicate the new vessel and gear catches more cod, haddock, and yellowtail than the old vessel and gear and that the effect is more pronounced for smaller fish of each species. The calibration factor for yellowtail declined from 3.86 at small lengths to 1.97 at large lengths.

59) Cadrin (2010) presents a comprehensive review of geographic patterns of abundance, geographic variation, and movement to suggest that yellowtail flounder in the northeast US should be managed as three separate stocks despite apparent homogeneity of genetic variation. This work was the basis for maintaining the current US-Canada transboundary Georges Bank stock definition as a separate management unit, combining the Cape Cod and Gulf of Maine stocks into one stock and combining the Southern New England and Mid-Atlantic stocks into one stock, resulting in the three current stocks of yellowtail flounder: Cape Cod-Gulf of Maine, Georges Bank, and Southern New England-Mid-Atlantic.

60) Legault et al. (2011) presents the TRAC update assessment for Georges Bank yellowtail flounder through 2010. Catch and all three survey indices declined. The strength of the 2005 year-class continued to be revised downwards, because it did not appear strong in any of the recent surveys or the fishery catch. The Split Series model exhibited a strong retrospective, so the Base VPA was re-considered and renamed the Single Series model as a sensitivity analysis. The Single Series model exhibited a stronger retrospective pattern than the Split Series model. The Split Series model estimated increasing SSB to 8,800 mt in 2010, below average 2005 year-class and poor recent recruitment, and low recent F (below Fref in 2010).

61) Legault (2011) evaluated the survey design efficiency of the DFO and NEFSC bottom trawl surveys for cod, haddock, and yellowtail flounder on Georges Bank. There was no obvious change in sampling allocation for any of the three surveys that would benefit all three species in terms of relative efficiency. Yellowtail flounder has lower survey efficiency than cod or haddock in all three surveys. All three surveys were considered to provide appropriate indices of population abundance for all three species.

62) Legault et al. (2012) presents the TRAC update assessment for Georges Bank yellowtail flounder through 2011. Catch remained essentially the same at 1,160 mt in 2010 and 1,1,69 mt in 2011, and the surveys either remained about the same (DFO

and NEFSC fall) or increased (NEFSC spring). The Split Series model exhibited a strong retrospective pattern. Unadjusted model results indicated increasing SSB in recent years to 4,600 mt in 2011, poor recent recruitment, and F had always been above Fref. Applying a retrospective adjustment to the SSB and F created even worse perception of stock status. A number of sensitivity runs were explored to "fix" the retrospective pattern, including retrospective adjustment of the Single Series model, adding catch in recent years, increasing the natural mortality rate in recent years, and a combination of adding catch and increasing natural mortality in recent years. Based on the Split Series model with retrospective adjustment and the four sensitivity analyses, the TRAC recommended a quota of 400-500 mt, a major reduction relative to recent quotas (which had not been caught).

63) Barkley and Cadrin (2012) estimated discard mortality of yellowtail flounder using reflex action mortality predictors (RAMP). A controlled experimental trawl was used to test the seven reflex actions (predictors). Mortality was significantly related to reflex impairment. Exposure to air was the more influential stressor in the survivability of yellowtail flounder, suggesting that discard mortality in the fishery could be reduced by limiting the duration of on-deck air exposure for the fish. An example application of RAMP monitoring demonstrated a 42–73% range of discard mortality estimates from the southern New England trawl fishery.

64) NEFSC (2012) presents the SAW54 benchmark assessment of southern New England-Mid Atlantic yellowtail flounder. The most considerable developments were a transition from VPA to ASAP, inclusion of Bigelow survey data, revised assumption of natural mortality (from M=0.2 to Lorenzen age schedule rescaled to a lifetime M=0.3), and alternative rebuilding target based on the entire series of recruitment or the most recent decades. The revised M assumption was based on the gonadosomatic index approach, average maximum size in the population approach and longevity. The revised and updated assessment confirmed results from the 2005 GARM2 assessment, which showed that the retrospective pattern experienced in earlier years did not persist into the mid 2000s.

65) Pereira et al. (2012) conducted geospatial analysis of habitat use in yellowtail flounder on Georges Bank comparing the constant density model, the proportional density model, and the basin model using US survey data. The overall area occupied by flounder increased by a factor of two when abundance was high, and local density increased predominantly in high quality habitat that had been closed to commercial fishing. The results are most supportive of both the constant density model and the basin model.

66) Legault et al. (2013) is a working paper that has not been officially approved as a TRAC reference document yet but presents the TRAC update assessment for Georges Bank yellowtail flounder through 2012 and was the basis for management advice. The combined Canada/US yellowtail flounder catch in 2012 was 722 mt, with neither country filling its portion of the quota. Since 2004, there has been no directed Canadian fishery because fishermen have not been able to find commercial densities

of yellowtail flounder. Despite the low catch, the two bottom trawl surveys conducted in spring 2013 declined to low values relative to their entire time series. All three bottom trawl surveys indicate low recruitment for the most recent three cohorts. This assessment updates the Split Series and Single Series models. Both formulations exhibit strong retrospective patterns and rho adjustments are recommended for both determining stock status and providing catch advice. When the rho adjustments are applied, both formulations indicate low adult biomass at the start of 2013 (826 mt or 1,683 mt) and high fishing mortality in 2012 (F = 0.78 or 0.45). Catches of less than 200 or less than 500 mt are required to achieve the TMGC objective of not overfishing or allowing adult biomass to increase. Due to the assumption used for the 2012 year-class in the projections (geometric mean of recent ten years), the increase in adult biomass will be optimistic if the 2012 year-class is as poor as the recent year-classes.

67) Wood and Cadrin (2013) present mortality estimates and movement observations for yellowtail flounder in New England from analysis of tagging conducted during 2003-2006 using traditional Brownie tag-recovery models and the program MARK. Estimates of survival from the tag-recovery models confirm the general magnitude of total mortality derived from age-based stock assessments but indicate that survival was greater for females than for males. Movement among stock areas was low.

68) Goethel et al. (2014) developed a statistical catch-at-age model with movement among three areas and applied it to the yellowtail flounder stocks in New England. Tagging data during 2003-2006 informed the movement rates among the stocks. Results indicated that movement among stocks was low, estimates of stock size and fishing mortality were similar to those from conventional stock assessments, and incorporating stock connectivity did not resolve residuals patterns. Despite low movement estimates, new interpretations of regional stock dynamics may have important implications for regional fisheries management given the source-sink nature of movement estimates.

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