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Evaluating the Impact of By-catch on the Recovery of American Plaice on the Newfoundland Grand Banks (NAFO Divisions 3LNO).

by

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Abstract

Simulations are used to evaluate recovery time for American plaice on the Newfoundland Grand Banks (NAFO Divisions 3LNO) under various by-catch levels. These simulations take into account the precision of the stock size estimates currently available for this stock, as well as the observed variability in the stock-recruitment process. We also explore two interpretations of the stock-recruitment data: the first assumes that recruitment prospects are poor due to the persistence of a low recruitment regime as observed since 1986, while the second assumes that future recruitment will return to historical levels as the spawning stock increases. We conclude that changes in the productivity of the stock could have a major impact on the dynamics of the stock in future years, and that recovery time will depend upon which recruitment process prevails in the future and upon our ability to control removals.

Introduction

For American plaice on the Newfoundland Grand Banks (NAFO Divisions 3LNO), recent assessments have indicated that the stock spawning biomass (SSB) is low in comparison to historical levels. There has been a by-catch in fisheries directed at other groundfish species and concerns have been expressed on the impact of such by-catch on the recovery of this stock. This paper uses simulations that take into account the precision of the stock size estimates currently available for this stock, as well as the observed variability in the stock-recruitment process, to evaluate the impact of various by-catch levels on stock rebuilding.

Materials and Methods

The population of American plaice in NAFO Divisions 3LNO is simulated until year 2036 by combining 1) a simple catch equation, 2) age-specific information on weight and 3) a discrete function representing age-specific allocation of fishing mortality (partial recruitment). The projections provide a description of population numbers and biomass, numbers and biomass of mature fish, catch numbers and biomass, as well as fishing mortalities. All quantities are age-specific and time-specific. The method is described in details in Rivard et al. (1999).

Monte-Carlo simulations are used to capture the uncertainties in our estimation of stock abundance and the dynamics of the recruitment process. Each simulation included 1500 replicates (or more in certain cases) based on sampling the assumed distribution of initial population size and the observed recruitment within pre-determined ranges of SSB.

Precision of initial population size estimates

Estimates of population numbers and their variances were obtained from an ADAPT analysis (Morgan at al., 1999) using historical catch-at-age and independent indices of abundance for 3LNO American plaice (Table 1). For the simulations, the initial population size for each age ($N_{i,1999}$) was sampled from a log-normal distribution with mean and variance provided by the ADAPT estimate expressed on the arithmetic scale. Morgan at al. (1999) assumed a value of 0.6 for natural mortality 1989 to 1996 and of 0.2 for the remaining years.

We also tested the sensitivity of these results by applying the same scenarios to the sampling of the recruitment-SSB pairs obtained from an ADAPT analysis using an M of 0.2 for all years.

Modeling recruitment process and variability

Figure 1 shows that recruitment and spawning stock size, as determined by Morgan et al. (1999), are only weakly related for American plaice of the Newfoundland Grand Banks. Long-term simulations require assumptions on the dynamics linking recruitment to the stock spawning biomass. Various ways have been suggested to capture both the dynamics and the uncertainties of the recruitment process by resampling the recruit-SSB scatter points (e.g. Getz and Schwartzmann, 1981; Overholtz *et al*, 1986). In our simulations, the observed range of SSB is split into quartiles and the observed recruitment is sampled with replacement within these quartiles. Since this approach is based on resampling the observations, it does not require making assumptions about the recruitment probability density function (pdf). The re-sampling was done from the bias-corrected recruitment/SSB pairs estimated by Morgan et al. (1999), as provided in Table 2. The benefit of non-parametric descriptions of stock-recruitment relationships is that they are able to capture the dynamics of the recruitment process without requiring explicit assumptions about the shape of the relationship.

In 1998 (see NAFO Redbook, 1998), a first attempt was made to calculate provisional reference points for American plaice in Div. 3LNO. Calculations were largely based on data from a sequential population model used in the 1993 assessment. The results indicated that B_{lim}, the biomass level at which the probability of having good recruitment is greatly reduced value, is of the order of 150,000 t. From the results of the 1999 assessment, the spawning biomass level at which there is no probability of having good recruitment is of the order of 60,000 t. It should be noted that the 1999 assessment used maturity data for the calculation of the spawning biomass while the previous calculations from the 1993 assessment assumed that all fish of age 9 and over were mature. This change in the definition of the SSB has an important effect on SSB values.

Low and high productivity periods

The stock-recruitment scatter-plot suggests that there are two distinct periods of productivity in this stock: a period of high productivity from 1960 to 1985 with mean recruitment at age 5 of 220 million and a period of extremely low productivity since 1986 to 1996 with a mean recruitment of 71 million. Simulations were used to evaluate the impact of a persistence of the current low recruitment regime on future stock trends under various by-catch scenarios. It should be noted that for the period of low recruitment, the sampling of recruitment-SSB pairs was not from quartiles but from the two ranges separated by the median; the low number of observations prevents splitting the SSB range in quartiles for re-sampling.

Modeling tools

The spreadsheet model described in Rivard et al. (1999) was used for the simulations. Risk analyses are performed using an Add-in to Excel called @Risk (Anon. 1997). This approach allows the user to specify uncertainty in a) population dynamic parameters, b) in initial conditions of the state variables and c) in the stock-recruit relationship. It also provides tools to calculate the probability of achieving limits or targets in the simulation years, to calculate the time it takes to reach these targets and to evaluate other elements of interest to managers. In particular, the model allows one to account for fishing mortality resulting from by-catch in periods of moratorium. The model, which was initially implemented to study strategies based on F-controls, was extended to permit the specification of constant-catch strategies.

Results and Discussion

The results of the simulations are presented in Table 3 and Figure 3. Four F-scenarios were considered: 1) No fishing (perfect control of by-catch); 2) F=0.07, which is equivalent to the level of by-catch observed since 1995; 3) F=0.14, or twice the by-catch fishing level; and 4) F=0.2. Each scenario was evaluated under two recruitment hypothesis: i.e. future recruitment will respond to biomass changes in a manner similar to that observed 1) since 1960 [labeled "re-sampling full range of recruitment in the Table] or 2) since 1986, which is believed to correspond to a low recruitment regime. For the purpose of this paper, the first milestone for stock rebuilding was taken as 60,000 t.

Time to reach the first milestone for rebuilding and B_{lim}

The results indicate that the recovery of American plaice in 3LNO will depend upon the dynamics of the recruitment process and upon our ability to control removals. These simulations indicate that, in 50% of the cases, the SSB reaches the first milestone for rebuilding (60,000 t) in 2004 for the low recruitment regime, and 2003 for the full regime under "no catch scenario" (see table 3). Similarly, under the "no-catch scenario", 2010 is the first year that SSB will be above B_{lim} (150,000 t) for the low recruitment regime and 2006, for the full regime. For the full regime, the first milestone is reached by the end of 2003 for fishing mortalities smaller than 0.2. For the low recruitment regime, the recovery time to the first milestone increases slightly as F increases (see table 3), from 2004 under no fishing to 2007 with an F of 0.2. There is a major difference between the level of biomass and the level of potential yield under each of the assumed productivity regimes. Both the projected biomass and yield under the low recruitment regime are about half the projected levels under the full recruitment dynamics or "full regime".

B_{MSY} *and* F_{MSY} *estimates*

An approximation to the age-structured stock production model was obtained by using the last year of the long-term projection as a proxy to equilibrium biomass and equilibrium yield under various "constant F" scenarios. Results are presented in Figure 2, both for the full range of recruitment and for the low recruitment regime.

These results indicate that the maximum equilibrium yield under the low recruitment regime is about half the equilibrium yield inferred from re-sampling the full recruitment range. It should also be noted that these equilibrium curves were obtained by using constant vectors for mean weights-at-age and maturity-at-age. These approximations could be refined by using a re-sampling scheme similar to that used for the recruitment to capture the dynamics of these variables as a function of total biomass. Similarly, as the simulations were done without a plus-group (fish were assumed to leave the stock after age 25), the long-term yield could be underestimated if fish live longer than 25 years (although fish of such ages have rarely been observed). In any case, as there is little information on the growth of fish beyond age 25, little can be done at present to improve our knowledge of the dynamics of the stock at high levels (i.e. beyond the historical high observed).

Sensitivity analysis and other sources of uncertainty

We tested the sensitivity of these results to the assumption of a higher natural mortality from 1989 to 1996 used in the ADAPT-estimates of the recruitment-SSB pairs. The same scenarios were applied to the sampling of the recruitment-SSB pairs obtained from a new ADAPT analysis using an M of 0.2 for all years. The results of the sensitivity run are presented in Table 4 and Figure 4.

This sensitivity test indicated that, in 50% of the cases, the SSB had reached the first milestone for rebuilding (60,000 t) by 2011 under the low recruitment regime (was 2004), and 2005 under the full regime (was 2003) for the "no catch" scenario. Under the "no-catch scenario", the stock spawning biomass did not reach B_{lim} (150,000 t) before 2021 (was 2010) in the low recruitment regime and 2010 (was 2006), for the full regime. For the full regime, the first milestone was reached by 2005-2006 for all fishing mortalities (was end of 2003). For the low recruitment regime, the recovery time to the first milestone increased noticeably as F was increased (see table 4), from 2011 under "no fishing" to beyond 2020 with an F of 0.2 (was from 2004 under no fishing to 2007 with an F of 0.2). Under the low recruitment regime, the spawning biomass did not reach 150,000 t until well beyond 2020 under any of the F-scenarios.

In addition, "constant catch" scenarios were done using 3000 t catch for all years for the full regime, and 1,500 t and 2,000 t, respectively, for the low regime. The results of these scenarios are also presented in Table 4. Under the full regime, a constant catch of 3,000 t has virtually no impact on the time to reach the first milestone, adding only one year in comparison to the "no fishing" scenario. Under the low recruitment regime, a constant catch of 1,500 t added four years to the median time to reach the first milestone, while a constant catch of 2,000t added six years in comparison to the "no fishing" scenario. Under the full regime, a constant catch of 3,000 t has virtually no impact on the time to reach B_{lim}, adding only one year to recovery time in comparison to the "no fishing" scenario. Under the low recruitment regime, B_{lim} was reached only well beyond year 2020 in either of the two "constant catch" scenarios.

The simulations performed in this study took into account only the uncertainty in the estimation of the initial stock size and in the stock-recruitment process. The uncertainty and stochastic processes associated with fish growth, fishery selection patterns (partial recruitment factors) or maturity have not been included in these simulations. However, the analytical framework and software tools used in this study would allow taking these sources of uncertainty into account.

Conclusions

These simulations provided insight on the time it could take, for the American plaice stock on the Newfoundland Grand Banks, to recover from its current low level under various fishing scenarios. These results suggest that changes in the productivity of the stock could have a major impact on the dynamics and productivity of the stock in future years and that recovery time will largely depend upon which recruitment process prevails in the future.

If we assume that the low recruitment regime will prevail in the immediate future, the projections done from the 1999 assessment results (Table 3) suggest that the median time to reach the first milestone is increased by one year only in comparison to the "no fishing" scenario. With a doubling of the fishing mortality corresponding to the recent by-catch levels, the median time to reach the first milestone is also increased by one year only.

However, the sensitivity analysis done to evaluate the impact of using a value of 0.6 for natural mortality from 1989 to 1996 suggests that recovery time could be higher if natural mortality has, in fact, not changed during that period. In this case, recent by-catch levels could increase the median time to reach the first milestone by three to four years (i.e. 2014-2015, in comparison to 2011 under "no fishing") under a low recruitment regime. Higher fishing levels increased the median recovery time markedly. In 50% of the simulations (median), the milestone of 60,000 t was reached only by 2020 with a fishing mortality in the range of the 1998 estimate, and was still far from being reached in year 2020 with an F of 0.2 (which is below the $F_{0.1}$ level of 0.26).

Overall, the expected maximum yield at equilibrium under a low recruitment regime is about one half that expected under a regime where recruitment is allowed to return to the levels that existed in the sixties and seventies.

While simulations such as the ones used here allow estimates of the probability distributions for the parameters of interests, the results have been described solely in terms of the median to simplify their description. These distributions should also be investigated in future studies as they serve as a basis for the calculation of the probability of various outcomes, under specific scenarios of interest to the managers.

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Table 1. Age-specific estimates of population abundance at the beginning of 1999 from an ADAPT analysis (Morgan et al., 1999), relative error of stock size estimates, partial recruitment, mean weight at age (mid-year) and maturity at age used in the simulations.

Age	Stock Numbers for 1999 (x1000)	Relative Error of stock numbers (%)	Partial recruitment	Mean Weight mid-year (kg)	Maturity %
5	43000	50	0.022	0.15	0.015
6	29733	50	0.049	0.21	0.070
7	19093	36	0.106	0.30	0.249
8	18718	30	0.189	0.41	0.542
9	10319	28	0.292	0.59	0.778
10	6207	28	0.386	0.79	0.913
11	3378	26	0.533	1.01	0.972
12	1790	26	0.653	1.22	0.998
13	818	26	0.779	1.47	1.000
14	397	27	1.000	2.07	1.000
15	120	29	1.000	2.20	1.000
16			1.000	2.28	1.000
17			1.000	2.66	1.000
18			1.000	2.86	1.000
19			1.000	3.02	1.000
20			1.000	3.18	1.000
21			1.000	3.34	1.000
22			1.000	3.50	1.000
23			1.000	3.66	1.000
24			1.000	3.82	1.000
25			1.000	3.98	1.000

Table 2. Recruitment at age 3 and Stock Spawning Biomass for American plaice in NAFO Divisions 3LNO, as calculated from ADAPT (Morgan et al., 1999).

Year	Recruits at age 5	SSB		Year	Recruits at age 5	SSB
				1979	203242	106502
1960		106633		1980	202593	113954
1961		125770		1981	191839	106565
1962		140215		1982	197590	107951
1963		146453		1983	202034	123011
1964		160566		1984	207754	139225
1965	263120	183311		1985	203768	165479
1966	275990	214924		1986	183497	155475
1967	245960	229410		1987	169195	160001
1968	221650	206372		1988	209982	147349
1969	174460	178934		1989	229713	144362
1970	170170	144334		1990	240994	103503
1971	161590	124677		1991	140970	57646
1972	207350	99959		1992	101418	31538
1973	260260	79805		1993	82203	15821
1974	326040	70702		1994	77104	16479
1975	291320	74776		1995	57633	7766
1976	277500	66863		1996	49997	16237
1977	231833	77019		1997	26692	16852
1978	216600	90895		1998	31620	13810

Table 3. Results of simulations done to evaluate the impact of various fishing mortality levels on stock recovery for American plaice in 3LNO. Each scenario is based on 1500 replicates for the top panel and 2000 for the bottom panel. These simulations used recruitment-SSB data from a population reconstruction using M=0.6 from 1989 to 1996, and M=0.2 for the other years.

	Re-sampling full range of recruitment							
	No catch		F = 0.07 (current bycatch level)		F= 0.14 (twice current bycatch)		F = 0.20	
Year	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)
1999	19624	0	19624	697	19624	1374	19624	1937
2000	27429	0	26782	1011	26157	1936	25665	2665
2001	36987	0	35389	1409	33836	2631	32652	3554
2002	50699	0	47729	1942	45018	3547	42922	4719
2003	**71132**	**0**	**66241**	**2632**	**62013**	**4745**	58788	6224
2004	97602	0	89982	3540	83618	6299	**78660**	**8193**
2005	128236	0	117480	4627	108310	8150	101609	10526
2006	**162533**	**0**	147275	5879	134576	10238	125175	13172
2007	195919	0	**174841**	**7268**	**157925**	**12498**	145645	15916
2008	229798	0	202367	8764	180518	14869	**164772**	**18705**
2009	266585	0	229923	10717	200998	17779	181478	21916
2010	304454	0	257545	12257	221466	20019	197386	24458
2011	341934	0	285878	13719	241816	22096	213634	26539
2012	381251	0	313103	15135	262840	23832	230405	28375
2013	418812	0	340555	16465	284651	25706	247797	30405
2014	455750	0	367014	17781	305330	27480	264806	32404
2015	489294	0	390689	19027	324923	29339	281519	34451
2016	522664	0	413992	20383	342527	31306	295792	36616
2017	552861	0	434546	21765	356976	33265	307296	38715
2018	580839	0	451937	22883	368244	34939	316763	40417
2019	604340	0	465724	23808	376638	35931	322292	41521
2020	623152	0	476101	24516	384081	36714	327284	42349

	Re-sampling recruitment since 1986							
	No catch		F = 0.07 (current bycatch level)		F= 0.14 (twice current bycatch leve		F = 0.20	
Year	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)
1999	19645	0	19645	698	19645	1375	19645	1939
2000	27324	0	26682	995	26064	1904	25551	2619
2001	36009	0	34374	1345	32825	2500	31601	3362
2002	45653	0	42676	1747	39956	3164	37831	4163
2003	56044	0	51252	2188	47034	3859	43869	4982
2004	**66524**	**0**	59631	2651	53784	4567	49422	5773
2005	77538	0	**67995**	**3155**	**60162**	**5298**	54689	6580
2006	89546	0	76547	3591	66635	5925	59649	7273
2007	103414	0	86609	4092	73939	6627	**65338**	**8032**
2008	120652	0	99730	4668	84335	7469	73337	8933
2009	140722	0	115857	5311	97312	8420	84252	9998
2010	**161887**	**0**	133044	6018	111693	9472	97219	11226
2011	183295	0	**150585**	**6798**	126280	10712	110101	12666
2012	204423	0	166811	7632	139743	11977	122465	14183
2013	224975	0	182115	8557	**152614**	**13335**	133033	15732
2014	244750	0	196799	9573	163863	14853	142747	17445
2015	262123	0	209594	10357	173605	16032	**150605**	**18830**
2016	277771	0	219771	11017	180760	16909	156217	19835
2017	290814	0	228159	11559	186560	17668	160573	20554
2018	302981	0	235525	12026	191079	18214	164040	21075
2019	313164	0	241535	12393	194651	18637	166171	21498
2020	321636	0	245901	12667	197214	18937	168035	21790

Table 4. Results of simulations done to evaluate the impact of various fishing mortality levels on stock recovery for American plaice in 3LNO. Each simulation represents 1500 replicates obtained by resampling recruitment-SSB data from a population reconstruction using M=0.2 for all years (sensitivity run).

	Re-sampling full range of recruitment									
	No catch		F = 0.07		F= 0.14		F = 0.20		Constant catch	
Year	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)
1999	11,652	0	11,652	437	11,652	859	11,652	1,209	11,619	3,000
2000	15,296	0	14,879	602	14,483	1,147	14,153	1,573	12,538	3,000
2001	19,831	0	18,829	807	17,901	1,492	17,175	1,997	14,262	3,000
2002	26,679	0	24,850	1,066	23,278	1,932	21,989	2,538	18,279	3,000
2003	36,096	0	33,169	1,401	30,720	2,492	28,892	3,236	24,869	3,000
2004	50,700	0	46,877	1,831	43,463	3,239	41,160	4,204	37,129	3,000
2005	**68,925**	**0**	**63,040**	**2,430**	58,249	4,288	54,794	5,550	51,281	3,000
2006	87,295	0	78,939	3,104	**71,882**	**5,424**	**66,826**	**6,976**	**66,490**	**3,000**
2007	105,105	0	93,828	3,877	84,828	6,699	78,564	8,558	83,114	3,000
2008	125,088	0	110,700	4,782	99,007	8,102	90,789	10,226	100,731	3,000
2009	144,962	0	125,378	5,803	110,373	9,690	99,636	12,025	116,913	3,000
2010	**164,332**	**0**	139,993	6,641	121,005	10,879	108,412	13,312	132,410	3,000
2011	186,110	0	**154,921**	**7,440**	132,107	11,952	116,036	14,409	**151,194**	**3,000**
2012	207,513	0	169,472	8,277	141,028	12,963	122,614	15,407	167,436	3,000
2013	234,390	0	186,701	9,053	**152,934**	**14,008**	131,438	16,510	186,745	3,000
2014	262,938	0	209,049	9,915	167,790	15,136	143,223	17,547	208,931	3,000
2015	295,057	0	231,087	10,806	184,536	16,351	**157,009**	**19,006**	233,279	3,000
2016	328,072	0	253,568	11,906	201,709	17,819	171,151	20,530	260,067	3,000
2017	362,781	0	279,514	13,247	221,236	19,671	185,805	22,229	290,552	3,000
2018	400,575	0	307,474	14,649	241,361	21,381	200,233	24,201	325,235	3,000
2019	437,894	0	335,710	16,028	260,661	23,354	214,620	26,376	360,059	3,000
2020	470,401	0	360,437	17,464	278,815	25,245	227,672	28,243	396,605	3,000

	Re-sampling recruitment since 1982											
	No catch		F = 0.07		F= 0.14		F = 0.20		Constant catch of 2000t		Constant catch of 1500t	
Year	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)	Median SSB (t)	Median Yield (t)
1999	11,590	0	11,590	436	11,590	858	11,590	1,208	11,618	2,000	11,639	1,500
2000	15,063	0	14,645	589	14,247	1,121	13,919	1,535	13,318	2,000	13,668	1,500
2001	19,090	0	18,106	764	17,199	1,406	16,473	1,876	15,434	2,000	16,120	1,500
2002	23,907	0	22,125	954	20,557	1,705	19,336	2,226	18,043	2,000	19,167	1,500
2003	28,855	0	26,165	1,157	23,844	2,012	22,047	2,570	20,970	2,000	22,609	1,500
2004	33,769	0	29,902	1,352	26,705	2,299	24,430	2,875	23,948	2,000	26,141	1,500
2005	38,283	0	33,188	1,555	29,122	2,586	26,260	3,196	26,740	2,000	29,306	1,500
2006	42,174	0	35,769	1,705	30,853	2,781	27,560	3,377	29,188	2,000	32,179	1,500
2007	45,642	0	37,956	1,855	32,219	2,974	28,396	3,580	31,397	2,000	34,723	1,500
2008	49,415	0	40,234	2,061	33,620	3,249	29,386	3,841	33,853	2,000	37,452	1,500
2009	53,159	0	42,143	2,145	34,543	3,314	29,748	3,865	35,995	2,000	39,939	1,500
2010	57,328	0	43,633	2,234	34,712	3,342	29,702	3,875	37,545	2,000	41,641	1,500
2011	**63,153**	**0**	45,893	2,347	35,265	3,403	29,795	3,890	39,056	2,000	43,743	1,500
2012	70,895	0	49,559	2,476	35,890	3,452	29,885	3,896	40,813	2,000	46,476	1,500
2013	80,352	0	54,675	2,652	36,699	3,523	30,076	3,911	42,830	2,000	50,144	1,500
2014	90,909	0	**62,240**	**2,888**	38,003	3,615	30,105	3,926	45,939	2,000	55,765	1,500
2015	101,089	0	70,530	3,190	39,658	3,741	30,297	3,930	50,588	2,000	**63,613**	**1,500**
2016	111,400	0	79,183	3,544	41,931	3,931	30,460	3,952	57,030	2,000	73,148	1,500
2017	121,866	0	87,437	3,976	45,156	4,147	30,618	3,963	**65,807**	**2,000**	83,464	1,500
2018	132,446	0	95,942	4,497	50,363	4,458	30,751	3,991	75,085	2,000	93,065	1,500
2019	141,522	0	103,772	5,029	56,852	4,871	30,742	4,016	84,650	2,000	102,777	1,500
2020	148,461	0	110,330	5,433	**63,338**	**5,416**	30,775	3,990	93,804	2,000	112,651	1,500

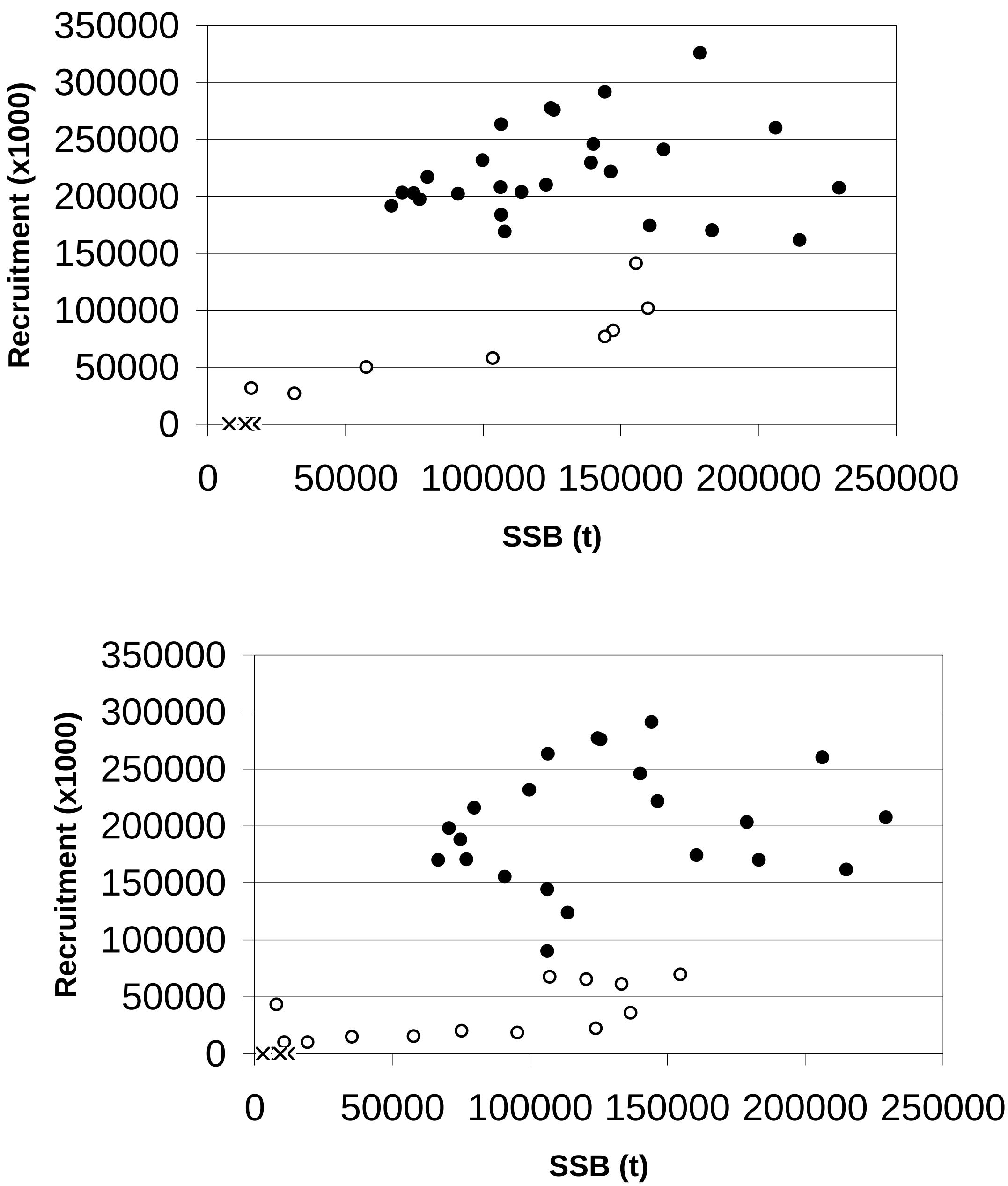
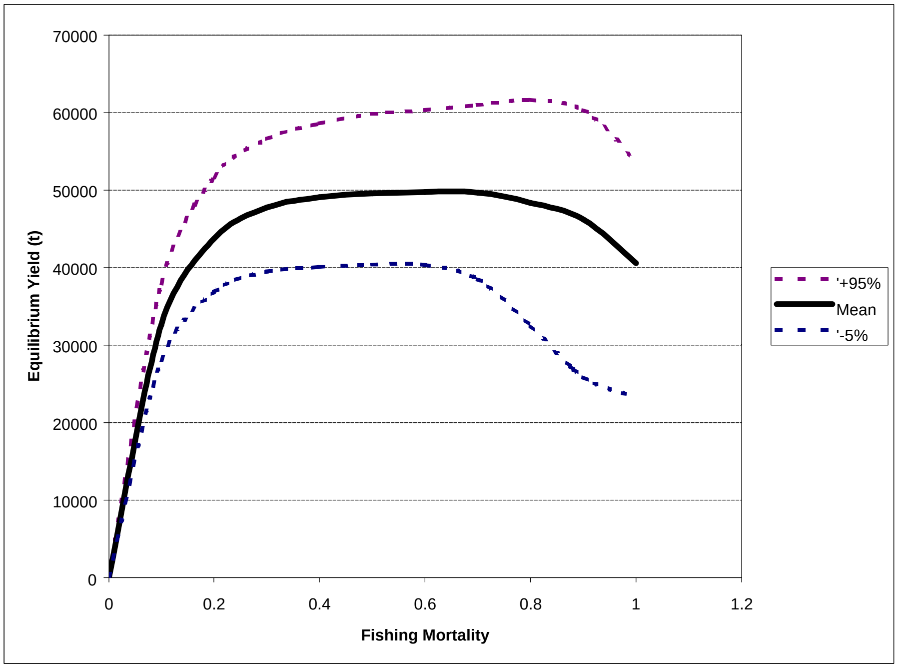


Fig. 1. Stock-recruit scatter-plot for American plaice in NAFO Divisions 3LNO. Top panel: obtained from a population reconstruction using M=0.6 from 1989 to 1996, and M=0.2 for other years. Bottom panel: obtained from a population reconstruction using M=0.2 for all years. Open circles represent the observations during the low recruitment regimes.



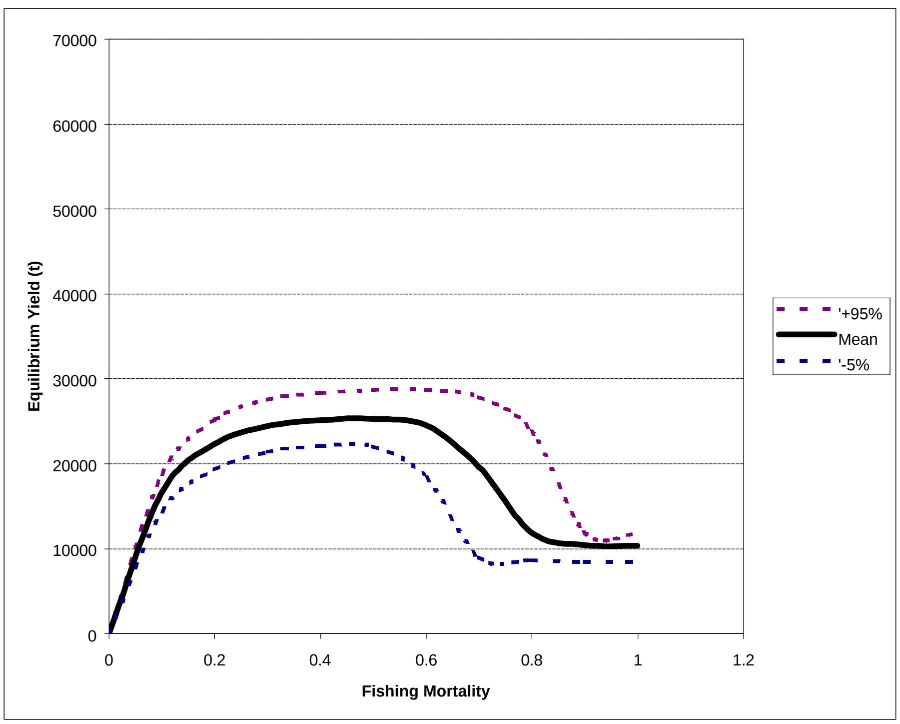
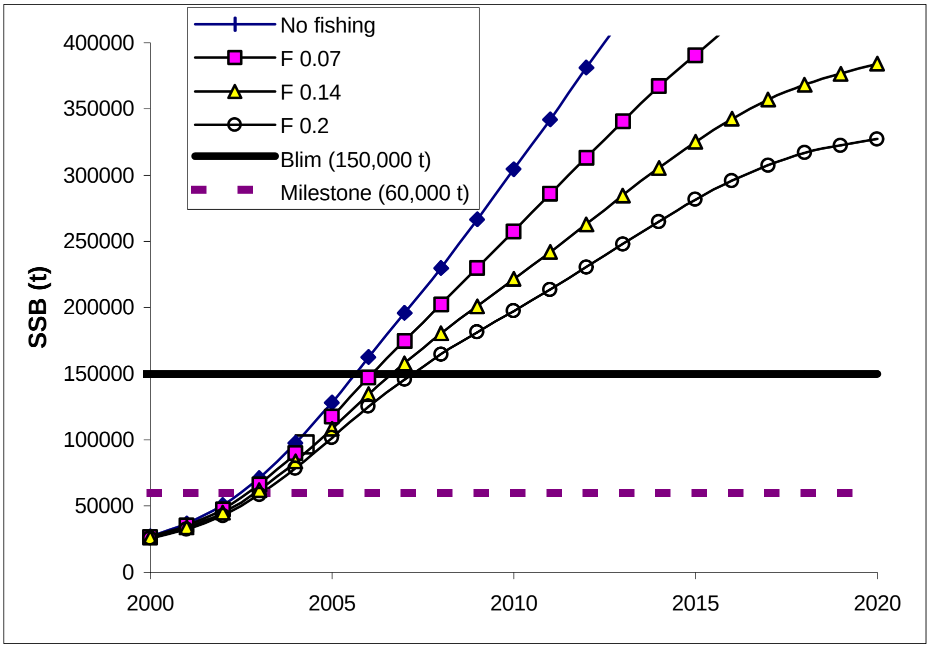


Fig. 2. Production model corresponding to the full recruitment dynamics (top panel) and the low recruitment regime since 1986 (bottom panel). These are based on constant-F projections where F was varied from 0 to 1.0 in 0.1 increments. The dashed lines identify the envelope delimited by the 5% and 95% percentiles of the results from 100 replicates at each F level. The recruitment used for re-sampling came from a population reconstruction using M=0.6 from 1989 to 1996, and M=0.2 for other years.



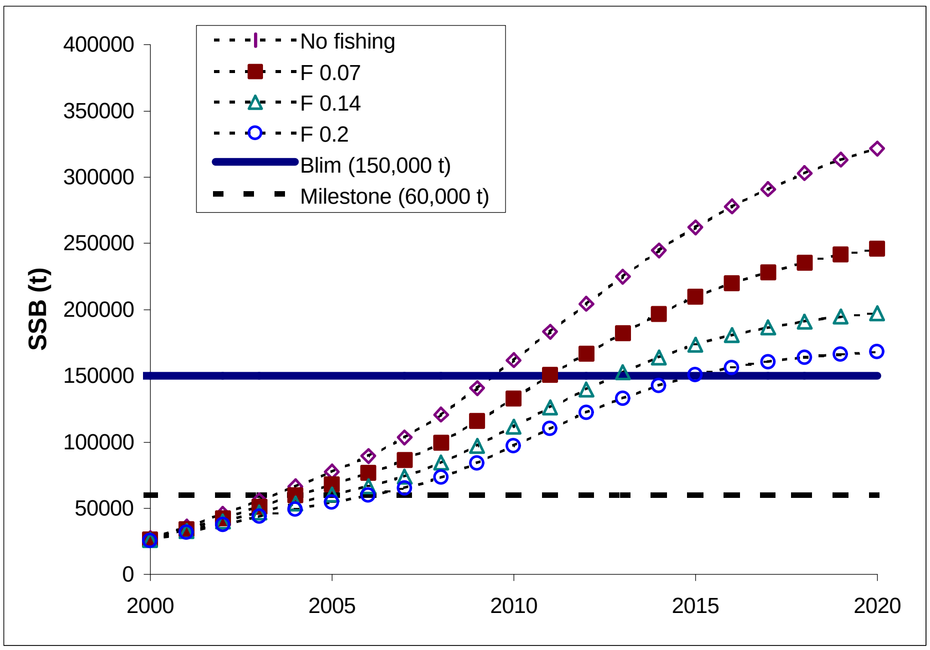
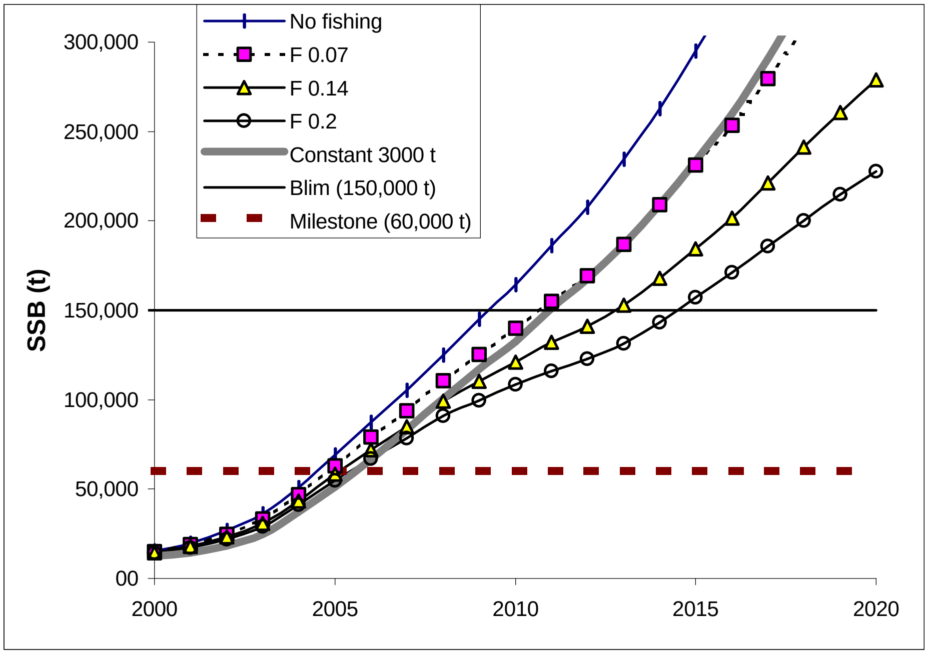


Figure 3. Trajectory of the median SSB for American plaice in 3LNO from the simulations assuming that recruitment relate to SSB in a manner similar to that observed since 1960 (top panel) or in a manner similar to that observed since 1986 (bottom panel). These simulations used recruitment-SSB data from a population reconstruction using M=0.6 from 1989 to 1996, and M=0.2 for other years.



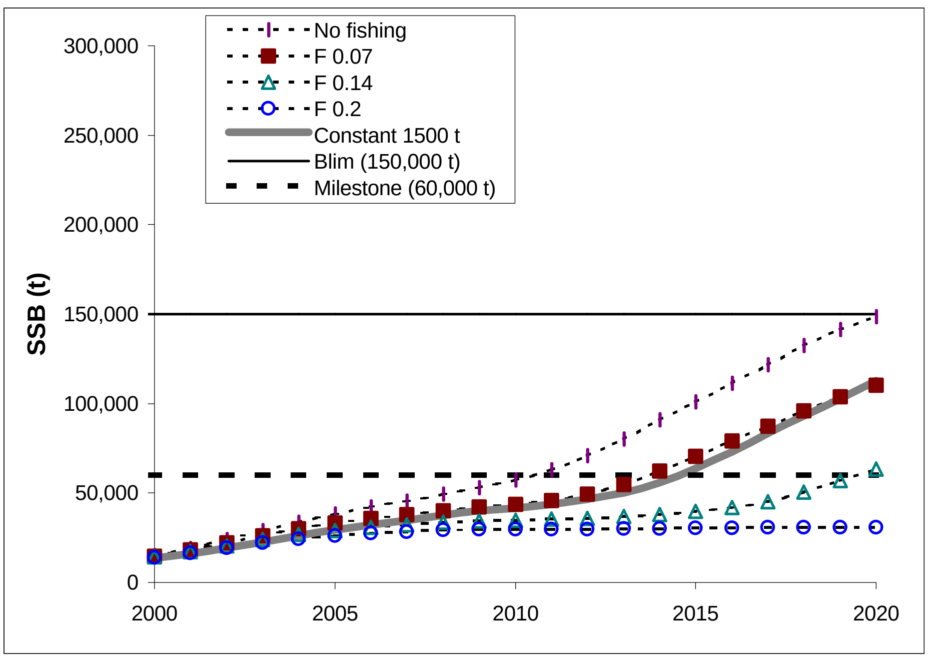


Figure 4. Trajectory of the median SSB for American plaice in 3LNO from the simulations assuming that recruitment relate to SSB in a manner similar to that observed since 1960 (top panel) or in a manner similar to that observed since 1982 (bottom panel). These simulations were made using recruitment-SSB data generated from a population reconstruction using M=0.2 for all years.