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Maritimes Region **Région des Maritimes**

Investigating Reference Points for American Plaice on the Scotian Shelf (4VWX)

Étude des points de référence pour la plie canadienne sur le plateau néo-écossais (4VWX)

G.M. Fowler

Population Ecology Division, Science Branch
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia B2Y 4A2

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ABSTRACT

A maximum sustainable yield based harvest control rule for Maritimes Region (Scotian Shelf and Bay of Fundy) American plaice was proposed, reviewed and accepted in February 2012 through the Canadian Science Advisory Secretariat peer review process. This is intended to apply the Precautionary Approach to management of the resource according to the Department of Fisheries and Oceans guidelines. This Research Document describes the development and application of the model used to estimate the reference points that define the harvest control rule, with particular focus on the assumptions.

RÉSUMÉ

Un rendement maximal soutenable basé sur la règle de contrôle des prises de plie canadienne dans la région des Maritimes (plateau néo-écossais et baie de Fundy) a été proposé, examiné et accepté en février 2012, grâce au processus d'examen par les pairs du Secrétariat canadien de consultation scientifique. Ce rendement doit s'appliquer à la gestion des ressources fondée sur l'approche de précaution, conformément aux lignes directrices de Pêches et Océans Canada. Ce document de recherche décrit l'élaboration et l'application du modèle utilisé pour estimer les points de référence définissant la règle de contrôle des prises, l'accent étant mis sur les hypothèses.

INTRODUCTION

In February 2012, the Canadian Science Advisory Secretariat held a meeting to review proposals for precautionary reference points, in the form of Harvest Control Rules (HCR), to guide the management of commercially exploited populations of marine and anadromous species in the Maritimes Region of Atlantic Canada, an area comprising the Scotian Shelf, Bay of Fundy, and the Canadian portion of Georges Bank. Reference points accepted by the review process were designated to be formally documented as research documents.

This paper documents the reference points determined for the North American Fisheries Organization (NAFO) Divisions 4VWX American plaice (*Hippoglossoides platessoides*) population, a stock of flounder distributed throughout the Maritimes Region (Fig. 1).

BACKGROUND

A stage-based model of American plaice population dynamics had been developed for a Recovery Potential Assessment (DFO, 2011) after the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) evaluated plaice in Maritimes and Gulf Regions as Threatened. The model partitioned commercial landings and survey estimates of abundance by sex and maturity stage. For the Recovery Potential Assessment (RPA), two variants of the model were considered: 1. Length (and age) of maturity constant over time, and 2. Length (and age) of maturity declining over time (based on aged fish post-1970s and various research studies prior to the 1970s). The model purporting decline in length and age of maturity over time was better supported than the model assuming constant growth. This model was chosen as a basis from which to derive estimates related to Maximum Sustainable Yield (MSY) as reference points.

POST-RPA MODEL DEVELOPMENT

The long-term projections of interest to COSEWIC provide less reliable estimates of the most recent population status and short-term trajectory expectations than one would usually want for management purposes. To better accommodate the shorter-term projections desired for stock assessments, the RPA model was modified to improve fitting between observed and predicted abundance throughout the historically represented time period. This was accomplished by:

1. Incorporating estimation of recruitment based on aged survey sampling during 1970-1988, 1999 and 2010.
2. Accounting for changes in length at maturity and natural mortality in more temporal detail, using seven time periods to reflect state regimes (the RPA model used three time periods).
3. Applying an upper bound of 0.3 on natural mortality.

Natural mortality estimates were originally unconstrained (0.0 -1.0) with uninformative priors. These estimates were very high in the RPA model for all sexes and maturity stages. They dropped considerably, for all but juvenile males, after recruitment was added to the model and the number of regimes expanded. With these changes, the model fitting made more use of recruitment variability (much of the observation error for survey estimates was associated with recruitment), and the juvenile-adult transition theta’s than natural mortality to account for survey trends. The M estimates on juvenile males seemed implausibly high without collaborative high M estimates on juvenile females. As well, high M’s on juvenile males were being estimated for the first two periods (1970-1985), whereas the underlying hypothesis behind the M estimation was increasing M in later periods (cold water incursion on Banquereau, seal population growth, ecosystem shifts since fishery collapses). The current model (Fig. 2) constrains all M estimates to not exceed 0.3, which may be too restrictive.

PRELIMINARY MODELLING FOR MSY ESTIMATES

Default methods for deriving reference points based on MSY or similar metrics, according to Department of Fisheries and Oceans (DFO) protocols (DFO, 2009), requires that the historically highest productivity regime be assumed as the basis for estimates. Applying this approach to 4VWX American plaice, a female-only Spawning Stock Biomass at MSY (SSB_{MSY}) of 32,381 t was estimated as the Removal Reference, with corresponding Limit Reference Point (LRP=40% of SSB_{MSY}) and Upper Stock Reference (USR=80% of SSB_{MSY}) at 12,952 t and 25,905 t, respectively; the USR and LRP bounding the Cautious Zone in which management responses are deemed necessary to mitigate negative effects of fishing. The SSB_{MSY} value assumes:

1. An intrinsic rate of population growth based on the highest inter-year population growth predicted by the model, adjusted up by an arbitrary 10%.
2. A shape parameter for the population growth curve that puts the ratio of SSB_{MSY} to female SSB carrying capacity (K) at about 60%, a ballpark ratio across groundfish species in general where research has provided some basis for estimates of B_{MSY} and K.
3. The productivity regime of the 1970s, the most productive period in the historically monitored time series for this population.
4. Carrying capacity estimated for the 1970s.

The carrying capacity was estimated as if the observed population abundances of the 1970s were some fraction of equilibrium abundance, with the estimate of intrinsic growth rate applied to the maximum predicted abundance of the historical regime period 1970-1976, compensated for density-dependence by a shape parameter.

The population model works with numbers of fish, so MSY was determined in numbers of fish, which was then converted to tons. The conversion is based on the numbers-to-tons equivalence of q-adjusted survey numbers at length. The SSB_{MSY} is a female-only metric to avoid complicating interpretations resulting from an extreme trend in catch proportion by sex over time (Fig. 3). Most of the plaice large enough to be of interest to the fishery today are female, representing over 75% of the adult catch since 1995. In the 1970s, males represented 30-50% of the catch.

Deriving SSB_{MSY} from the model with these assumptions and the default protocol resulted in a HCR (Fig. 4) that associated a predominance of Cautious Zone SSB_{MSY} values with a very low fishing mortality rate (F).

FINAL MODEL FOR DERIVING MSY ESTIMATES

Decline in growth of plaice over time confounds estimation of a constant MSY, as the productivity regime has changed greatly since the start of the time series. In 1971, 1,576 adult females equated to 1 ton of fish. By 2010, adult females were 4,635 fish/ton, three times the number of fish required to achieve the same SSB_{MSY} as in 1971.

A brief summary of the history of commercial fishing of plaice provides some perspective on MSY estimates. American plaice on the Scotian Shelf were of no interest to fisheries until the 1960s, with fishing not reaching the historical regime MSY until 1965 (Table 1). The historically familiar plaice fishery was confined to the Southern Gulf of St.Lawrence, with little or no extension into waters of Maritimes Region. The survey time series for 4VWX initiates in 1970, at a time when Scotian Shelf plaice were probably still near equilibrium. Predicted population SSB commonly exceeds SSB_{MSY} until the 1980s (Fig. 5). Only four years (1972, 1973, 1977, and 1984) in the time series have catches of SSB above SSB_{MSY} from a population SSB that is below SSB_{MSY}. With the loss of the cod and haddock fisheries in 4VW, American plaice catches dropped off, as they were often not worth the effort to fish in their own right. It seems questionable that the population could have reached an MSY equilibrium, as these typically arise from stocks that were fished intensively for longer periods of time.

To put the productivity in context, spawners can be looked at in terms of numbers, Spawning Stock in Numbers (SSN), and SSN_{MSY}, rather than weights (Fig. 6). Much of the trend observed with spawners represented as a weight disappears. When spawners are depicted as numbers, SSN drops below the SSN_{MSY} line much less frequently, and the pattern better reflects the expectation of a fishery starting in the mid-1960s.

The equivalent HCR (Fig. 7), in numbers rather than weights, moves most of the fishing mortality to the right of the USR. This explains the association of low F's with SSBs in the Cautious Zone when depicted as weights.

Representation of reference points as numbers rather than weights for American plaice was deemed more appropriate to monitor stock status. This form of HCR adheres to the default protocol with respect to productivity regime, as one can still base the reference points on the most productive period. There has been some debate whether the choice of units was considered part of the protocol or not.

SENSITIVITY TO ASSUMPTIONS

The estimate of intrinsic population growth rate could be too low, as it may derive from a population closer to virgin equilibrium than MSY equilibrium. If faster rates of population growth are assumed, MSY would increase. The shape parameter denoting density dependent compensation or depensation could vary from the 1.91 assumption in either direction. More delay in the role of density-dependence (smaller values of the shape parameter) would increase MSY, while less delay would decrease MSY. Sensitivity of MSY to these assumptions (Table 2), especially with respect to density-dependence, can be extreme. Further investigation of these assumptions would be required to narrow down the range of possible values for MSY.

SSN_{MSY} estimates do not account for differences in contributions to recruitment related to age and/or size within the SSN. Typically larger females produce more eggs, and their eggs tend to be more viable than those of smaller females. Disproportionate trends in abundance within the SSN could compromise MSY estimates.

The shape parameter depicting the mechanism of density-dependence assumes that pressure is exerted on adult components of the population (e.g., resource or habitat competition, predator responses). It may be that density-dependent mechanisms act instead on early life history stages, such as the metamorphic settlement stage of a flatfish. If so, the carrying capacity would be that of an unmonitored population component, and one that might bear a tenuous relationship to SSN.

If the assumed cap on natural mortality of 0.3 is too low, the underlying population model would change, and this would alter MSY estimates, probably making them smaller.

SECONDARY INDICATOR: FEMALE L50

An indicator of change in productivity regime would be warranted if a biomass version of the HCR was adopted. To adjust MSY for productivity regimes, the female L50 (Fig. 8) could then serve as a metric to classify/quantify the regime. The female L50 also reflects a corresponding trend in age at 50% maturity (Fig. 9) that should be kept in mind. However, maturity sampling would then have to be included in the survey protocol. Perhaps instituting a five-year periodicity for age and maturity sampling would be sufficient to track and adjust for changes in maturity at length and age.

MANAGEMENT CONSIDERATIONS

The model regards all of 4VWX American plaice as one population, such that the reference points are intended to sustain the population as a whole. However, American plaice in 4X/5 (Bay of Fundy) are marginal to the population distribution, such that the indicators of stock status cater mostly to 4VW American plaice. Thus, the 4X/5 component, treated as a separate management unit, is highly vulnerable to local depletion. This would not necessarily be reflected by the HCR but might be a concern for fishery management, as the 4X/5 fishery would not be sustainable if MSY was allocated disproportionately to the population density. In this regard, it is worth noting that one of the contributing reasons COSEWIC listed 4VWX American plaice as Threatened (COSEWIC, 2009) was contraction in the design-weighted area occupied index for adult American plaice, which was due to loss of western components (4X/5).

There remains a possibility that an unknown proportion of 4X/5 American plaice derive from non-4VW spawning components (e.g., Browns Bank, Gulf of Maine), which could produce localized recruitment patterns that do not correspond with 4VW.

The apparent healthiness of the American plaice population when assessed in terms of numbers might seem inconsistent with the COSEWIC designation as Threatened. To allay confusion, bear in mind that COSEWIC regards all plaice throughout the Scotian Shelf and Gulf of St. Lawrence as the same population (a Designatable Unit, DU). The Southern Gulf component of this DU is in very dire straits. The Scotian Shelf component itself has exhibited population decline and contraction in adult distribution. It is also pertinent that the COSEWIC evaluation preceded modelling of temporal trends in size at maturity, which was not conducted until the RPA. This changed the perception of aspects of the declining trend, associating the decline in abundance almost exclusively with juvenile American plaice.

The reference points estimated for 4VWX are appropriate for the historically depicted length distribution of commercial catches. A change in the exploited length distribution that increased fishing mortality on first spawners (targeting smaller fish) would invalidate the current HCR.

The HCR does not consider the possibility of reversing the trend of declining age and size of maturity of plaice as an objective.

If growth rate continues to decline, MSY in constant numbers will translate into declining MSY in terms of weight over time.

To monitor stock status requires that SSN be determined annually, which essentially means updating the population structure each year. A simple survey-based proxy for SSN, that might lend itself to automatic updates, could not be found.

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Table 1. Commercial catches (mt) of American plaice since 1961, adjusted for reported landings of unspecified flounder. Adjustments since 2000 are prorations of 1999 determinations of unspecified flounder (Fowler and Stobo, 1999).

Calendar Year	Reported landings of plaice and unspecified flounder				Catch of plaice adjusted for Unspecified Flounder		Total catch of plaice
	4VW		4X/5				
	Plaice	Unspecified Flounder	Plaice	Unspecified Flounder	4VW	4X/5	
1961	1384	237	198	25	1384	212	1596
1962	1485	757	242	120	1485	307	1792
1963	2059	.	250	.	2059	250	2309
1964	2570	194	512	.	2570	512	3082
1965	7504	90	694	.	7504	694	8198
1966	13480	30	726	.	13480	726	14206
1967	9664	.	1106	.	9664	1106	10770
1968	18319	17	946	1	18319	946	19265
1969	12865	2	870	.	12865	870	13735
1970	7723	9	635	2	7723	635	8358
1971	13756	.	545	1	13756	545	14301
1972	10087	43	566	681	10087	937	11024
1973	12093	176	339	806	12093	778	12871
1974	16314	101	458	716	16314	848	17162
1975	11451	288	296	834	11451	751	12202
1976	10838	547	309	496	10838	579	11417
1977	7308	46	449	898	7308	938	8246
1978	6244	33	512	1027	6244	1072	7316
1979	5526	91	828	1212	5526	1489	7015
1980	6891	29	681	1858	6891	1694	8585
1981	6258	21	514	1556	6258	1362	7620
1982	5320	11	377	1763	5320	1338	6658
1983	5523	50	584	2023	5523	1687	7210
1984	5793	8	335	1995	5793	1422	7215
1985	4120	10	317	2200	4120	1516	5636
1986	3090	68	592	3234	3090	2355	5445
1987	4623	42	262	2380	4623	1559	6182
1988	3087	89	366	2205	3087	1568	4655
1989	3365	93	481	976	3365	1013	4378
1990	1919	32	470	3012	1919	2112	4031
1991	217	1414	996	3621	1262	2872	4134
1992	493	1883	418	4155	1830	2682	4512
1993	123	1656	9	3907	1298	2139	3437
1994	106	1408	111	3061	1106	1779	2885
1995	370	921	29	1283	1024	728	1752
1996	647	543	67	975	1033	598	1631
1997	948	678	214	603	1429	543	1972
1998	1128	348	132	646	1375	484	1859
1999	1183	399	222	525	1467	509	1975
2000	551	245	273	557	725	577	1301
2001	284	170	118	406	405	340	745
2002	213	15	155	177	224	251	475
2003	294	76	122	200	347	231	578
2004	116	37	49	194	142	155	297
2005	123	0	37	193	124	143	266
2006	168	1	41	222	169	162	331
2007	94	3	69	231	96	195	291
2008	28	3	15	220	30	135	165
2009	3	5	23	281	6	176	182
2010	1	15	53	341	11	239	250
2011	2.5	0.4	27.4	134.9			

Table 2. Sensitivity of MSY estimates and related values for carrying capacity (K), SSN_{MSY} and F_{MSY}, to values assumed for intrinsic population growth rate and density dependence (shape parameter). Values for K, SSN_{MSY} and MSY are expressed in millions of fish.

Varying Intrinsic Rate of Population Growth (Shape fixed)

Growth Rate	Shape	K	SSNmsy	MSY	Fmsy
0.331	1.91	84	51	8.1	0.16
0.356	1.91	84	51	8.7	0.17
0.381	1.91	84	51	9.3	0.18
0.406	1.91	84	51	9.9	0.19
0.431	1.91	84	51	10.5	0.21
0.456	1.91	84	51	11.1	0.22
0.481	1.91	84	51	11.7	0.23
0.506	1.91	84	51	12.3	0.24
0.531	1.91	77	46	11.7	0.25
0.556	1.91	77	46	12.3	0.27

Varying Shape Parameter (Rate fixed)

Growth Rate	Shape	K	SSNmsy	MSY	Fmsy
0.331	1.5	84	315	34.8	0.11
0.331	1.6	84	159	19.8	0.12
0.331	1.7	84	98	13.4	0.14
0.331	1.8	84	69	10.1	0.15
0.331	1.9	84	52	8.2	0.16
0.331	2	84	42	7.0	0.17
0.331	2.1	84	35	6.1	0.17
0.331	2.2	84	31	5.5	0.18
0.331	2.3	84	27	5.1	0.19
0.331	2.4	84	25	4.7	0.19

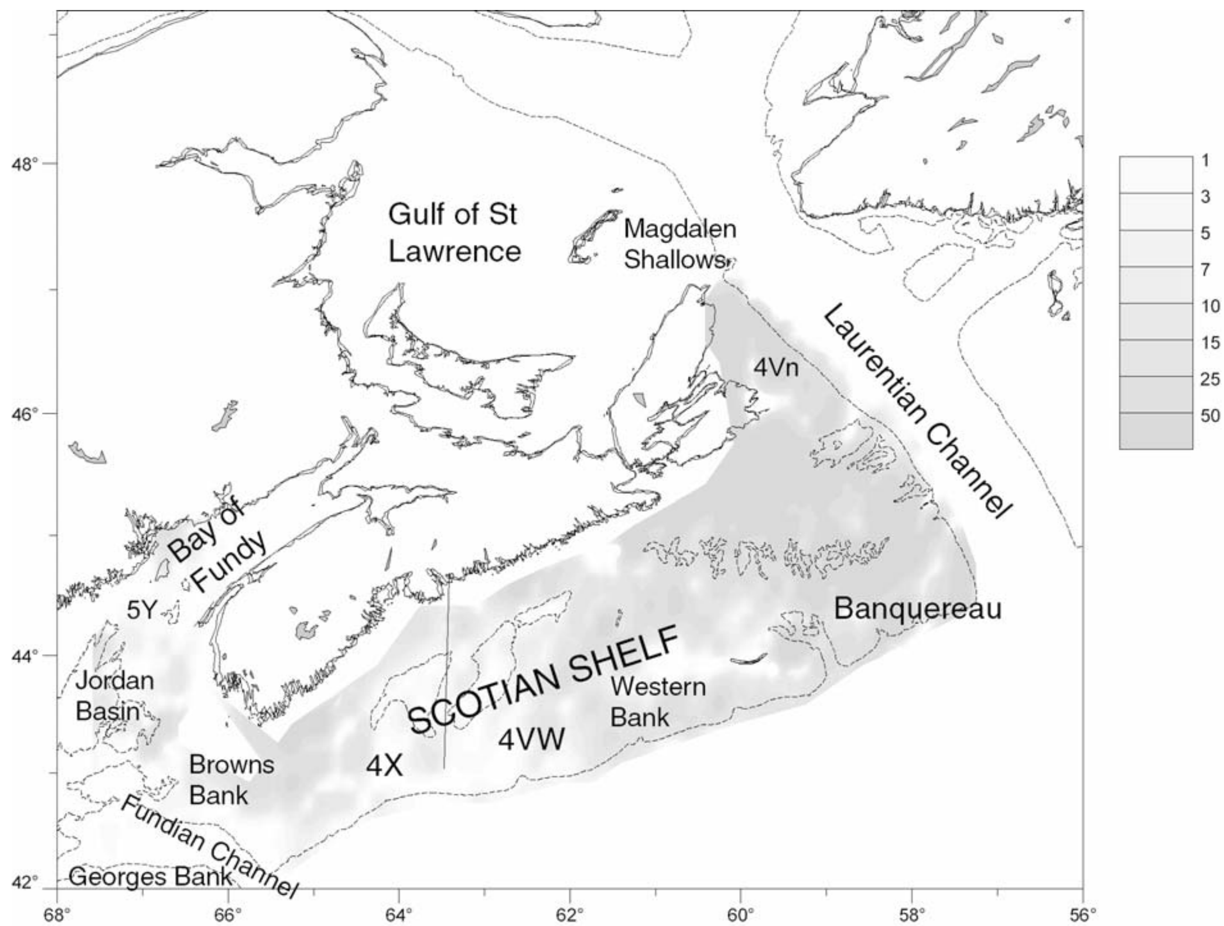

Figure 1. American plaice distribution (catch in kgs) from summer research vessel surveys. Catches are depicted by Delaunay Triangles.

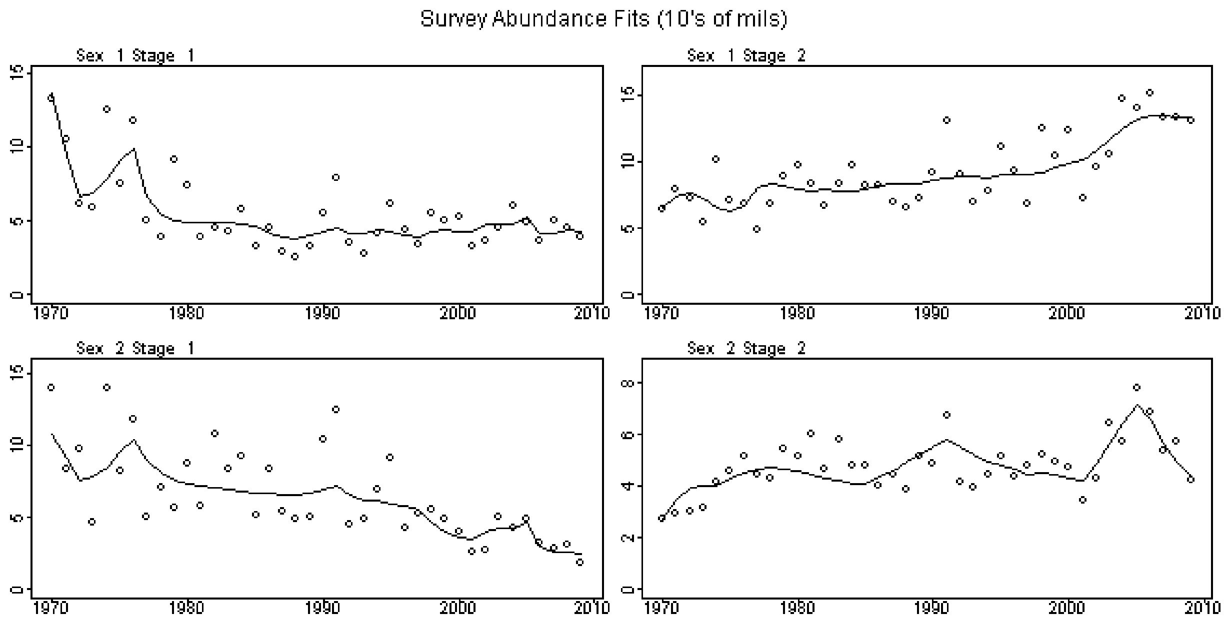

Figure 2. Fit of the q-adjusted predicted abundance from the population model (solid line) to observed abundance estimates from the DFO summer research vessel survey (open circles). Sexes are coded males 1, females 2, and maturity stages are coded juveniles 1, adults 2.

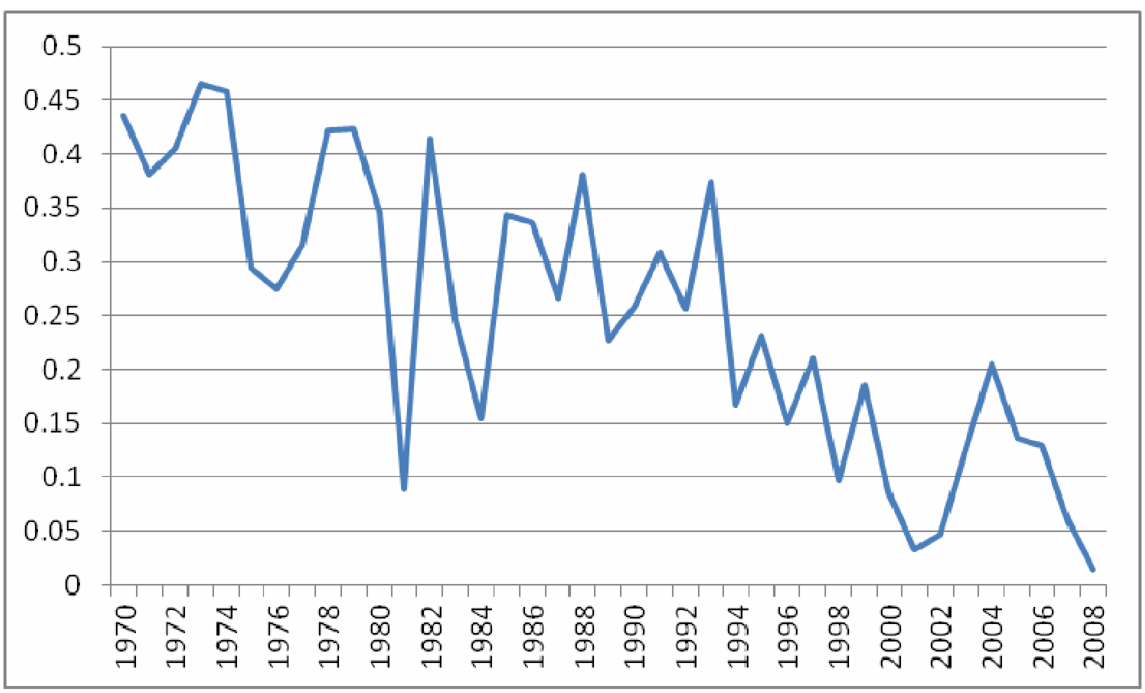

Figure 3. Males as proportion of adults in the commercial catch.

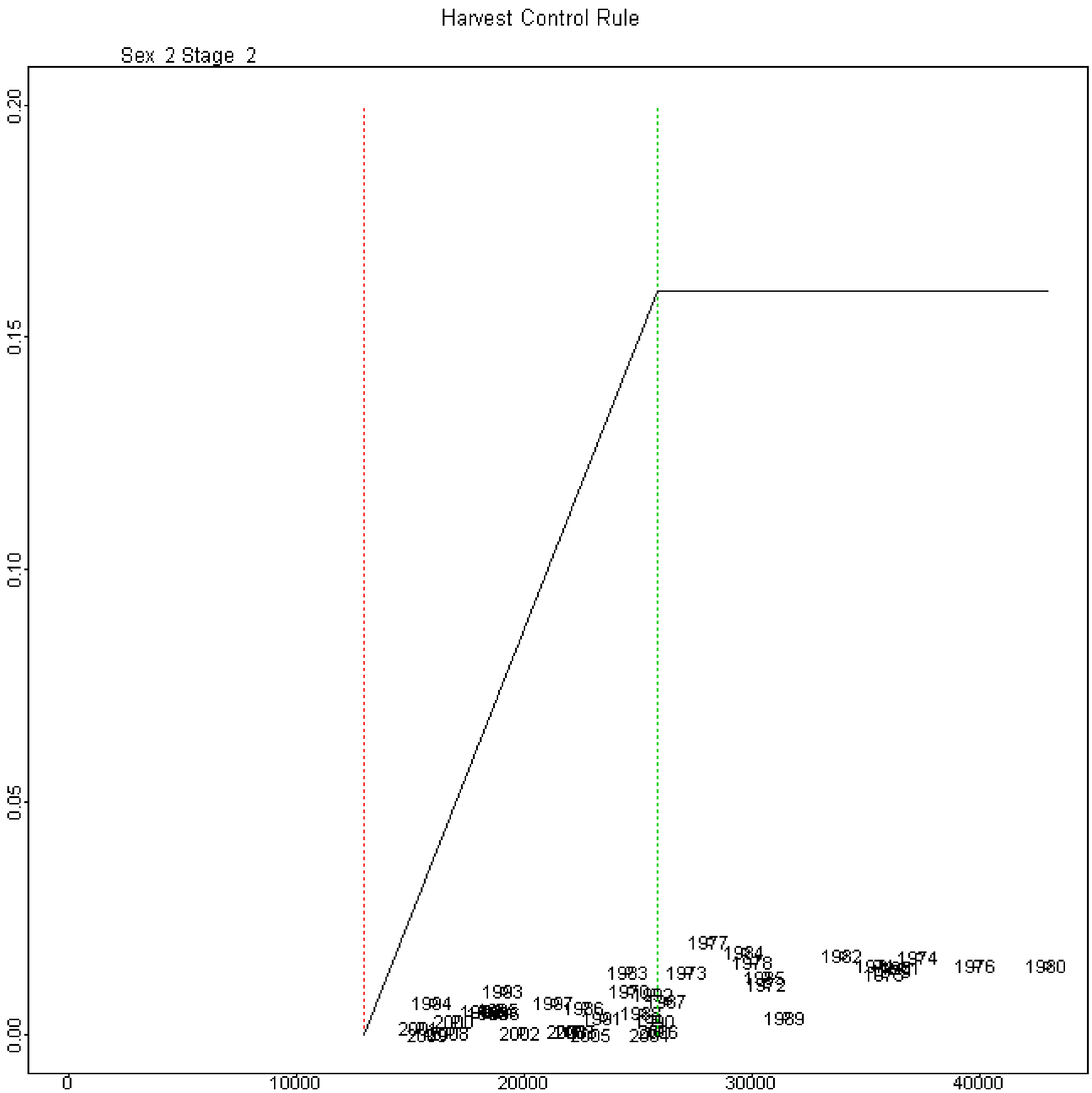

Figure 4. The Harvest Control Rule for fishing mortality (vertical axis) on Spawning Stock Biomass (SSB) (horizontal axis). The vertical lines represent the Lower and Upper Reference Points bounding the Cautious Zone. The precautionary F line is a diagonal slider in the Cautious Zone, attaining a plateau at F_{MSY} for SSB values above SSB_{MSY}.

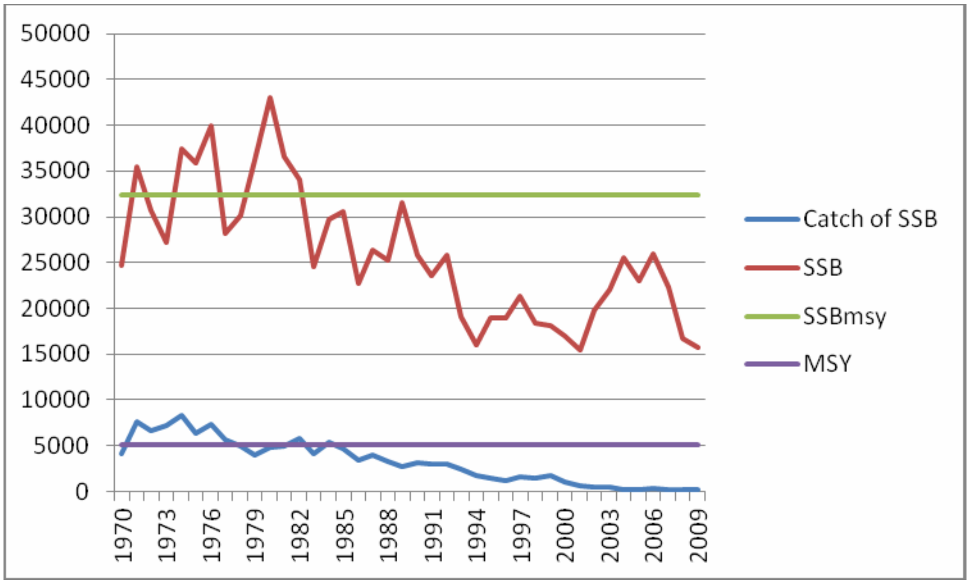

Figure 5. Time series of the population SSB and removals from the SSB by commercial fishing. Horizontal lines depict SSB_{MSY} and MSY. All values are in tons.

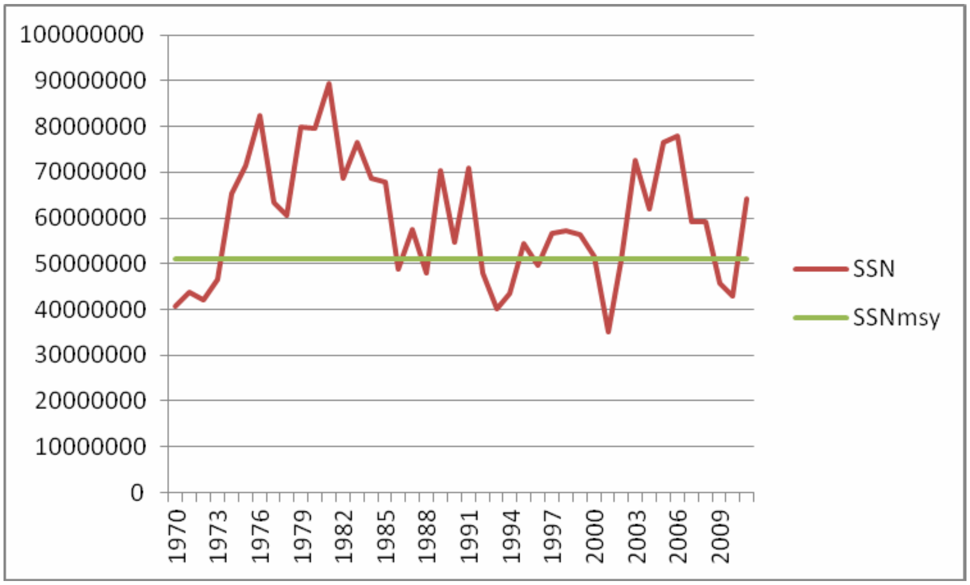

Figure 6. Time series of Spawning Stock in Numbers (SSN). The horizontal line depicts SSN_{MSY}.

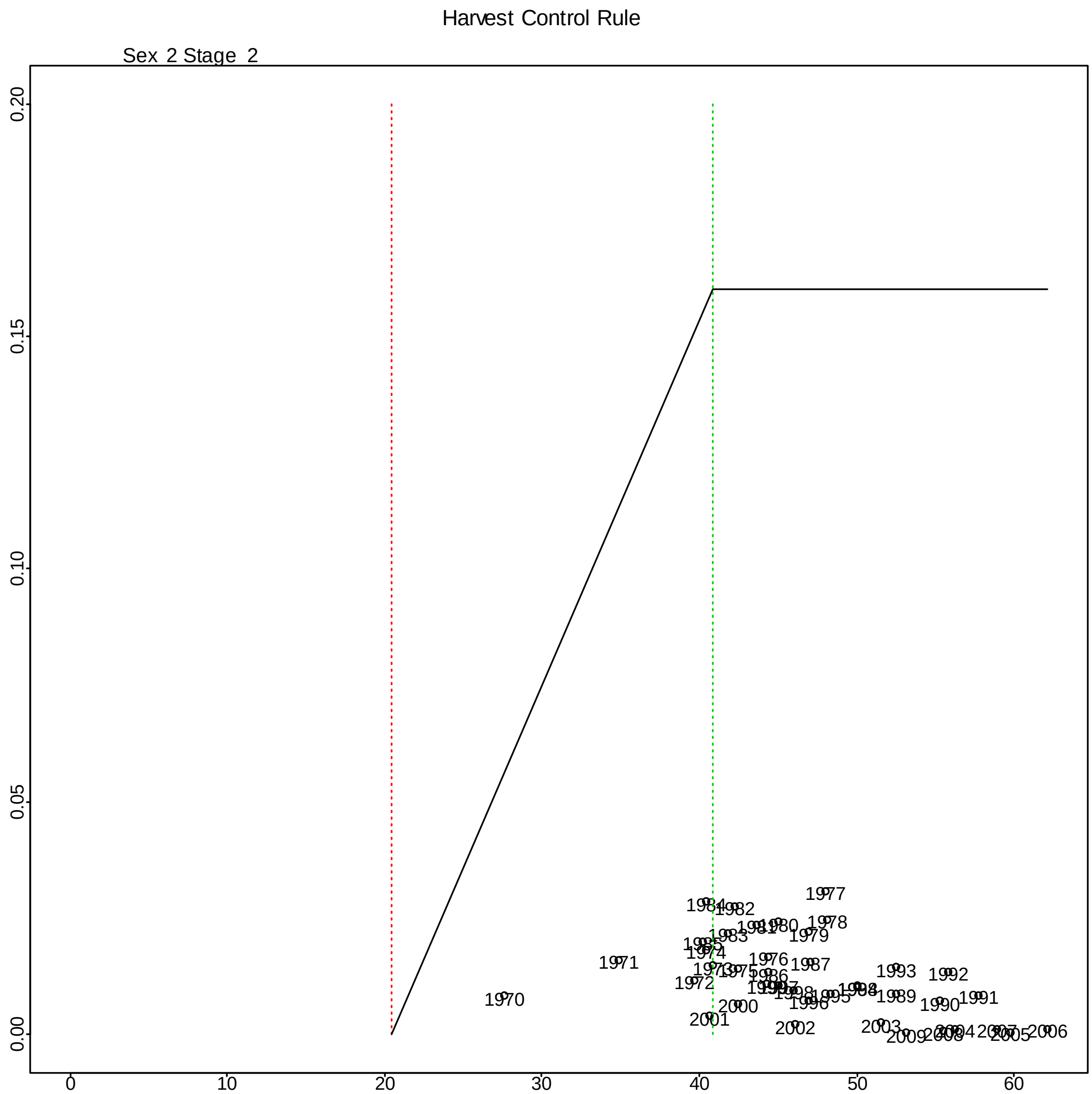

Figure 7. The Harvest Control Rule for fishing mortality (vertical axis) on SSN (horizontal axis). The vertical lines represent the Lower and Upper Reference Points bounding the Cautious Zone. The precautionary F line is a diagonal slider in the Cautious Zone, attaining a plateau at F_{MSY} for SSN values above SSN_{MSY}.

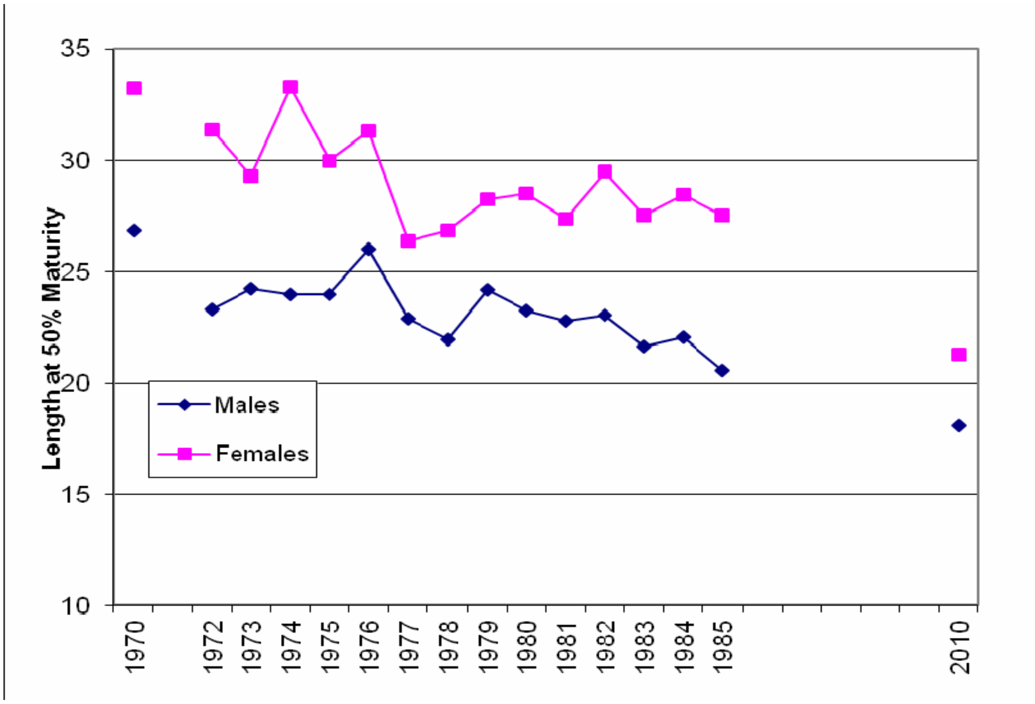

Figure 8. Lengths at 50% maturity of 4VWX American plaice since 1970. Blank years were inadequately sampled (mostly not at all) for maturity stage.

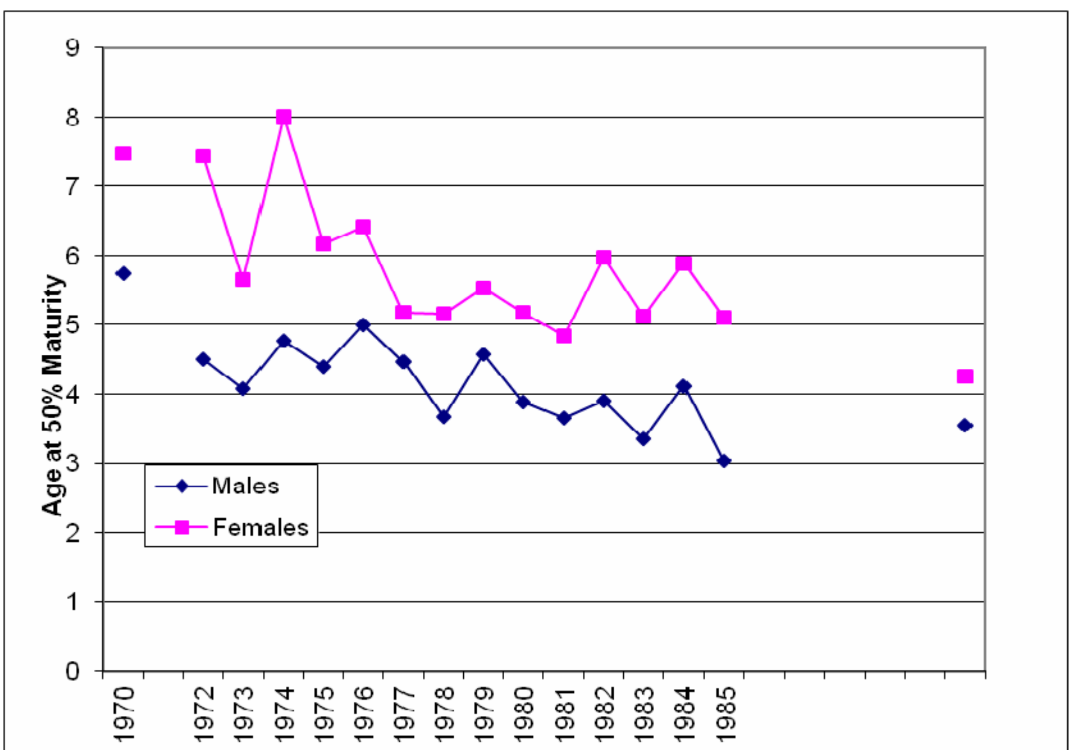

Figure 9. Ages at 50% maturity of 4VWX American plaice since 1970. Blank years were inadequately sampled (mostly not at all) for maturity stage.