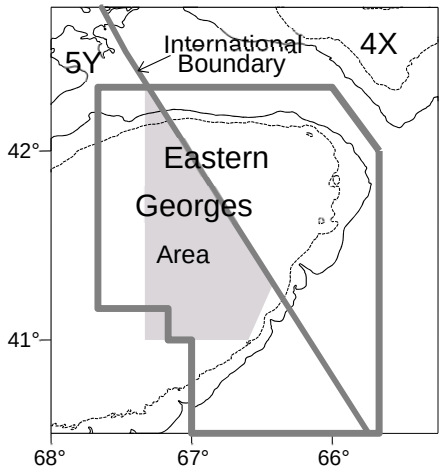
Transboundary Resources Assessment Committee

Status Report 2016/01 (Revised)

EASTERN GEORGES BANK COD

[5Zjm; 551,552,561,562]



Summary

- Combined Canada/USA catches were 608 mt, including 25 mt of discards in the 2015 calendar year.

- The estimated adult population biomass at the beginning of 2016 from the Vitutal Population Analysis (VPA) "M 0.8" model was 11,026 mt.

- Recruitment at age 1 has been low in recent years, with the 2003 year class remaining the highest estimated recruitment since 2000. The 2010 year class at age 1 is equivalent to two thirds of the 2003 year class based on the 2016 assessment. The current estimate of the 2013 year class is 4.4 million fish.

- A suite of indicators derived solely from survey and fishery data were summarized. Briefly, average survey biomass shows no evidence of rebuilding, and recruitment has been poor for the last 25 years. Relative F has declined since 1995, although total Z has remained high.

- Fishing mortality (ages 4-9) in 2015 was estimated to be 0.05. In recent years, ages 6+ are not fully selected by the fishery. In 2015, ages 3-4 were fully recruited. Consequently, the $F_{4\text{-}9}$ cannot be directly compared to F=0.11, so it is difficult to conclude whether we are achieving low risk of exceeding F=0.11.

- Average weight at length, used to reflect condition, declined throughout the time series, but has started to show improvement since 2009. Lower weights at age in the population in

recent years, a truncated age structure, poor recruitment and high total mortality[1] have contributed to the lack of rebuilding.

- A projection was made that considered a constant F approach consistent with the Transboundary Management Guidance Committee (TMGC) harvest strategy to reduce F to promote rebuilding when stock conditions are poor, and the empirical approach yielded a range of potential catch advice. For the 2017 quota, consistent with catch advice from both approaches, TRAC recommends an upper bound of 700 mt, which reflects precision associated with both lines of evidence.

Table 1. Catches and Biomass (thousands mt); Recruits (millions)

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Avg[1]	Min[1]	Max[1]
Canada[9]	Quota	1.4	1.6	1.2	1	0.9	0.5	0.5	0.5	0.5	0.5			
	Catch	1.2	1.5	1.2	0.8	0.7	0.5	0.4	0.5	0.5		5.3	0.4	17.9
	Landed	1.1	1.4	1	0.7	0.7	0.4	0.4	0.4	0.5		5.2	0.4	17.8
	Discard	0.1	0.1	0.2	0.1	<0.1	0.1	<0.1	<0.1	<0.1		<0.1	<0.1	0.4
USA[9]	Quota[2]	0.5	0.7	0.5	0.3	0.2	0.2	0.1	0.2	0.1	0.1			
	Catch[2]	0.3	0.5	0.5	0.3	0.2	<0.1	<0.1	<0.1	<0.1				
	Landed	0.2	0.2	0.4	0.4	0.3	0.1	<0.1	<0.1	<0.1		3.2	<0.1	10.6
	Discard	0.3	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	0.3
Total[9]	Quota	1.9	2.3	1.7	1.3	1.1	0.7	0.6	0.7	0.65	0.625			
	Catch[3,4]	1.5	2.0	1.7	1.1	0.9	0.5	0.4	0.5	0.6				
	Catch	1.7	1.7	1.8	1.3	1.0	0.6	0.4	0.6	0.6		8.5	0.5	26.5
From "M 0.8" model														
Adult Biomass[5]		7.7	9.5	11.1	10.0	8.4	7.0	7.9	8.5	8.6	11.0	25.2	5.9	59.7
Age 1 Recruits		1.5	1.7	0.9	1.1	3.5	1.5	0.5	4.4	2.8		5.6	0.5	24.1
Fishing mortality[6]		0.24	0.23	0.14	0.17	0.13	0.08	0.05	0.05	0.05		0.33	0.05	0.66
Exploitation Rate[7]		17%	19%	17%	21%	25%	8%	7%	7%	6%		26%	6%	44%
Exploitation Rate[8]		20%	20%	22%	20%	15%	9%	1%	1%	1%		23%	1%	46%

[1]1978-2015
[2]for fishing year from May 1-April 30
[3]for Canadian calendar year and USA fishing year May 1-April 30
[4]sum of Canadian landed, Canadian discard, and USA catch (includes discards)
[5]Jan 1 ages 3+
[6]ages 4-9
[7]ages 4-5; M=0.2
[8]ages 6-8; M=0.8
[9] unless otherwise noted, all values reported are for calendar year

Fishery

Combined Canada/USA catches in 2015 were 608 mt, which included 25 mt of discards, with a quota of 650 mt (Table 1). Historically, catches averaged 17,200 mt between 1978 and 1993, peaking at 26,463 mt in 1982. Catches declined to 1,683 mt in 1995, then fluctuated at about 3,000 mt until 2004, and have subsequently declined (Figure 1).

[1] "natural total mortality" revised to "total mortality"

Canadian catches increased from 458 mt in 2014 to 492 mt in 2015. Discards were estimated at 7 mt from the mobile gear fleet. Since 1996, the Canadian scallop fishery has not been permitted to land cod. Estimated discards of cod by the Canadian scallop fishery were 13 mt in 2015.

USA catches in 2015 were equal to those in 2014 at 116 mt. Estimated discards of cod for 2015 were 5 mt, almost entirely from the otter trawl groundfish fishery. Preliminary estimates of the USA catches (landings plus discards) for fishing year 2015 were 82 mt, 66.1% of the 124 mt quota.

The combined Canada/USA 2015 **fishery age composition** (landings + discards), by number, was dominated by the 2011 and 2013 year classes. By weight, the 2011 and then the 2010 year classes dominated the 2015 fishery (ages 4 and 5). The contribution to the catch of fish older than age 7 continues to be small in recent years: 0.4% by number and 1% by weight in 2015. Both the Canadian and the USA fisheries were adequately sampled to determine length composition of the catch.

Harvest Strategy and Reference Points

The Transboundary Management Guidance Committee (TMGC) has adopted a strategy to maintain a low to neutral risk of exceeding the fishing mortality reference, F_{ref}. When stock conditions are poor, fishing mortality rates should be further reduced to promote rebuilding. At the 2013 eastern Georges Bank cod benchmark meeting, it was agreed that F_{ref}=0.18 is not consistent with the Virtual Population Analysis (VPA) "M 0.8" model. At the 2014 TRAC, it was agreed that F=0.11 was a more appropriate fishing mortality reference point for the VPA "M 0.8" model than F_{ref}, whereas the ASAP continues to apply F_{ref}=0.18 for the consequence analysis.

State of Resource

Evaluation of the state of the resource was based on results from an age structured analytical assessment (i.e., VPA "M 0.8" model), which used fishery catch statistics and sampling for size and age composition of the catch for 1978 to 2015 (including discards). The VPA was calibrated to trends in abundance from three research bottom trawl survey series: DFO, NMFS spring, and NMFS fall. A statistical catch at age model (ASAP), which uses the same data as the VPA, was also examined. In addition, a suite of indicators derived solely from survey and fishery data were reviewed.

At the 2013 benchmark review, there was no consensus on an assessment model; however, it was agreed that the VPA "M 0.8" model would be used to provide catch advice (Claytor and O'Brien, 2013). Natural mortality (M) was fixed at 0.2 for all the ages in all years, except for ages 6 and older in years after 1994, where M=0.8. The scale of the values were much lower for the ASAP results, although the trend was comparable.

Since 1995, **adult population biomass** (ages 3+) estimated by the VPA "M 0.8" model has fluctuated between 5,900 mt and 18,800 mt (Figure 2). The estimated adult population biomass at the beginning of 2016 from the VPA "M 0.8" model was 11,026 mt, which was about 20% of the adult biomass at the start of the time series in 1978 (Figure 2).

Recruitment at age 1 has been low in recent years, with the 2003 year class remaining the highest estimated recruitment since 2000. The 2010 year class at age 1 is equivalent to two thirds of the 2003 year class based on the 2016 assessment. The current estimate of the 2013 year class from the VPA "M 0.8" model is 4.4 million fish. The current estimate of the 2014 year class from the VPA "M 0.8" model is 2.8 million fish at age 1 (Figure 2), although survey and model estimates are highly uncertain.

Fishing mortality (population weighted average of ages 4-9) in 2015 was estimated from the VPA "M 0.8" model to be 0.05 (Figure 1). However, in recent years, fish ages 6+ are not fully selected by the fishery. As a result, this average $F_{4\text{-}9}$ does not reflect exploitation on fully recruited ages. In 2015, age 3 and age 4 were fully recruited, with F values of 0.12 and 0.10, respectively. Consequently, the average F on ages 4-9 cannot be directly compared to F=0.11, so it is difficult to conclude whether a low risk of exceeding F=0.11 is being achieved.

A suite of indicators derived solely from survey and fishery data are summarized in Table 5. Briefly, average survey biomass shows no evidence of rebuilding, while recruitment has been poor for the last 25 years. Relative F has declined since 1995, although total Z has remained high.

Productivity

Recruitment, age structure, fish growth, and spatial distribution typically reflect changes in productive potential. The current biomass is well below the threshold where higher recruitment is observed (Figure 3). The **population age structure** displays a low proportion of ages 7+ compared to the 1980s. Average weight at length, used to reflect condition, declined throughout the time series, but has started to show improvement since 2009. Lower weights at age in the population in recent years, a truncated age structure, poor recruitment, and high total mortality have contributed to the lack of rebuilding. The survey **weight at age** had been declining throughout the 1990s and 2000s, but is beginning to show some signs of improvement since 2010 for select ages. The research survey **spatial distribution** patterns of adult (3+) cod have not changed over the past decade.

Outlook

This outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2017 and 2018.

Benchmark formulation (VPA "M 0.8" model)

Uncertainty about current biomass generates uncertainty in forecast results, which is expressed here as the probability of exceeding F=0.11 and change in adult (ages 3+) biomass from 2017 to 2018 and from 2018 to 2019. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, risk calculations are dependent on the data and model assumptions and do not account for uncertainty due to variations in weight at age, partial recruitment to the fishery, natural mortality, systematic errors in data reporting, the possibility that the model may not reflect stock dynamics closely enough, and retrospective bias. In particular, recent changes in partial recruitment to the fishery make it difficult to draw conclusions about exceeding F=0.11.

For **projections**, the average of the most recent three years of fishery and survey weight data were used for fishery weights and beginning year population weights, respectively, for 2017-2019. The 2016-2018 partial recruitment pattern (PR) was based on the most recent five years of estimated partial recruitment. The 2010-2014 average of recruitment at age 1 was used for 2017-2019 projections. The projection could be optimistic if the abundance of the 2015 and 2016 year classes is lower. Catch in 2016 was assumed to be equal to the 2016 quota (625 mt), and F=0.11 in 2017 and 2018.

Deterministic projection makes forecasts from the point estimates of stock abundance either by providing a quota or a fishing mortality reference level for each year of the projection horizon. Risk analysis makes forecasts using the point estimates as well as accounting for their uncertainties. In the stochastic projection, risks analysis is expressed as the consequence of alternative catch quota options in relation to a given reference fishing mortality

In 2017, a 50% risk of not exceeding F=0.11 corresponds to catches less than 1,319 mt, and a lower (25%) risk of not exceeding F=0.11 corresponds to catches less than 1,138 mt (Figure 5, Table 2a). Due to the expected contribution of the 2013 year class, which is larger compared to other recent year classes, a catch of 1,687 mt has a low risk (25%) that 2018 age 3+ biomass will be lower than 2017 (Figure 5, Table 2b).

In 2018, a 50% risk of not exceeding F=0.11 corresponds to catches less than 1,483 mt, and a lower risk (25%) of not exceeding F=0.11 corresponds to catches less than 1,289 mt (Figure 6, Table 2a). A catch of 2,424 mt has a low risk (25%) that 2019 age 3+ biomass will be lower than 2018 (Figure 6, Table 2b).

Table 2a. Risk of fishery catch exceeding F reference point 0.11 in 2017 and 2018 for VPA "M 0.8".

Probability	**0.25**	**0.5**	**0.75**
2017	1,138 mt	1,319 mt	1,607 mt
2018 (if F_{2017}=0.11)	1,289 mt	1,483 mt	1,763 mt

Table 2b. Risk that ages 3+ biomass will not increase from 2017 to 2018 and from 2018 to 2019 for VPA "M 0.8".

Probability	**0.25**	**0.5**	**0.75**
2017 to 2018	1,687 mt	2,180 mt	2,848 mt
2018 to 2019 (if $F_{2017\text{-}18}$=0.11)	2,424 mt	2,739 mt	3,073 mt

Consequence Analysis

This consequence analysis is based on the VPA and ASAP models. Natural mortality is assumed to be higher for age 6+ in the VPA (M=0.8) since 1994 compared to M=0.2 for all ages in the ASAP model. Comparison of the 2016 assessment results of the two models indicates that biomass (ages 3+) is estimated to be higher in the VPA, in contrast to the ASAP model that estimated lower biomass. A consequence analysis to understand the risks associated with

assumptions of the VPA "M 0.8" and ASAP "M 0.2" models, as presented at TRAC 2016, was examined (Table 3). This consequence analysis shows: 1) the projected catch (ages 3+) at F_{ref}=0.18 and F=0.11, and percent change in biomass, as if each model represented the "true state" of the resource; and 2) the consequences to fishing mortality and expected biomass (ages 3+) when 'true state' catch levels are removed under the assumptions of the other "alternate state" model.

In 2017, a catch of 1,319 mt (see Table 2a; p=0.5) would result in an increase of 5.1% in the VPA "true state" and a decrease of 0.5% in the ASAP "alternate state" in the 2018 biomass. A catch of 515 mt (ASAP result at F_{ref}=0.18 and p=0.5) would result in a 19% increase in the 2018 biomass based on the ASAP "true state" and an increase of 10.6% based on the VPA "alternate state".

In 2018, a catch of 1,483 mt (see Table 2a; p=0.5) would result in an increase in the 2019 biomass of 9.3% in the VPA "true state" and an increase of 10.4% in the ASAP "alternate state". A catch of 646 mt (ASAP result at F_{ref}=0.18, p=0.5) would result in a 29% increase in the 2019 biomass based on the ASAP "true state", and an increase of 26.9% based on the VPA "alternate state".

Table 3. Consequence analysis of risks of different management actions taken for Atlantic cod from eastern Georges Bank. Projected catch and biomass (ages 3+) are presented for each of two 'true state of nature' management models: VPA "M 0.8" model with F=0.11 and ASAP "M=0.2" model with Fref=0.18 during 2016 - 2018 on the main diagonal ("true state"). The risks of the alternative management actions "alternate state" are on the counter diagonal (see text). Fishing mortality (F), January 1 stock biomass, and percent change in biomass (% B) from the previous year are presented for each projection.

CONSEQUENCE ANALYSIS				
Catch 2015		492 mt		
Quota 2016		625 mt		
			VPA 0.8	**ASAP**
2015 biomass (3+)			10,048	1,717
2016 biomass (3+)			11,026	N/A
Projected catch				
VPA F=0.11			"true state"	"alternate state"
2017 catch = 1319 mt		2017 F	0.11	0.53
		2018 Biomass (mt)	12,811	3,215
		% B from 2017	5.1%	-0.5%
2018 catch = 1483 mt		2018 F	0.11	0.62
		2019 Biomass (mt)	14,003	3,551
		% B from 2018	9.3%	10.4%
ASAP F=0.18			"alternate state"	"true state"
2017 catch = 515 mt		2017 F	0.044	0.18
		2018 Biomass (mt)	13,484	4,016
		% B from 2017	10.6%	19%
2018 catch = 646 mt		2018 F	0.046	0.18
		2019 Biomass (mt)	15,477	5,185
		% B from 2018	26.9%	29%
		F<=Fref & biomass increase > 10%		
		F< =Fref & biomass increase < 10%		
		F> Fref and biomass increase < 10%		
		F> Fref and biomass increase > 10%		

Emprical Approach

The empirical approach method was developed to provide quota advice independently of the two models (Table 4). The method adjusts recent quotas by recent population biomass trends derived from fitting the average of the three surveys (DFO spring, NMFS spring, NMFS fall) to a *loess* smoother. The trend used to adjust quota was estimated from the most recent 3-year block of the *loess* smooth (2014-2016), and uncertainty about the trend was derived by bootstrapping the original loess fit 1000 times to produce 90% probability intervals (Figure 4). This method is essentially a constant exploitation approach, which relies on recent quotas (2013-2015).

Table 4. Quota advice (mt) resulting from application of the empirical approach method, where recent average quota (650 mt) is multiplied by the most recent 3-year average biomass trend (600 mt in 2013; 700 mt in 2014; 650 mt in 2015). Percentiles reflect uncertainty in the estimated 3-year average biomass trend from the robust loess smooth, rather than risk. The percentiles (50% = median) reflect the probability that the true average 3-year trend is within a given bound (e.g., between 5% and 95%, we expect the true average 3-year trend will fall within these bounds 90% of the time).

Year	5%	25%	50%	75%	95%
2017	565.5	643.5	689	760.5	806

TRAC Advice

While management measures have resulted in a decreased relative exploitation rate since 1995, total mortality has remained high and adult biomass has fluctuated at a low level. The continuing poor recruitment since the early-1990s, and the assumed high natural mortality on ages 6+ since 1995, are important factors for this lower productivity. Rebuilding will not occur without improved recruitment. Given the extremely low spawning stock biomass (SSB), TRAC advises that management aim to rebuild SSB.

While the consensus at the 2013 benchmark was to use the VPA "M 0.8" model for catch advice, the TRAC is not recommending the VPA "M 0.8" model stochastic catch advice this year, due to concerns about model performance and temporal changes in factors that can affect stock dynamics.

A deterministic projection was made that considered a constant F approach consistent with the TMGC harvest strategy to reduce F to promote rebuilding when stock conditions are poor. The F corresponding to the 2016 quota was F=0.062, which is below the VPA "M 0.8" model reference point of F=0.11. Making a projection from the VPA "M 0.8" model estimated 2016 numbers at age, assuming the 2016 quota of 625 mt is caught, and assuming the same specifications for weights at age and PR, results in a deterministic quota of 719 mt. The empirical approach yielded a range of potential catch advice between 565-806 mt (5%-95%), with the median catch advice being 689 mt (Table 4). For the 2017 quota, consistent with catch advice from both approaches, TRAC recommends an upper bound of 700 mt. This upper bound reflects precision associated with both lines of evidence.

Special Considerations

The consequence analysis reflects the uncertainties in the assessment model assumptions. Despite these uncertainties, all assessment results, and all biological and fishery indicators, suggest that low catches are needed to promote rebuilding.

The 2016 NMFS spring survey was delayed by about a month, and ages were not available in time for TRAC, so an age length key from the DFO survey was applied to lengths from the NMFS spring survey. This could add uncertainty to model results this year.

The distribution map of the 2016 NMFS spring survey did not appear to vary from the recent 10 year average distribution map.

For the 2016 Eastern Georges Bank cod assessment, the 2015 catch at age for the US fishery was supplemented with age and length samples from statistical area 522 due to low samples from the eastern Georges Bank statistical areas. As of May 1, 2016, US quota for Eastern Georges Bank cod can be converted to quota for cod from western Georges Bank. Fish may only be caught in the western area under this quota conversion program. Quota cannot be converted from the western area to quota for the eastern area. It is unclear, at present, if this provision will result in a decrease in the number of trips that fish exclusively in the eastern area - which could impact US catch sampling for the 2017 TRAC assessment. A similar program has been in place in the US for haddock since May 1, 2014.

Table 5. Summary of biological and fishery indicators.

Indicator	**Metric**	**Results**
Age Diversity	Shannon-Weiner Age Diversity Index for each survey.	Variable but declining since 1992 in the DFO survey for ages 1-10+; variable and declining since 1985 for ages 1-10+ in NMFS spring. No trend for NMFS fall.
Condition	Fulton's K for all 3 surveys.	Downward trend is seen throughout the series until 2009, but all three surveys show a recent improvement.
Depth and Temperature Range	Biomass-weighted and abundance-weighted mean depth and temperature occupied from the 1970-2015 NMFS spring and NMFS fall survey data.	Cod remain in a preferred depth even though temperature fluctuates.
Maturity and Juvenile Growth	Median maturity at age (A50) and length (L50) from DFO and NMFS spring surveys.	Variable in recent years, ranging between ages 2.0 and 2.5, and juvenile growth has been increasing since about 2005.
Maximum Length	Maximum length from the 3 surveys.	Maximum length shows a decline since the early-1990s in the DFO survey and since the early-1970s in the NMFS spring and NFMS fall surveys.
Mean Length Trend	Weighted mean length of cod from the 3 surveys.	Weighted mean length is variable without trend.
Recruitment	Survey indices of numbers at age 1.	Recruitment <1990 was higher, with more frequent large year classes. Since 1990, only been three larger recruitment events (2003, 2010, 2013), but the magnitude of these is less than what was produced before 1990.
Relative Depletion	Survey biomass indices from individual surveys.	Fall survey biomass index declined to 25% of the average 1968-1972 abundance, spring NMFS index declined to 15% of the average 1968-1972 abundance, and DFO biomass index declined to 21% of the average 1987-1991 abundance.

Indicator	Metric	Results
Survey abundance trends	Population numbers at Age.	Since the mid-1990s, population numbers at ages 1-3 have been low, ages 4-6 have stayed at comparable levels, and older ages 7-8 have included zero catches despite lower relative fishing mortality.
Survey biomass trends	Mean relative biomass from the NMFS fall, NMFS spring, and DFO surveys averaged.	Comparison of averaged surveys from 1991 to 2002, with 2003-2014 showing no evidence of rebuilding.
Total mortality (Z) and relative fishing mortality (F)	Catch curve analyses from DFO and NMFS spring surveys. Relative fishing mortality from fishery and DFO and NMFS spring surveys.	High Z on fully recruited fish, often exceeding 1. NMFS spring survey shows consistently high fully recruited Z on all cohorts throughout the time period. The DFO survey shows a further increase in Z on fully recruited fish since 2006. Relative fishing mortality (F) has shown a substantial decline since the early time period, with no difference in trends between age groups.

Source Documents

Andrushchenko, I., L. O'Brien, R. Martin, and Y. Wang. 2016. Assessment of Eastern Georges Bank Cod for 2016. TRAC Reference Document 2016/02.

Brooks, E.N., I. Andrushchenko, Y. Wang, and L. O'Brien. 2016. Biological and Fishery Indicators and Models Projection Performance for Eastern Georges Bank Cod. TRAC Reference Document 2016/03.

Brooks, E.N., I. Andrushchenko, Y. Wang, and L. O'Brien. 2016. Developing an Emprical Approach for Providing Catch Advice for Eastern georges Bank Cod . TRAC Reference Document 2016/04.

Claytor, R., and L. O'Brien, editors. 2013. Proceedings of the Transboundary Resources Assessment Committee (TRAC): Transboundary Resources Assessment Committee Eastern Georges Bank Cod Benchmark Assessment. TRAC Proceedings 2013/01.

Curran, K.J, and E.N. Brooks, editors. 2016. Proceedings of the Transboundary Resources Assessment Committee (TRAC): Eastern Georges Bank Cod and Haddock, and Georges Bank Yellowtail Flounder. Report of Meeting held 12-14 July 2016. TRAC Proceedings 2016/01.

Wang, Y. 201.6. A Comparison of VPA, ASAP and Empirical Approach Applications to Eastern Georges Bank Cod (*Gadus morhua*). TRAC Reference Document 2016/05.

Correct Citation

TRAC. 2016. Eastern Georges Bank Cod. TRAC Status Report 2016/01.

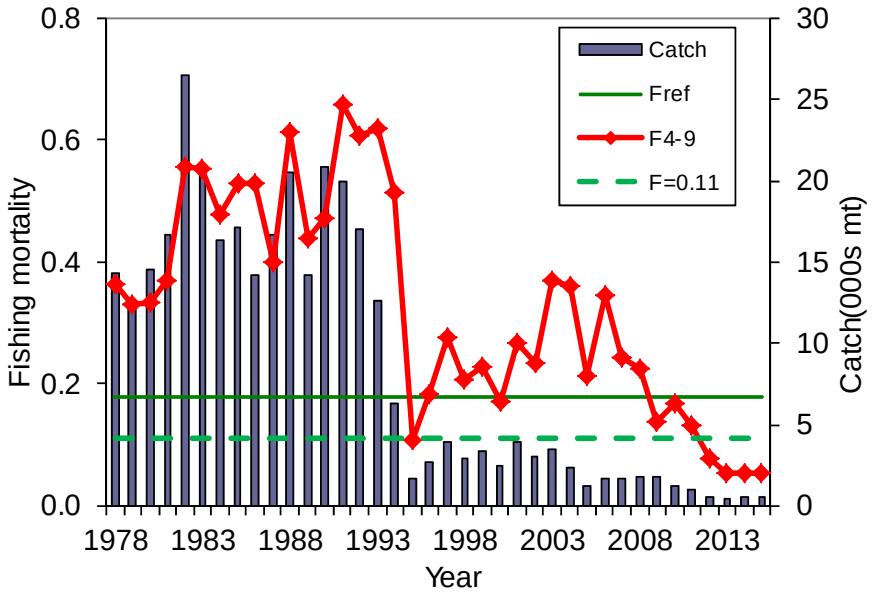


Figure 1. Catches and fishing mortality (F) for EGB cod from VPA "M 0.8".

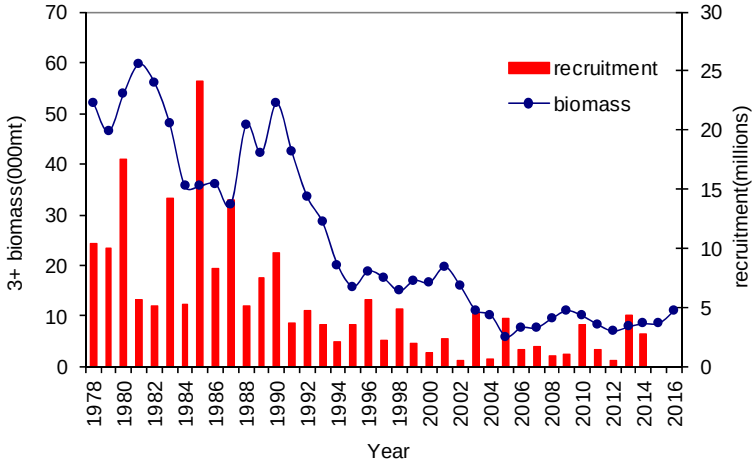


Figure 2. Biomass and recruitment for EGB cod from VPA "M 0.8".

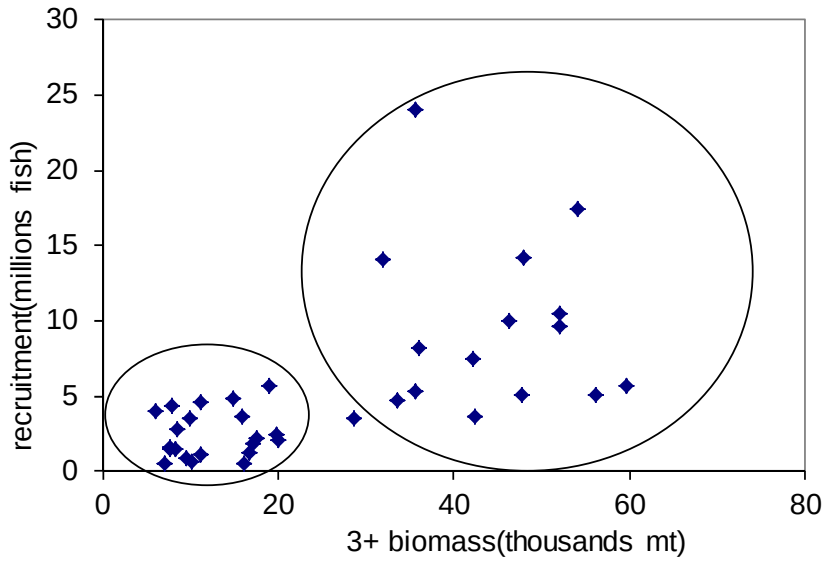


Figure 3. Stock recruitment patterns for EGB cod from VPA "M 0.8".

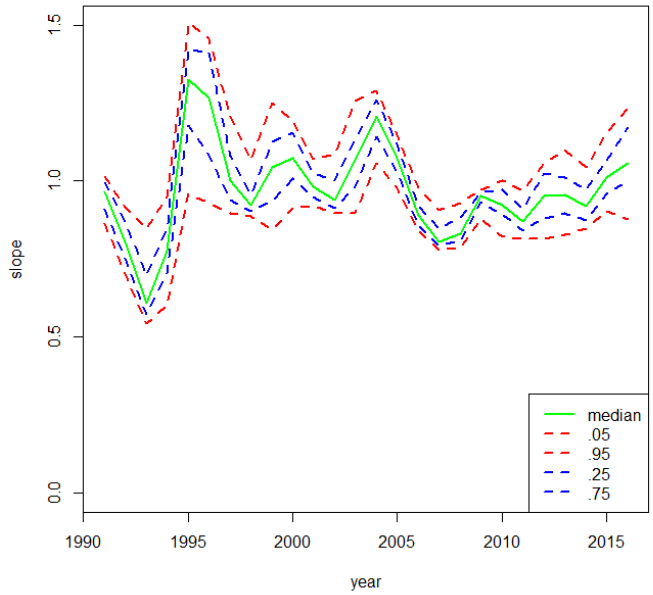


Figure 4. Bootstrap CI on the estimated 3-year trend from the average survey biomass index. A value of 1.0 means no change, values<1 indicate a decrease, values>1 indicate an increase.

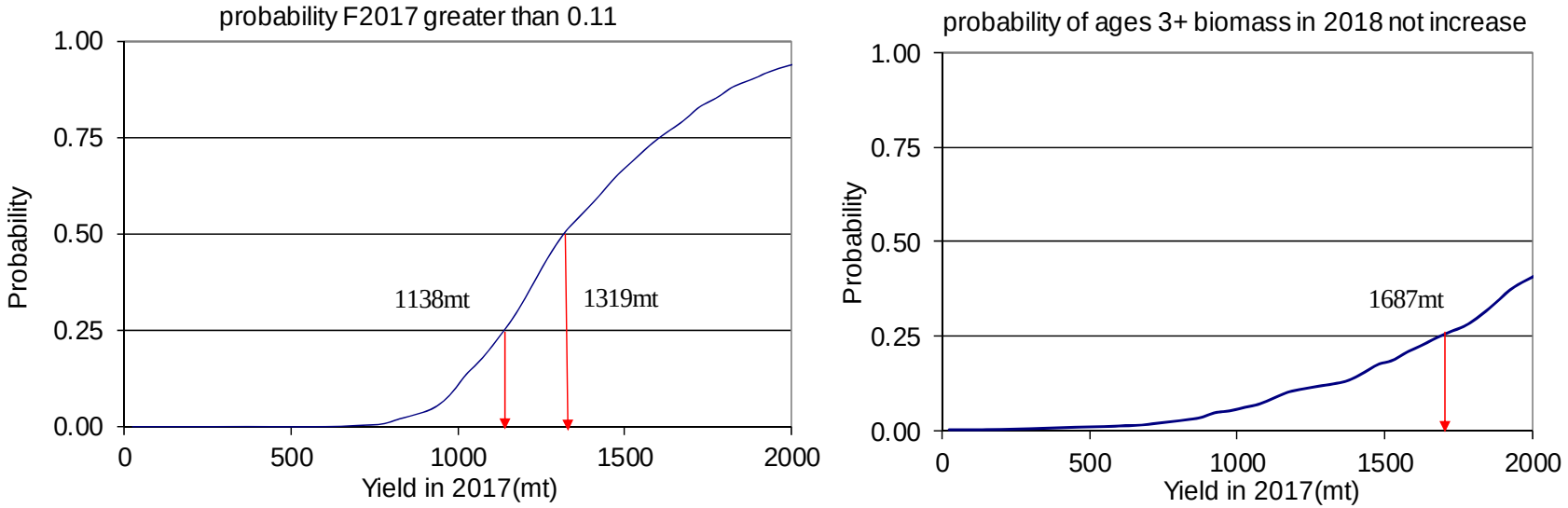


Figure 5. 2017 Projections and risks from VPA "M 0.8" results for EGB cod assuming 2016 catch of 625 mt.

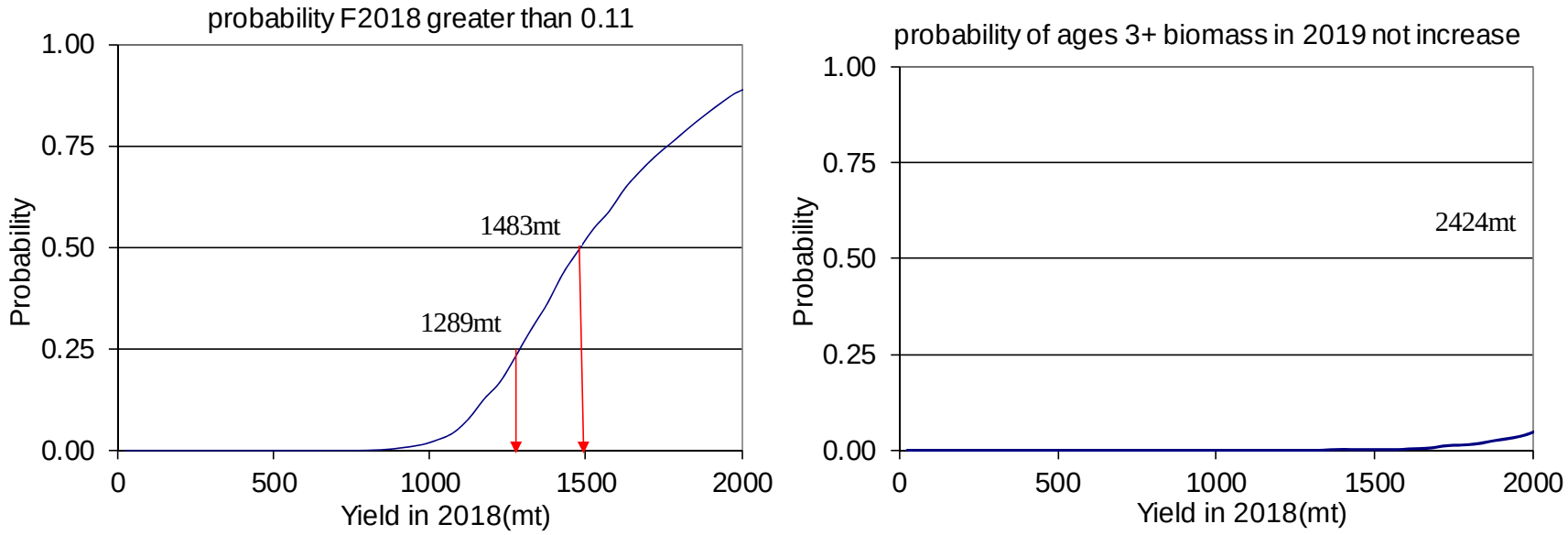


Figure 6. 2018 Projections and risks from VPA "M 0.8" results for EGB cod assuming 2017 catch at F=0.11.