Fisheries and Oceans Canada Pêches et Océans Canada
Science Sciences

C S A S **S C C S**

Canadian Science Advisory Secretariat **Secrétariat canadien de consultation scientifique**

Research Document 2012/173 **Document de recherche 2012/173**

Newfoundland and Labrador Region **Région de Terre-Neuve et Labrador**

Virtual population assessment (VPA) estimates of stock size and maximum sustainable yield (MSY) reference points for 3Ps cod

Points de référence pour l'estimation de la taille du stock et du rendement maximal soutenu (RMS) par analyse de population virtuelle (APV) pour la morue de la zone 3Ps

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Correct citation for this publication:

Shelton, P.A. and Morgan, M.J. 2013. Virtual population assessment (VPA) estimates of stock size and maximum sustainable yield (MSY) reference points for 3Ps cod. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/173. ii + 39 p.

ABSTRACT

3Ps cod has a long catch history that is not currently included in the stock assessment used for providing scientific advice to fisheries managers. Reference points based only on recent (depleted) stock history may not reliably reflect real limits of stock productivity or targets for maximizing yield. To include a longer period in the calculation of reference points an ADAPT VPA was fit to available catch and survey data going back in time as far as possible. Catch numbers at age from 1959 to 2009 were included. The survey indices were the offshore survey from 1983 to 1996 and the inshore-offshore index from 1997 to 2009. A segmented regression recruitment model was fit to the VPA estimates of SSB and R. The fitted SR model was used to estimate Fmsy and Bmsy based reference points. Long term average weights and maturities were used in this calculation while the partial recruitment vector used was the average over the period since the moratorium. Bmsy was estimated to be 91 kt of SSB and Fmsy to be 0.38. Recent SSB is estimated to have been near or below 40% Bmsy while F has been near or above Fmsy. Uncertainty about the reliability of commercial catch data has precluded applying VPA in recent assessments. However, the VPA and SR models could be used in simulation testing of feedback harvest control rules (HCRs) through a management strategy evaluation (MSE) process. Assumptions in the current VPA and stock recruit model could be varied to create the reference set of operating models. MSE does not require a single “best” assessment model.

RÉSUMÉ

Une longue partie de l'historique de la pêche à la morue dans la zone 3Ps n'est actuellement pas comprise dans l'évaluation des stocks utilisée pour fournir des avis scientifiques aux gestionnaires des pêches. Il est possible que les points de référence basés uniquement sur le récent historique du stock (épuisé) ne reflètent pas fidèlement les limites véritables de la productivité du stock ou les cibles de maximisation de la production. Afin d'inclure une plus longue période dans le calcul des points de référence, on a ajusté une APV ADAPT aux données des relevés et aux données sur les prises disponibles en remontant le plus loin possible dans le temps. La composition des captures selon l'âge de 1959 à 2009 a été incluse. On a utilisé comme indices les relevés hauturiers de 1983 à 1996 et l'index côtier-hauturier de 1997 à 2009. Un modèle de recrutement régressif segmenté a été ajusté aux estimations par l'APV de la BSR et du recrutement. Le modèle stock-recrutement ainsi ajusté a été utilisé pour estimer des points de référence basés sur le F_{rms} et le B_{rms}. Pour ce calcul, on a utilisé le poids moyen et la maturité moyenne à long terme, mais on s'est servi de la moyenne sur toute la période depuis le moratoire comme vecteur de recrutement partiel. Le B_{rms} a été estimé à 91 kt de la BSR, et le F_{rms} à 0,38. On estime que la BSR récente se situait à près de 40 % ou moins du B_{rms} alors que le F était proche du F_{rms} ou supérieur à celui-ci. Le manque de certitude quant à la fiabilité des données sur les prises commerciales a empêché l'application d'APV aux récentes évaluations. Cependant, le modèle de l'APV et le modèle stock-recrutement pourraient être utilisés pour des essais en simulation des règles de contrôle des prises rétroactives au moyen d'un processus d'évaluation des stratégies de gestion. Les hypothèses du modèle de l'APV et du modèle stock-recrutement actuels pourraient être modifiées de sorte à créer un ensemble de modèles opérationnels de référence. Il n'est pas nécessaire d'utiliser un unique « meilleur » modèle pour l'évaluation des stratégies de gestion.

INTRODUCTION

The cod stock in NAFO Subdiv. 3Ps is one of the most important cod stocks in Atlantic Canada and is one of the few stocks on which a commercially viable fishery reopened after the moratorium in the mid-1990s. It includes both an inshore small boat fixed gear fishery and a large vessel offshore trawl fishery fishing the same stock complex. To meet DFO's requirements for sustainable management, reference points and harvest control rules, need to be developed and applied in the management of the stock. This is difficult in the absence of a model of stock productivity. A limit reference point (LRP) has previously been established based on Brecovery, the spawner biomass from which the stock previously demonstrated a rapid recovery. This LRP is considered to be the 1994 spawning stock biomass (SSB) value (DFO 2011) and currently a relative estimate is obtained from the application of SURBA to the survey at age data (Beare et al. 2005, Cadigan 2010).

A virtual population analysis (VPA) was last used in the assessment of this stock in 2005. Re-examination of this model fit in the 2006 assessment retrospectively led to the 2005 VPA being dismissed as a valid interpretation of the survey and catch data on statistical grounds, precluding use of the results to carry out updated projections from the 2005 assessment (in the absence of a complete 3Ps research vessel survey in 2006). Reasons for abandoning the VPA-based assessment have included variability in the survey index that is not thought to be related to stock size, non-homogeneous distribution of the stock across the survey area and fishing area, incomplete coverage of the stock by the survey and concerns about the reliability of the annual catch records compiled by DFO. The reliability of the catch data was first raised in Shelton et al. (1996) and was again questioned in the 2003 assessment based on a qualitative evaluation of the cross-products (sum of catch at age x weights at age). Over the period 2006-2008 scientific advice for the management of the stock was largely qualitative. In 2009 the SURBA survey-based method of estimating relative stock size and total mortality was introduced (DFO 2009). Consequently, issues related to the use of the survey data to track cohorts can be assumed to no longer be considered a significant concern. Only the admissibility of the catch data remains an issue to be resolved to return to a VPA, or preferably, to introduce a new age structured assessment approach that recognizes uncertainty in both the survey and the catch data (e.g. Age Structured Assessment Program (ASAP); NMFS toolbox http://nft.nefsc.noaa.gov/ASAP.html).

The current SURBA assessment of relative stock size and total mortality only provides estimates from 1983 onwards. Reference points based only on recent (depleted) stock history are not likely to reflect real limits of stock productivity or allow the estimation of reliable maximum sustainable yield (MSY) based reference points. Using commercial catch at age data in a VPA assessment, the stock history can be reconstructed back to 1959. This reveals more of the dynamics in terms of SSB and recruitment than using only a reconstruction from 1983 onwards.

The reliability of the catch data is a major issue that needs to be resolved if reliable assessments of 3Ps cod are to be achieved. One concern that has been raised in previous assessments of this stock is the lack of correspondence between the nominal landings and the sum of the products of catch numbers x catch weights. We briefly look at the sum of products and compare them to the nominal landings. Despite concerns about the reliability of the catch data we consider that an updated VPA analysis can provide valuable insight into the past dynamics of the stock over the period for which catch at age data are available, and provide some insight into MSY-based reference points and the current state of the stock relative to these reference points. We argue that much of the dynamics of the stock was revealed within the converged part of this VPA which occurs prior to the decision to abandon VPA as an assessment model. There has been no study that has argued that all historic VPA results for this stock should be considered invalid.

The DFO Precautionary Approach (PA) policy (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm) requires that harvest control rules be developed and applied in the management of fish stocks in Canada. Such rules can best be tested by applying them to computer simulated fish stocks using Management Strategy Evaluation techniques (MSE; e.g. Smith 1994). Under this approach it is not necessary to have a single "best" assessment model. Instead candidate management strategies are applied to a range of alternative possible scenarios and hypotheses captured within a reference set of operating models. This approach requires age structured operating models that take into account the survey and catch at age, through VPA, ASAP or some other similar approach. It is feasible to carry out an MSE approach on age-aggregated production models but this is not possible for 3Ps cod because of the lack of a clear stock signal in the age-aggregated data. The objectives of this study are to provide an updated VPA, fit a stock–recruit model, and obtain MSY-based estimates of reference points. This analysis is not proposed as an alternative assessment of the stock, but should be considered more in the light of one analysis that could be incorporated together with other analyses into a management strategy evaluation to find harvest control rules that would be robust to the various uncertainties that exist with regard to the status and dynamics of 3Ps cod.

METHODS

Cross-products analysis of catch data

The consistency between the catch at age data and the nominal total landings data (Fig. 1) were examined by calculating the sum of products SOP_y for each year from age disaggregated catch numbers at age $N_{a,y}$ (Table 1) and catch weights $W_{a,y}$ at age (Table 3) such that

$$SOP_y = \sum_{a=1to14} N_{a,y} W_{a,y} .$$

It should be noted that individual fish are not weighed as part of the catch sampling program. Instead lengths are measured and an annual age-length key is applied to obtain catch at age. Mean lengths at age are then computed and a time-invariant length-weight relationship is applied to obtain mean weights at age. A common weight at age vector is applied prior to 1977 but the reason for this is unknown.

VPA - ADAPT

The current VPA was set up in a standard way following the basic format of previous ADAPT analyses for this stock (see for example Brattey et al. 2005). No attempt was made to vary the structure to improve the fit. The tuning indices used were offshore converted winter/spring research bottom trawl survey (Campelen survey units) for the period 1983-96 and ages 2-12 and the inshore-offshore Campelen survey for 1997-2009 and ages 2-12 (Table 2, Fig. 3). The assumption was made that fishing mortality (F) on the oldest age (14, not a plus group) was set equal to the average on ages 11-13 (except 1993 because of zero catch at older ages in that year). In other words a flat-topped fishery partial recruitment (selectivity) curve was assumed. Natural mortality (M) was assumed to be 0.2 throughout. Numbers at age from 3 to 14 in 2010 and survey catchabilities at age were estimated. Catch at age from 1959 to 2009 were included in the analysis (Table 1).

MSY based reference points

SSB estimates were computed from the VPA estimates of numbers at age (Table 6), female proportions mature at age (Table 5) and stock weights at age (Table 4). A segmented stock-recruit (SR) model was fit to the SSB and recruitment (R) estimates (numbers at age 2, Table 6) from the VPA output using the Julious Algorithm (Julious 2001). The SR fit was then used in a standard population projection model (Appendix 1) to generate equilibrium yield and SSB for a range of F values. M was assumed to be equal to 0.2. In addition to the estimate of survivors in the last year of the VPA, biological inputs were maturity, selectivity, stock weights, and catch weights (Table 8, Fig. 12). Maturity at age values were taken to be the long term average for the period 1959 to the present. Selectivity or partial recruitment to the fishery was set at the average for the post-moratorium period 1997 to the present, scaled to the average for ages 5-10. Stock weights and catch weights were averaged over the period 1976 to the present (i.e. going back to the earliest year for which annual weights at age are available).

RESULTS

Cross-products analysis of catch data

The results of the cross-product analysis are plotted in Fig. 2. The values are ((Nominal Landings - Sum of the cross-products)/Nominal Landings)*100. Positive values therefore indicate that the nominal landings exceeded the sum of the cross-products. There is considerable variation in this metric prior to 1978, with both large positive and large negative departures. This corresponds to the period when a single weight at age vector was applied. Departures from zero over this period are therefore not necessarily indicative of problems in the catch numbers at age data. Nominal landings include fish older than age 14 whereas only fish age 14 and younger are included in the sum of cross products, providing an additional potential cause for disagreement between the two metrics. Overall, the difference is more than 20% in only 2 of the 18 years from 1959 to 1977 and is more than 15% in only 4 years. From 1978 to 1997 the variation is small but thereafter there is an increasing trend with landings exceeding the cross products, a trend which has not been explained.

VPA – ADAPT estimates

As in previous analyses, the ADAPT VPA model fit is not strong with an overall MSE 0.63. The individual MSE values for each survey-age estimate range from less than 0.2 to nearly 1.2 (Fig. 4.) The corresponding coefficient of variations (CVs) on the estimates of survivors range from 50% to 190%. The plot of residuals against age shows a large amount of variability, particularly for the offshore survey series (Fig. 5). Both index time series residuals show a pattern when plotted against year (Fig. 6). Estimated numbers at age and fishing mortality from the VPA model are given in Tables 6 and 7. While the general trends in 2+ biomass, total 2+ population numbers, and SSB (Figs. 7-9) have been described based on previous VPA analyses, the updated VPA emphasizes the prolonged decline in recruitment (Fig. 10) and the impact this has had on population numbers (Fig. 8). The 2+ population number is estimated to be now about $1/5^{th}$ of what it was in the 1960s. Increases in SSB following the moratorium (Fig. 9) came from increased overall survival because of less fishing, and hence lower fishing mortality (Fig. 11), and improved weights at age of fish up to age 8 (Table 4), and not from improved recruitment.

MSY based reference points

Results for yield per recruit, spawner per recruit, and stock-recruit models for 3Ps cod are given in Figs. 13-16. Recruits per spawner are plotted in Fig. 17. Estimates of equilibrium surplus yield are plotted against spawning stock biomass and fishing mortality in Figs. 18 and 19. Estimates of reference points and related metrics for 3Ps cod based on these models are given in Table 9. Projected deterministic population growth from the inputs given in Table 8 are shown relative to 40%Bmsy and Bmsy under zero F and current (2009) average F for ages 5-10 in Figs 20 and 21. Bmsy was estimated to be 91 kt of SSB and Fmsy to be 0.38. The trajectory of the stock in F and SSB phase space is illustrated in absolute terms in Fig. 22 and relative to Fmsy and Bmsy in Fig. 23. These plots show the VPA time series commencing on a point close to Fmsy and Bmsy, an increasing trend in F to more than 3x Fmsy, followed by collapse to a very low SSB level. SSB recovered fairly quickly thereafter with the reduction in F but with F again increasing to above Fmsy, this increase was short-lived and the stock declined to the vicinity of 40%Bmsy with F around Fmsy.

DISCUSSION

The lack of an adequate population model of 3Ps cod that includes both survey and catch data limits the ability of scientific assessments to provide meaningful advice on total allowable catch (TAC) based fisheries management. It is difficult to verify the lack of adequacy of the commercial catch data based on the present catch monitoring system. It should be noted that for many years the annual assessments considered the catch data to be adequate for VPA analysis and it is not clear that recently invoked issues retroactively revoke the historical series which has been used in many published scientific studies on 3Ps cod. This should be clarified.

Catch information is derived from a variety of sources including dockside monitoring, log books, purchase slips, hails (information relayed by boats that are not going to be dockside monitored), and onboard observer data. Dockside monitoring and observer programs are run by private enterprise and quality control audit data are not made available to stock assessment reviews. Instead of a statistical sample design, a census approach is attempted to estimate catch, i.e. an attempt to add together all known fish landings. Instead of the census approach currently being applied, it may be better to attempt to census fishing effort (using vessel monitoring system and logbook data) and then estimate catch based on statistically designed stratified random sampling of catch rates (catch per unit effort or CPUE), taking into account area, season, gear type, directed species, vessel size effects, etc. In this way resources could be allocated to sampling catch-effort strata in a statistically valid manner to achieve a specified level of precision for deriving the catch estimate and both the total catch and confidence intervals could be properly estimated and used in the stock assessment.

It is important to try and verify the validity of the existing catch series. A cross-products approach does not seem to indicate major problems with the catch data over the period for which fish weight data are available (Fig. 2). Variation in the cross-products in the early period could simply be a consequence of using fixed weights at age rather than a problem with catch at age numbers. The reason for the positive trend in the percentage difference in the recent period is not known.

Although both the total catch and total survey data for 3Ps cod may be noisy (year effects), there are significant and coherent year class effects in the age disaggregated data from both sources (Shelton and Miller 2007). Indeed, it is this quality in the survey data that allows the current assessment method (SURBA) to be applied to 3Ps cod. ADAPT VPA is not the best method to apply to assess stock status when there is error in both the survey data and in the catch data. Age structured assessment models that take into account both sources of error would be more appropriate. Although the overall fit is poor, the VPA analysis provides one internally consistent overall interpretation of the available data and it has the advantage over the SURBA assessment that stock size is scaled by the magnitude of the catch. Thus results can be interpreted directly with regard to TAC management. This is not possible with SURBA. While the VPA presented here is not considered to be the "best" model for the current assessment for a variety of reasons, it could nevertheless provide the basis for one or more "operating models" in the context of MSE. Initial testing of proposed harvest control rules could be carried out on a simple deterministic projection of the 3Ps cod stock using the VPA analysis, stock-recruit model and projection inputs presented in this paper as a basis.

The biomass estimated by the VPA shows an overall declining trend over the time period from 1959 to the present, interspersed with two increases, one following the extension of jurisdiction in 1977 when fishing effort was reduced and one following the moratorium during which fishing effort was much reduced (Fig. 7). Population numbers increased slightly in the first of these episodes, but not the second (Fig 8). The recruitment time series shows an overall decreasing trend. (Fig. 10) with some high values which contributed to the first biomass increase but very low values concomitant with the second biomass increase. Weights at age were average during the first biomass increase but were elevated up to age 8 concomitant with the second biomass increase. Thus the first increase was due to a combination of fairly good recruitment and high survival, whereas the second increase was due to good survival and increased weights at age.

Spawner biomass from the VPA gives a more optimistic picture than total biomass and population numbers because proportions mature at younger ages increased considerably since the late 1980s (Table 4). Despite this increase in spawner biomass, recruits per spawner collapsed over this period so that spawner biomass produced very few recruits surviving to age 2 (see also Shelton et al. 2006). Studies have yet to identify the causes for the sharp decline in recruitment rate but hypotheses could include a high frequency of skipped spawning and less viable early life stages because of more first time spawners (Kjesbu et al. 1996, Morgan and Rideout 2005, Trippel 1998).

A range of reference points and associated metrics were estimated from the VPA model population estimates, stock-recruit model fit and projection inputs (Table 9). F0.1 was widely considered within DFO Atlantic Canada to be a good target reference point to ensure that overfishing did not occur but was abandoned in the late 1980s when cod stocks started to decline (Shelton 2007). The estimated value of F0.1 is 0.19, similar to past estimates for this stock and is half the average fishing mortality on ages 5-10 from 2000 to the present (from Table 7) of 0.36. In fact the estimate of Fmsy is close to this recent value at 0.38. Under the DFO PA Policy (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-back-fiche-eng.htm) Fmsy is considered to be a limit reference point, not a target reference point. SSBlim in Table 9 is the VPA estimate of the SSB in 1994, equivalent to the current Blim adopted for 3Ps (measured in SURBA units in the assessment). It should be noted that from the VPA results this is about 1/3 of the default Blim value of 40%Bmsy proposed in the DFO PA Policy. Further, the ratio of Bmsy to carrying capacity (K) is 0.25, indicating that the production function for 3Ps cod is highly skewed so that high surplus yield is maintained until a low stock size. This skewness is common in groundfish stocks but is a concern because MSY based reference points correspond to a high degree of depletion from the virgin or unexploited biomass (K in Table 9). To deal with such cases the New Zealand PA framework, as an example, sets the limit reference point on either a specified percentage of K or a specified percentage of Bmsy, whichever is higher. Note that the ratio of the adopted Blim for 3Ps cod to the unexploited biomass (Blim/K) is only 0.03 corresponding to 97% depletion. The current ratio of SSB to the adopted Blim is 2.94 underlining the observation that Brecovery, the basis for the current Blim, is too low based on the VPA analysis. The ratio of SSB to Bmsy is 0.4, placing the stock at the DFO default Blim of 40%Bmsy. Estimates of the unexploited SSB for 3Ps cod (K) of 358 kt and MSY of 41 kt do not seem unreasonable given the historic catch history. Based on the VPA analysis presented here, SSB has been at or below 40%Bmsy since 2006, recruitment is very low and fishing mortality is 2xF0.1. These are not conditions conducive to rapid stock rebuilding. While we do not advocate using the above VPA-based reference points for the management of the stock, the analysis indicates that the current Blim based on Brecovery may be too low.

Current management of 3Ps cod is not based on a predetermined management strategy incorporating harvest control rules. Instead annual management decisions are made on an ad hoc basis. Although there is no specific stated management objective for 3Ps cod, one could assume that rebuilding to the vicinity of Bmsy over some prescribed period of time with a specified probability would be a general objective under the DFO PA policy. Management has not been effective in this regard and simple feedback harvest control rules should be considered to achieve stock rebuilding. If the assessment was based on the current VPA and stock-recruit model fit, (or some other assessment model incorporating catch) it would be relatively straightforward to develop candidate harvest control rules and to undertake initial simulation testing using deterministic projections. More thorough evaluation would require a management strategy evaluation accounting for various sources of uncertainty, including model uncertainty. Evaluation of TAC-based harvest control rules using the current SURBA model would likely be very difficult.

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ACKNOWLEDGEMENTS

We would like to thank Eugene Murphy for the survey and catch at age information, John Brattey for the maturity at age and all of the technical and ships' crew involved in the collection of the data. Two reviewers within Aquatic Resources Division provided useful comments on the draft manuscript.

Table 1. Catch numbers at age for 3Ps cod.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1959	0	1001	13940	7525	7265	4875	942	1252	1260	631	545	44	1
1960	0	567	5496	23704	6714	3476	3484	1020	827	406	407	283	27
1961	0	450	5586	10357	15960	3616	4680	1849	1376	446	265	560	58
1962	0	1245	6749	9003	4533	5715	1367	791	571	187	140	135	241
1963	0	961	4499	7091	5275	2527	3030	898	292	143	99	107	92
1964	0	1906	5785	5635	5179	2945	1881	1891	652	339	329	54	27
1965	0	2314	9636	5799	3609	3254	2055	1218	1033	327	68	122	36
1966	0	949	13662	13065	4621	5119	1586	1833	1039	517	389	32	22
1967	0	2871	10913	12900	6392	2349	1364	604	316	380	95	149	3
1968	0	1143	12602	13135	5853	3572	1308	549	425	222	111	5	107
1969	0	774	7098	11585	7178	4554	1757	792	717	61	120	67	110
1970	0	756	8114	12916	9763	6374	2456	730	214	178	77	121	14
1971	0	2884	6444	8574	7266	8218	3131	1275	541	85	125	62	57
1972	0	731	4944	4591	3552	4603	2636	833	463	205	117	48	45
1973	0	945	4707	11386	4010	4022	2201	2019	515	172	110	14	29
1974	0	1887	6042	9987	6365	2540	1857	1149	538	249	80	32	17
1975	0	1840	7329	5397	4541	5867	723	1196	105	174	52	6	2
1976	0	4110	12139	7923	2875	1305	495	140	53	17	21	4	3
1977	0	935	9156	8326	3209	920	395	265	117	57	43	31	11
1978	0	502	5146	6096	4006	1753	653	235	178	72	27	17	10
1979	0	135	3072	10321	5066	2353	721	233	84	53	24	13	10
1980	0	368	1625	5054	8156	3379	1254	327	114	56	45	21	25
1981	0	1022	2888	3136	4652	5855	1622	539	175	67	35	18	2
1982	0	130	5092	4430	2348	2861	2939	640	243	83	30	11	7
1983	0	760	2682	9174	4080	1752	1150	1041	244	91	37	18	8
1984	0	203	4521	4538	7018	2221	584	542	338	134	35	8	8
1985	0	152	2639	8031	5144	5242	1480	626	545	353	109	21	6
1986	0	306	5103	10253	11228	4283	2167	650	224	171	143	79	23
1987	0	585	2956	11023	9763	5453	1416	1107	341	149	78	135	50
1988	0	935	4951	4971	6471	5046	1793	630	284	123	75	53	31
1989	0	1071	8995	7842	2863	2549	1112	600	223	141	57	29	26
1990	0	2006	8622	8195	3329	1483	1237	692	350	142	104	47	22
1991	0	812	7981	10028	5907	2164	807	620	428	108	76	50	22
1992	0	1422	4159	8424	6538	2266	658	269	192	187	83	34	41
1993	0	278	3712	2035	3156	1334	401	89	38	52	13	14	5
1994	0	9	78	173	74	62	28	12	3	2	0	0	0
1995	0	3	7	56	119	57	37	7	2	0	0	0	0
1996	0	9	43	43	101	125	35	24	8	2	1	0	0
1997	0	66	427	1130	497	937	826	187	93	31	4	1	0
1998	0	91	373	793	1550	948	1314	1217	225	120	56	15	1
1999	0	49	628	1202	2156	2321	1020	960	873	189	110	21	8
2000	1	76	335	736	1352	1692	1484	610	530	624	92	37	16
2001	2	80	475	718	1099	1143	796	674	257	202	192	28	13
2002	1	155	607	1451	1280	900	722	419	355	96	70	71	14
2003	0	15	301	879	1810	1139	596	337	277	167	67	55	84
2004	4	62	113	654	1592	1713	649	266	180	104	47	17	24
2005	1	49	330	515	1007	1628	1087	499	143	95	41	26	12
2006	0	43	253	866	928	846	1055	632	237	80	36	19	7
2007	4	97	311	727	1071	769	482	524	414	160	45	35	25
2008	0	35	422	617	1105	976	634	350	295	193	91	27	12
2009	0	17	129	813	1000	902	460	205	99	114	86	56	12

Table 2. Survey mean numbers per tow at age for 3Ps cod.

Offshore Campelen converted

CanRV	2	3	4	5	6	7	8	9	10	11	12
1983.3	10.01	6.52	1.14	3.72	1.62	0.48	0.89	1.61	0.75	0.36	0.14
1984.3	5.4	2.33	1.55	0.63	2.11	0.77	0.37	0.46	0.71	0.18	0.14
1985.2	7.74	14.88	12.57	9.96	3.28	2.66	0.79	0.48	0.42	0.42	0.49
1986.2	6.62	5.65	6.48	7.95	6.33	2.13	1.47	0.84	0.29	0.24	0.29
1987.2	8.48	5.67	4.97	13.82	8.31	3.35	1.29	0.69	0.28	0.23	0.16
1988.1	9.13	5.93	2.96	2.84	6.5	5.84	3.65	1.49	0.84	0.74	0.35
1989.1	6.5	4.66	3.17	1.51	1.16	2.15	1.21	0.67	0.37	0.41	0.13
1990.1	1.48	9.82	14.49	10.89	5.67	3.84	3.14	1.15	0.71	0.32	0.16
1991.1	27.69	5.03	10	11.24	5.75	2.84	1.58	1.19	0.74	0.56	0.22
1992.1	1.8	6.95	2.11	4.15	2.03	1.03	0.53	0.26	0.24	0.08	0.04
1993.2	0	1.91	4.04	1.1	2.15	0.57	0.22	0.09	0.06	0.08	0.02
1994.3	1.63	1.46	4.31	6.1	1.73	1.62	0.5	0.08	0.04	0.03	0.02
1995.3	0.31	1.16	1.67	13.08	19.65	4.4	5.75	2.19	0.25	0.2	0.01
1996.3	1.08	3.67	3.62	1.32	2.69	2.91	0.54	0.46	0.09	0.09	0.02

Inshore-offshore Campelen

io	2	3	4	5	6	7	8	9	10	11	12
1997.3	1.68	2.44	1.01	0.46	0.25	0.26	0.21	0.12	0.04	0.01	0
1998.3	1.28	6.28	7.4	4.91	3.53	1.73	2.19	2.43	0.38	0.26	0.06
1999.3	3.05	2.52	2.26	2.41	2.12	1.54	0.39	0.68	0.52	0.07	0.02
2000.3	3.84	6.66	3.52	2.24	1.75	1.11	0.8	0.31	0.28	0.46	0.11
2001.3	2.88	11.44	10.58	3.71	1.74	1.08	0.66	0.6	0.32	0.43	0.8
2002.3	1.53	3.72	7.08	4.95	2.58	1.73	0.85	0.45	0.31	0.07	0.11
2003.3	2.62	2.24	3.67	5.88	3.51	1.34	0.63	0.28	0.16	0.17	0.04
2004.3	2.24	2.5	1.85	1.93	3.49	3.61	1.08	0.68	0.57	0.67	0.13
2005.3	1.63	7.32	7.27	3.49	2.08	1.52	1.2	0.41	0.09	0.15	0.06
2007.3	2.34	5.33	3.26	2.11	1.14	0.76	0.35	0.56	0.37	0.12	0.1
2008.3	4.09	4.3	3.27	1.99	1.22	0.5	0.34	0.12	0.14	0.08	0.04
2009.3	2.47	8.64	5.81	4.91	2.65	1.53	0.84	0.18	0.15	0.18	0.32

Table 3. Catch weights at age for 3Ps cod

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1959	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1960	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1961	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1962	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1963	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1964	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1965	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1966	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1967	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1968	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1969	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1970	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1971	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1972	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1973	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1974	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1975	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1976	0.00	0.28	0.69	1.08	1.68	2.40	3.21	4.10	5.08	6.03	7.00	8.05	9.16
1977	0.00	0.55	0.68	1.30	1.86	2.67	3.42	4.19	4.94	5.92	6.76	8.78	10.90
1978	0.00	0.45	0.70	1.08	1.75	2.45	2.99	4.10	5.16	5.17	7.20	7.75	8.72
1979	0.00	0.41	0.65	1.01	1.65	2.55	3.68	4.30	6.49	7.00	8.20	9.53	10.84
1980	0.00	0.52	0.72	1.13	1.66	2.48	3.60	5.40	6.95	7.29	8.64	9.33	9.58
1981	0.00	0.48	0.79	1.32	1.80	2.30	3.27	4.36	5.68	7.41	9.04	8.39	9.56
1982	0.00	0.45	0.77	1.17	1.78	2.36	2.88	3.91	5.28	6.18	8.62	8.64	11.41
1983	0.00	0.58	0.84	1.33	1.99	2.58	3.26	3.77	5.04	6.56	8.45	10.06	11.82
1984	0.00	0.66	1.04	1.40	1.97	2.64	3.77	4.75	5.56	6.01	9.04	11.20	10.40
1985	0.00	0.63	0.85	1.23	1.79	2.81	3.44	5.02	6.01	6.11	7.18	9.81	10.48
1986	0.00	0.54	0.75	1.18	1.84	2.43	3.15	4.30	5.50	6.19	8.72	8.05	11.91
1987	0.00	0.56	0.77	1.21	1.63	2.31	3.02	4.33	5.11	6.20	6.98	7.08	8.34
1988	0.00	0.63	0.82	1.09	1.67	2.17	2.92	3.58	4.98	5.61	6.60	7.46	8.92
1989	0.00	0.63	0.81	1.16	1.63	2.25	3.37	4.11	5.18	6.29	7.30	7.75	8.73
1990	0.00	0.58	0.86	1.27	1.85	2.45	3.00	4.22	5.09	6.35	7.60	8.31	10.37
1991	0.00	0.60	0.75	1.17	1.74	2.37	2.91	3.69	4.23	6.34	7.68	8.64	9.72
1992	0.00	0.46	0.69	1.04	1.56	2.23	2.89	4.14	5.54	6.42	7.82	10.40	11.88
1993	0.00	0.36	0.68	1.08	1.48	2.13	2.82	4.34	4.30	4.68	7.49	6.85	8.24
1994	0.00	0.62	0.82	1.30	1.86	2.05	2.75	3.59	4.38	6.29	7.77	6.78	8.07
1995	0.00	0.52	0.85	1.57	2.03	2.47	2.78	3.46	4.30	4.27	4.16	5.59	9.24
1996	0.00	0.67	0.98	1.48	2.05	2.53	2.94	3.23	4.03	4.82	4.68	7.26	9.92
1997	0.00	0.62	0.90	1.30	1.87	2.51	3.24	3.47	3.52	4.59	6.37	8.58	10.73
1998	0.00	0.62	1.02	1.57	2.05	2.42	3.10	4.04	4.13	4.62	5.21	6.39	9.69
1999	0.00	0.70	0.92	1.57	2.31	2.53	2.82	3.92	5.32	4.99	5.27	6.14	7.27
2000	0.00	0.62	0.90	1.36	2.07	2.74	2.81	3.15	4.60	6.54	6.12	6.42	7.73
2001	0.30	0.69	1.02	1.44	1.94	2.57	3.41	3.21	3.46	5.59	8.61	7.61	8.11
2002	0.32	0.57	1.02	1.54	2.04	2.32	3.10	4.33	3.90	3.87	6.05	8.89	7.94
2003	0.36	0.68	0.97	1.57	2.11	2.34	2.63	3.87	4.75	4.30	5.33	7.82	10.35
2004	0.28	0.59	0.96	1.37	2.04	2.49	2.74	2.85	5.02	6.71	5.25	7.13	8.79
2005	0.34	0.64	0.94	1.39	1.84	2.46	2.90	3.16	3.25	4.36	6.15	5.53	7.85
2006	0.34	0.57	1.01	1.55	1.94	2.17	2.75	3.44	3.47	3.13	4.92	6.59	7.50
2007	0.30	0.56	0.94	1.45	1.97	2.25	2.54	3.84	5.04	5.54	4.96	7.29	8.92
2008	0.21	0.63	0.89	1.30	1.91	2.20	2.43	2.59	3.47	4.82	4.98	4.55	7.77
2009	0.17	0.63	1.02	1.53	1.93	2.38	2.48	2.61	3.67	5.81	7.07	7.97	9.00

Table 4. Stock weights at age for 3Ps cod

Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1959	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1960	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1961	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1962	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1963	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1964	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1965	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1966	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1967	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1968	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1969	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1970	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1971	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1972	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1973	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1974	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1975	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1976	0.00	0.18	0.44	0.86	1.35	2.01	2.78	3.63	4.56	5.53	6.50	7.51	8.59
1977	0.00	0.49	0.44	0.95	1.42	2.12	2.86	3.67	4.50	5.48	6.38	7.84	9.37
1978	0.00	0.37	0.62	0.86	1.51	2.13	2.83	3.74	4.65	5.05	6.53	7.24	8.75
1979	0.00	0.31	0.54	0.84	1.33	2.11	3.00	3.59	5.16	6.01	6.51	8.28	9.17
1980	0.00	0.42	0.54	0.86	1.29	2.02	3.03	4.46	5.47	6.88	7.78	8.75	9.55
1981	0.00	0.38	0.64	0.97	1.43	1.95	2.85	3.96	5.54	7.18	8.12	8.51	9.44
1982	0.00	0.33	0.61	0.96	1.53	2.06	2.57	3.58	4.80	5.92	7.99	8.84	9.78
1983	0.00	0.43	0.61	1.01	1.53	2.14	2.77	3.30	4.44	5.89	7.23	9.31	10.11
1984	0.00	0.58	0.78	1.08	1.62	2.29	3.12	3.94	4.58	5.50	7.70	9.73	10.23
1985	0.00	0.58	0.75	1.13	1.58	2.35	3.01	4.35	5.34	5.83	6.57	9.42	10.83
1986	0.00	0.45	0.69	1.00	1.50	2.09	2.98	3.85	5.25	6.10	7.30	7.60	10.81
1987	0.00	0.46	0.64	0.95	1.39	2.06	2.71	3.69	4.69	5.84	6.57	7.86	8.19
1988	0.00	0.56	0.68	0.92	1.42	1.88	2.60	3.29	4.64	5.35	6.40	7.22	7.95
1989	0.00	0.54	0.71	0.98	1.33	1.94	2.70	3.46	4.31	5.60	6.40	7.15	8.07
1990	0.00	0.51	0.74	1.01	1.46	2.00	2.60	3.77	4.57	5.74	6.91	7.79	8.96
1991	0.00	0.56	0.66	1.00	1.49	2.09	2.67	3.33	4.22	5.68	6.98	8.10	8.99
1992	0.00	0.38	0.65	0.88	1.35	1.97	2.62	3.47	4.52	5.21	7.04	8.94	10.13
1993	0.00	0.23	0.56	0.86	1.24	1.82	2.51	3.54	4.22	5.09	6.94	7.32	9.25
1994	0.00	0.53	0.54	0.94	1.42	1.74	2.42	3.19	4.36	5.20	6.03	7.13	7.43
1995	0.00	0.38	0.72	1.13	1.63	2.14	2.39	3.08	3.93	4.32	5.12	6.59	7.92
1996	0.00	0.58	0.72	1.12	1.79	2.26	2.70	3.00	3.73	4.55	4.47	5.49	7.45
1997	0.00	0.48	0.78	1.13	1.67	2.27	2.86	3.20	3.37	4.30	5.54	6.34	8.83
1998	0.00	0.51	0.79	1.19	1.63	2.13	2.79	3.62	3.79	4.03	4.89	6.38	9.12
1999	0.00	0.62	0.76	1.27	1.90	2.28	2.61	3.49	4.64	4.54	4.93	5.66	6.82
2000	0.00	0.48	0.79	1.12	1.80	2.52	2.67	2.98	4.25	5.90	5.53	5.82	6.89
2001	0.00	0.57	0.79	1.14	1.62	2.31	3.06	3.00	3.30	5.07	7.50	6.83	7.22
2002	0.00	0.44	0.84	1.25	1.71	2.12	2.83	3.84	3.53	3.66	5.82	8.75	7.77
2003	0.00	0.57	0.75	1.27	1.81	2.19	2.47	3.46	4.53	4.09	4.54	6.88	9.59
2004	0.00	0.46	0.81	1.15	1.79	2.29	2.53	2.74	4.41	5.64	4.75	6.16	8.29
2005	0.00	0.51	0.74	1.16	1.59	2.24	2.69	2.94	3.04	4.68	6.42	5.38	7.48
2006	0.00	0.46	0.80	1.21	1.64	2.00	2.60	3.16	3.31	3.19	4.63	6.37	6.44
2007	0.00	0.47	0.73	1.21	1.74	2.08	2.34	3.20	4.13	4.37	3.90	5.90	7.62
2008	0.00	0.49	0.70	1.10	1.66	2.08	2.33	2.56	3.60	4.89	5.24	4.70	7.42
2009	0.00	0.46	0.80	1.17	1.58	2.13	2.34	2.52	3.07	4.47	5.83	6.29	6.38
2010	0.00	0.46	0.74	1.16	1.66	2.10	2.34	2.74	3.57	4.57	4.92	5.59	7.12

Table 5. Estimates of proportions mature at age (females) for 3Ps cod.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1959	0.00	0.00	0.01	0.07	0.19	0.47	0.76	0.91	0.97	0.99	1.00	1.00	1.00
1960	0.00	0.00	0.01	0.06	0.18	0.47	0.76	0.91	0.97	0.99	1.00	1.00	1.00
1961	0.00	0.00	0.01	0.05	0.23	0.40	0.76	0.91	0.97	0.99	1.00	1.00	1.00
1962	0.00	0.00	0.00	0.05	0.17	0.57	0.67	0.91	0.97	0.99	1.00	1.00	1.00
1963	0.00	0.00	0.01	0.01	0.17	0.44	0.86	0.86	0.97	0.99	1.00	1.00	1.00
1964	0.00	0.00	0.02	0.08	0.11	0.47	0.75	0.96	0.95	0.99	1.00	1.00	1.00
1965	0.00	0.00	0.02	0.09	0.41	0.57	0.80	0.92	0.99	0.98	1.00	1.00	1.00
1966	0.00	0.00	0.03	0.10	0.35	0.85	0.94	0.94	0.98	1.00	0.99	1.00	1.00
1967	0.00	0.00	0.02	0.13	0.43	0.74	0.98	0.99	0.99	0.99	1.00	1.00	1.00
1968	0.00	0.00	0.01	0.08	0.44	0.83	0.94	1.00	1.00	1.00	1.00	1.00	1.00
1969	0.00	0.00	0.00	0.04	0.34	0.82	0.97	0.99	1.00	1.00	1.00	1.00	1.00
1970	0.00	0.01	0.02	0.01	0.24	0.75	0.96	1.00	1.00	1.00	1.00	1.00	1.00
1971	0.00	0.00	0.03	0.09	0.13	0.68	0.95	0.99	1.00	1.00	1.00	1.00	1.00
1972	0.00	0.00	0.01	0.16	0.32	0.63	0.94	0.99	1.00	1.00	1.00	1.00	1.00
1973	0.01	0.01	0.03	0.08	0.51	0.69	0.95	0.99	1.00	1.00	1.00	1.00	1.00
1974	0.00	0.02	0.06	0.12	0.42	0.85	0.91	1.00	1.00	1.00	1.00	1.00	1.00
1975	0.00	0.01	0.07	0.23	0.43	0.86	0.97	0.98	1.00	1.00	1.00	1.00	1.00
1976	0.00	0.01	0.04	0.22	0.58	0.80	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1977	0.00	0.00	0.03	0.14	0.51	0.86	0.96	1.00	1.00	1.00	1.00	1.00	1.00
1978	0.00	0.00	0.01	0.11	0.39	0.79	0.97	0.99	1.00	1.00	1.00	1.00	1.00
1979	0.00	0.01	0.02	0.04	0.34	0.73	0.93	0.99	1.00	1.00	1.00	1.00	1.00
1980	0.00	0.00	0.04	0.10	0.24	0.69	0.92	0.98	1.00	1.00	1.00	1.00	1.00
1981	0.01	0.00	0.00	0.14	0.39	0.71	0.91	0.98	0.99	1.00	1.00	1.00	1.00
1982	0.00	0.03	0.03	0.06	0.39	0.79	0.95	0.98	0.99	1.00	1.00	1.00	1.00
1983	0.00	0.01	0.09	0.15	0.42	0.71	0.96	0.99	0.99	1.00	1.00	1.00	1.00
1984	0.00	0.00	0.02	0.21	0.50	0.90	0.90	0.99	1.00	1.00	1.00	1.00	1.00
1985	0.00	0.00	0.01	0.09	0.43	0.86	0.99	0.97	1.00	1.00	1.00	1.00	1.00
1986	0.00	0.00	0.01	0.04	0.30	0.68	0.97	1.00	0.99	1.00	1.00	1.00	1.00
1987	0.00	0.00	0.01	0.04	0.18	0.64	0.86	1.00	1.00	1.00	1.00	1.00	1.00
1988	0.00	0.00	0.01	0.08	0.22	0.55	0.88	0.94	1.00	1.00	1.00	1.00	1.00
1989	0.00	0.00	0.01	0.09	0.37	0.68	0.88	0.97	0.98	1.00	1.00	1.00	1.00
1990	0.00	0.01	0.02	0.07	0.49	0.80	0.94	0.98	0.99	0.99	1.00	1.00	1.00
1991	0.00	0.00	0.05	0.24	0.54	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00
1992	0.00	0.02	0.05	0.34	0.81	0.95	0.99	0.99	1.00	1.00	1.00	1.00	1.00
1993	0.00	0.02	0.10	0.46	0.83	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.00	0.00	0.11	0.41	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.01	0.04	0.43	0.82	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.01	0.02	0.07	0.33	0.82	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1997	0.00	0.03	0.09	0.50	0.86	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.00	0.02	0.15	0.40	0.93	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.00	0.02	0.10	0.46	0.82	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.00	0.00	0.08	0.38	0.81	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.00	0.03	0.07	0.35	0.76	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.00	0.03	0.16	0.63	0.75	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2003	0.01	0.02	0.14	0.58	0.97	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2004	0.00	0.04	0.10	0.52	0.91	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.00	0.02	0.21	0.41	0.87	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.00	0.02	0.11	0.61	0.80	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2007	0.00	0.01	0.07	0.38	0.90	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2008	0.00	0.00	0.05	0.25	0.77	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2009	0.00	0.01	0.03	0.32	0.61	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.00	0.01	0.05	0.47	0.80	0.88	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2011	0.00	0.01	0.05	0.35	0.96	0.97	0.97	1.00	1.00	1.00	1.00	1.00	1.00
2012	0.00	0.01	0.05	0.35	0.79	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00

Table 6. VPA estimates of numbers at age for 3Ps cod.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1959	72289	59008	106607	36496	23904	16082	5645	3874	3134	3433	1187	136	3
1960	61488	59185	47408	74722	23112	13052	8793	3774	2049	1439	2243	485	72
1961	58906	50342	47945	33861	39916	12896	7564	4081	2174	938	813	1470	146
1962	51940	48228	40810	34219	18430	18399	7312	2041	1690	560	370	428	702
1963	85751	42525	38362	27337	19930	11016	9937	4756	963	872	291	177	230
1964	98192	70207	33949	27353	16011	11579	6747	5417	3086	526	585	149	50
1965	102067	80392	55760	22587	17326	8464	6834	3835	2741	1940	131	186	74
1966	119195	83565	63731	36978	13283	10939	4017	3751	2048	1319	1294	46	44
1967	84886	97589	67560	39892	18568	6734	4386	1869	1436	750	617	710	10
1968	65573	69499	77307	45488	21092	9473	3408	2368	989	892	275	420	448
1969	42808	53686	55869	51947	25452	12013	4558	1619	1445	430	530	126	339
1970	72463	35049	43256	39345	32114	14394	5758	2159	619	543	297	326	44
1971	47368	59328	28013	28113	20632	17533	6089	2518	1113	315	285	174	159
1972	36951	38781	45971	17142	15324	10381	7018	2195	925	429	182	122	87
1973	49512	30253	31091	33181	9911	9353	4386	3385	1051	345	168	45	57
1974	65849	40537	23916	21216	16961	4527	4062	1629	979	401	129	40	24
1975	69123	53913	31486	14152	8455	8187	1447	1667	319	322	108	34	5
1976	90583	56593	42479	19190	6755	2879	1526	540	310	167	109	42	23
1977	48479	74163	42627	23881	8625	2960	1191	806	316	206	121	70	30
1978	28641	39691	59875	26666	12091	4188	1598	621	422	154	118	61	30
1979	43022	23450	32043	44381	16352	6307	1861	724	298	186	62	72	35
1980	77888	35223	19077	23465	27058	8843	3057	878	384	169	105	29	47
1981	49984	63769	28506	14153	14666	14834	4215	1381	426	212	88	46	5
1982	80514	40923	51287	20735	8768	7835	6906	1999	648	192	114	41	21
1983	74481	65920	33388	37399	12993	5070	3852	3026	1062	313	83	66	23
1984	62487	60980	53284	24917	22376	6977	2581	2122	1545	651	175	35	38
1985	30869	51160	49743	39548	16316	12024	3721	1588	1250	961	412	112	22
1986	41757	25273	41749	38344	25155	8744	5159	1722	740	537	470	239	72
1987	55139	34188	20415	29583	22185	10563	3338	2286	828	405	286	257	125
1988	56578	45144	27462	14052	14349	9439	3789	1467	884	373	198	164	90
1989	43445	46322	36116	18028	7051	5967	3234	1502	638	469	195	95	87
1990	17285	35570	36958	21487	7751	3211	2607	1651	693	322	258	108	52
1991	30641	14152	27312	22508	10255	3370	1305	1030	733	255	137	118	47
1992	18818	25086	10854	15198	9469	3145	842	352	293	220	112	45	52
1993	13677	15407	19256	5163	4947	1975	576	111	52	70	17	19	7
1994	25362	11198	12363	12425	2406	1253	437	117	13	9	11	3	3
1995	20753	20764	9160	10051	10017	1903	970	332	85	8	6	9	2
1996	16518	16991	16998	7493	8179	8094	1507	761	266	68	7	5	8
1997	13583	13524	13903	13878	6096	6605	6514	1202	601	210	54	5	4
1998	16974	11121	11013	10997	10343	4543	4564	4589	816	408	144	41	3
1999	26588	13897	9023	8680	8289	7072	2867	2557	2664	466	227	68	20
2000	22179	21769	11334	6821	6024	4849	3709	1433	1234	1398	212	87	37
2001	12069	18158	17754	8977	4921	3716	2454	1709	628	536	587	92	39
2002	10486	9879	14794	14107	6702	3041	2017	1295	796	284	258	309	50
2003	14490	8584	7949	11565	10242	4335	1682	1004	685	334	147	149	189
2004	16289	11863	7015	6236	8675	6756	2526	843	520	313	125	60	72
2005	14267	13333	9657	5641	4516	5670	3992	1485	452	265	163	60	34
2006	18638	11680	10872	7608	4154	2792	3181	2292	769	241	132	97	26
2007	17081	15259	9524	8673	5449	2567	1527	1658	1309	417	126	75	62
2008	26325	13981	12406	7517	6445	3497	1411	818	888	701	198	63	30
2009	11991	21553	11415	9776	5598	4282	1987	589	357	462	400	81	27
2010		9817	17631	9230	7271	3683	2694	1213	299	203	276	250	17

Table 7. VPA estimates of fishing mortality at age for 3Ps cod.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1959	0.00	0.02	0.16	0.26	0.41	0.40	0.20	0.44	0.58	0.23	0.69	0.44	0.45
1960	0.00	0.01	0.14	0.43	0.38	0.35	0.57	0.35	0.58	0.37	0.22	1.00	0.53
1961	0.00	0.01	0.14	0.41	0.57	0.37	1.11	0.68	1.16	0.73	0.44	0.54	0.57
1962	0.00	0.03	0.20	0.34	0.31	0.42	0.23	0.55	0.46	0.46	0.53	0.42	0.47
1963	0.00	0.03	0.14	0.33	0.34	0.29	0.41	0.23	0.40	0.20	0.47	1.06	0.58
1964	0.00	0.03	0.21	0.26	0.44	0.33	0.36	0.48	0.26	1.19	0.94	0.50	0.88
1965	0.00	0.03	0.21	0.33	0.26	0.55	0.40	0.43	0.53	0.20	0.84	1.23	0.76
1966	0.00	0.01	0.27	0.49	0.48	0.71	0.56	0.76	0.80	0.56	0.40	1.37	0.78
1967	0.00	0.03	0.20	0.44	0.47	0.48	0.42	0.44	0.28	0.80	0.19	0.26	0.42
1968	0.00	0.02	0.20	0.38	0.36	0.53	0.54	0.29	0.63	0.32	0.58	0.01	0.30
1969	0.00	0.02	0.15	0.28	0.37	0.54	0.55	0.76	0.78	0.17	0.29	0.86	0.44
1970	0.00	0.02	0.23	0.45	0.41	0.66	0.63	0.46	0.48	0.44	0.33	0.52	0.43
1971	0.00	0.06	0.29	0.41	0.49	0.72	0.82	0.80	0.75	0.35	0.65	0.49	0.50
1972	0.00	0.02	0.13	0.35	0.29	0.66	0.53	0.54	0.79	0.74	1.19	0.56	0.83
1973	0.00	0.04	0.18	0.47	0.58	0.63	0.79	1.04	0.76	0.78	1.23	0.41	0.81
1974	0.00	0.05	0.32	0.72	0.53	0.94	0.69	1.43	0.91	1.12	1.12	1.93	1.39
1975	0.00	0.04	0.30	0.54	0.88	1.48	0.79	1.48	0.45	0.88	0.75	0.21	0.62
1976	0.00	0.08	0.38	0.60	0.63	0.68	0.44	0.33	0.21	0.12	0.24	0.11	0.16
1977	0.00	0.01	0.27	0.48	0.52	0.42	0.45	0.45	0.52	0.36	0.49	0.66	0.50
1978	0.00	0.01	0.10	0.29	0.45	0.61	0.59	0.53	0.62	0.71	0.29	0.37	0.46
1979	0.00	0.01	0.11	0.29	0.41	0.52	0.55	0.43	0.37	0.37	0.55	0.22	0.38
1980	0.00	0.01	0.10	0.27	0.40	0.54	0.59	0.52	0.39	0.45	0.63	1.49	0.86
1981	0.00	0.02	0.12	0.28	0.43	0.56	0.55	0.56	0.60	0.42	0.57	0.56	0.52
1982	0.00	0.00	0.12	0.27	0.35	0.51	0.63	0.43	0.53	0.64	0.34	0.35	0.44
1983	0.00	0.01	0.09	0.31	0.42	0.48	0.40	0.47	0.29	0.38	0.66	0.36	0.47
1984	0.00	0.00	0.10	0.22	0.42	0.43	0.29	0.33	0.27	0.26	0.25	0.29	0.26
1985	0.00	0.00	0.06	0.25	0.42	0.65	0.57	0.56	0.65	0.51	0.34	0.23	0.36
1986	0.00	0.01	0.14	0.35	0.67	0.76	0.61	0.53	0.40	0.43	0.41	0.45	0.43
1987	0.00	0.02	0.17	0.52	0.65	0.83	0.62	0.75	0.60	0.52	0.36	0.85	0.57
1988	0.00	0.02	0.22	0.49	0.68	0.87	0.73	0.63	0.43	0.45	0.54	0.44	0.47
1989	0.00	0.03	0.32	0.64	0.59	0.63	0.47	0.57	0.48	0.40	0.39	0.41	0.40
1990	0.00	0.06	0.30	0.54	0.63	0.70	0.73	0.61	0.80	0.66	0.58	0.64	0.63
1991	0.00	0.07	0.39	0.67	0.98	1.19	1.11	1.06	1.00	0.62	0.92	0.62	0.72
1992	0.00	0.06	0.54	0.92	1.37	1.50	1.82	1.71	1.24	2.35	1.59	1.70	1.88
1993	0.00	0.02	0.24	0.56	1.17	1.31	1.39	1.93	1.54	1.62	1.70	1.62	1.65
1994	0.00	0.00	0.01	0.02	0.03	0.06	0.07	0.12	0.29	0.28	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.02	0.03	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.03	0.03	0.18	0.00	0.00
1997	0.00	0.01	0.03	0.09	0.09	0.17	0.15	0.19	0.19	0.18	0.09	0.27	0.00
1998	0.00	0.01	0.04	0.08	0.18	0.26	0.38	0.34	0.36	0.39	0.55	0.52	0.49
1999	0.00	0.00	0.08	0.17	0.34	0.45	0.49	0.53	0.44	0.59	0.75	0.41	0.58
2000	0.00	0.00	0.03	0.13	0.28	0.48	0.57	0.63	0.63	0.67	0.64	0.62	0.64
2001	0.00	0.00	0.03	0.09	0.28	0.41	0.44	0.56	0.59	0.53	0.44	0.41	0.46
2002	0.00	0.02	0.05	0.12	0.24	0.39	0.50	0.44	0.67	0.46	0.35	0.29	0.37
2003	0.00	0.00	0.04	0.09	0.22	0.34	0.49	0.46	0.58	0.79	0.69	0.52	0.66
2004	0.00	0.01	0.02	0.12	0.23	0.33	0.33	0.42	0.48	0.45	0.53	0.37	0.45
2005	0.00	0.00	0.04	0.11	0.28	0.38	0.35	0.46	0.43	0.50	0.32	0.64	0.49
2006	0.00	0.00	0.03	0.13	0.28	0.40	0.45	0.36	0.41	0.45	0.36	0.24	0.35
2007	0.00	0.01	0.04	0.10	0.24	0.40	0.42	0.42	0.43	0.54	0.50	0.71	0.58
2008	0.00	0.00	0.04	0.09	0.21	0.37	0.67	0.63	0.45	0.36	0.70	0.63	0.56
2009	0.00	0.00	0.01	0.10	0.22	0.26	0.29	0.48	0.36	0.32	0.27	1.38	0.65

Table 8. Model inputs for determining reference points.

Age	pop	sel	catwt	stkwt	mat
1	0	0	0	0	0
2	17535	0.000	0.077	0.000	0.002
3	9817	0.018	0.567	0.463	0.009
4	17631	0.112	0.853	0.688	0.049
5	9230	0.336	1.310	1.053	0.226
6	7271	0.696	1.861	1.555	0.535
7	3683	1.057	2.412	2.112	0.806
8	2694	1.244	3.031	2.690	0.938
9	1213	1.312	3.864	3.409	0.981
10	299	1.355	4.777	4.286	0.994
11	203	1.391	5.648	5.182	0.998
12	276	1.357	6.859	6.169	0.999
13	250	1.460	7.842	7.247	1.000
14	17	1.311	9.408	8.513	1.000

Table 9. Estimates of reference points and related metrics for 3Ps cod based on MSY, yield per recruit and spawner per recruit. The last two entries in the table refer to the current estimate of SSB.

Reference	Value
K	358kt
Bmsy	91kt
Bmsy/K	0.25
40%Bmsy	36kt
80%Bmsy	73kt
Brecov	13kt
MSY	41kt
Fmsy	0.38
F0.1	0.19
Fmax	0.38
Fcrash	0.57
F35%SPR	0.10
Blim (1994 SSB)	12.5kt
Blim/K	0.03
SSB/Blim	2.94
SSB/Bmsy	0.40

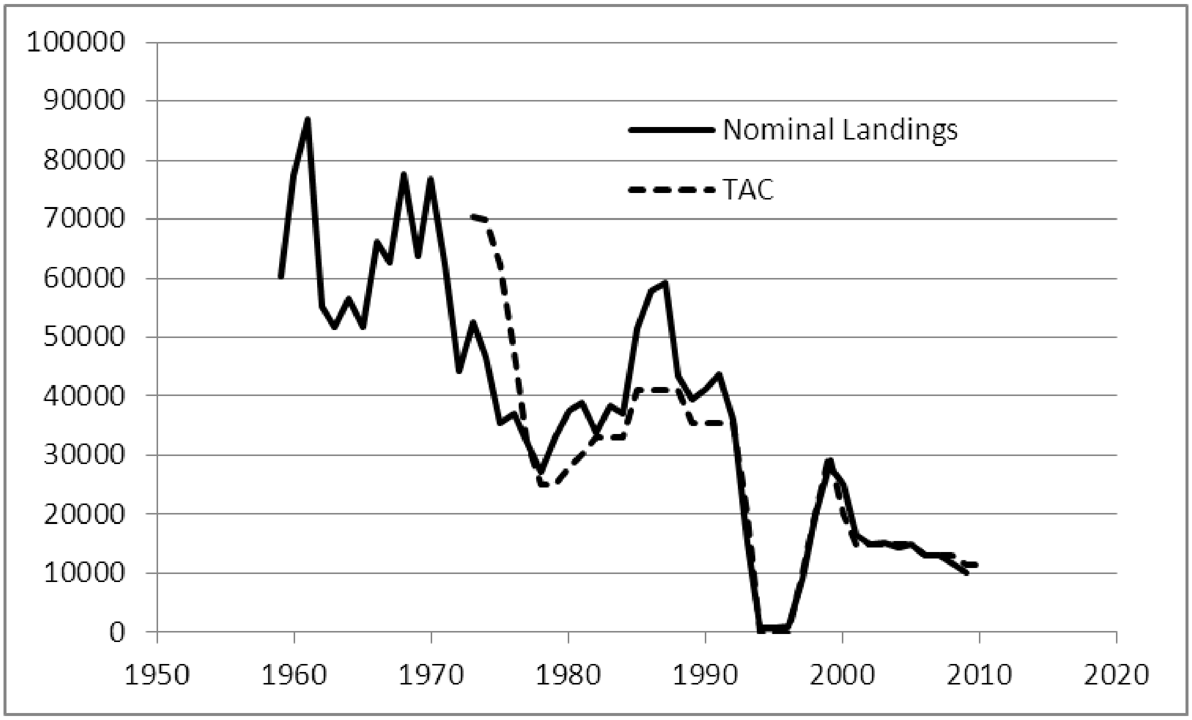

Figure 1. Nominal landings and TAC for the 3Ps cod fishery from 1959 to the present.

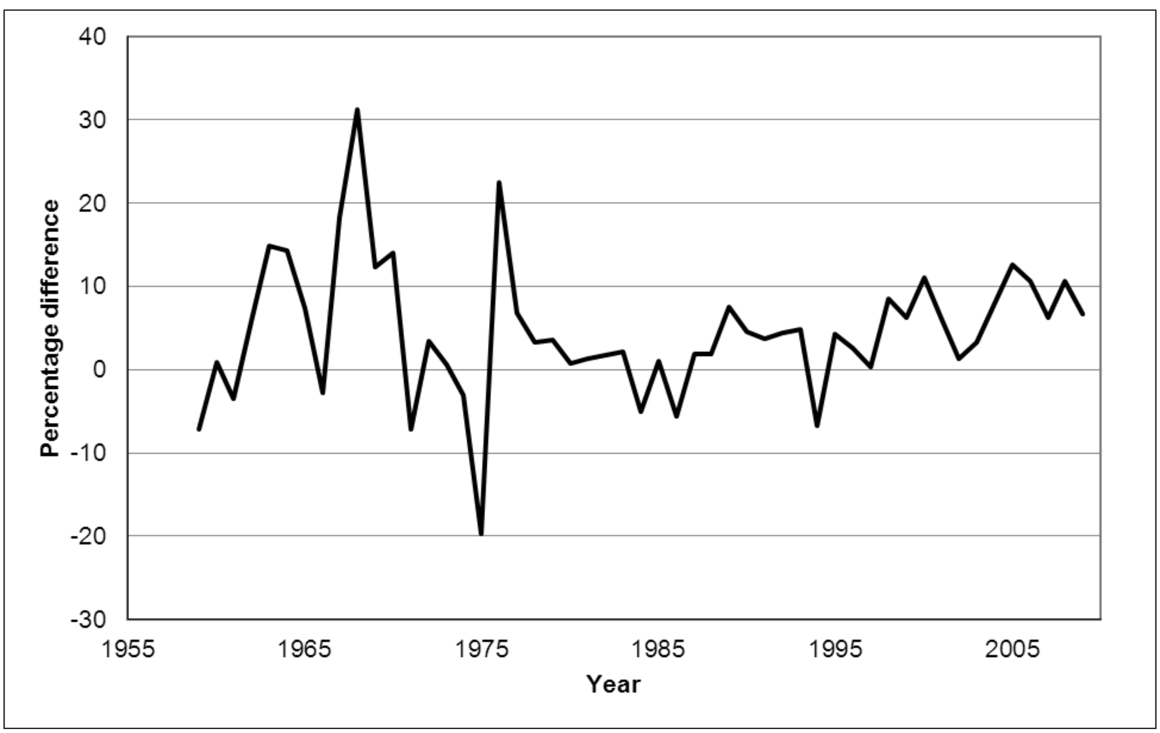

Figure 2. Sum of products correction for the catch at age to match the nominal landings.

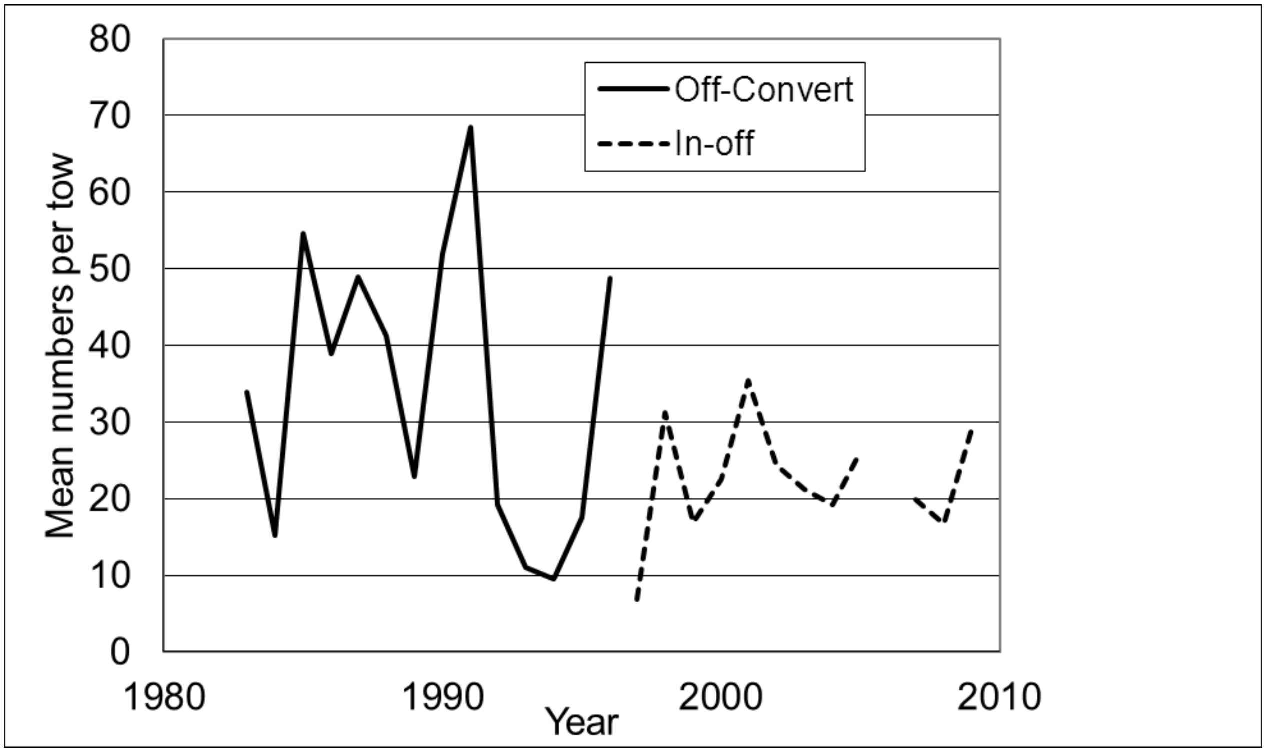

Figure 3. Tuning indices applied in the ADAPT reconstruction of the 3PS cod stock. Off-Convert is the Engel survey converted to Campelen equivalent units (1983-1996) and In-off is the extended Campelen survey which includes inshore strata (1997-2009). Age disaggregated indices are applied in the tuning of the ADAPT.

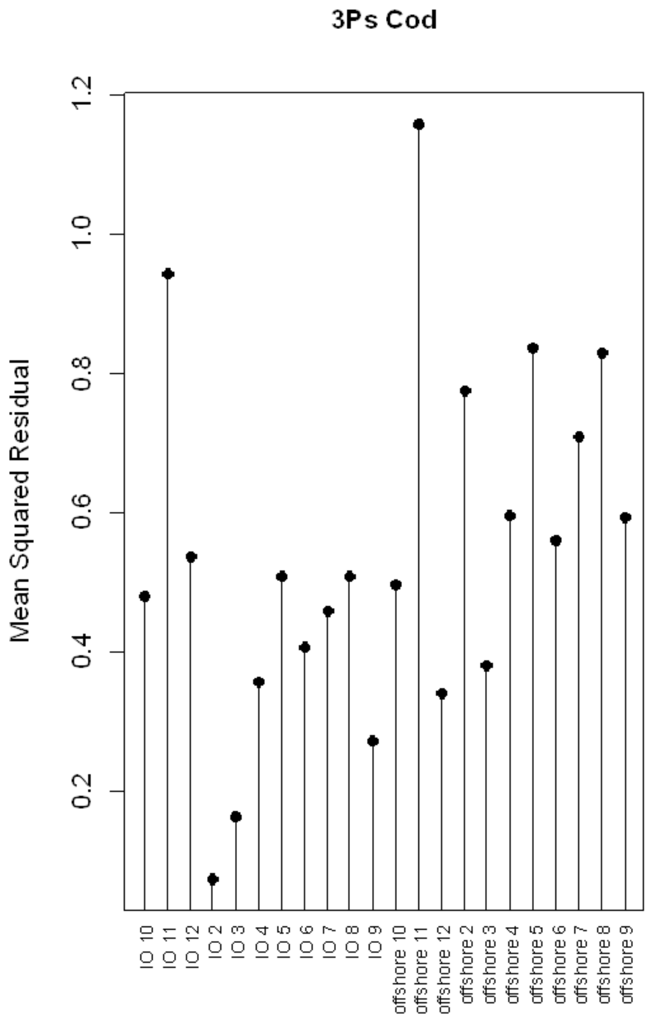

Figure 4. Mean square error for the ADAPT VPA model fit to 3Ps cod data.

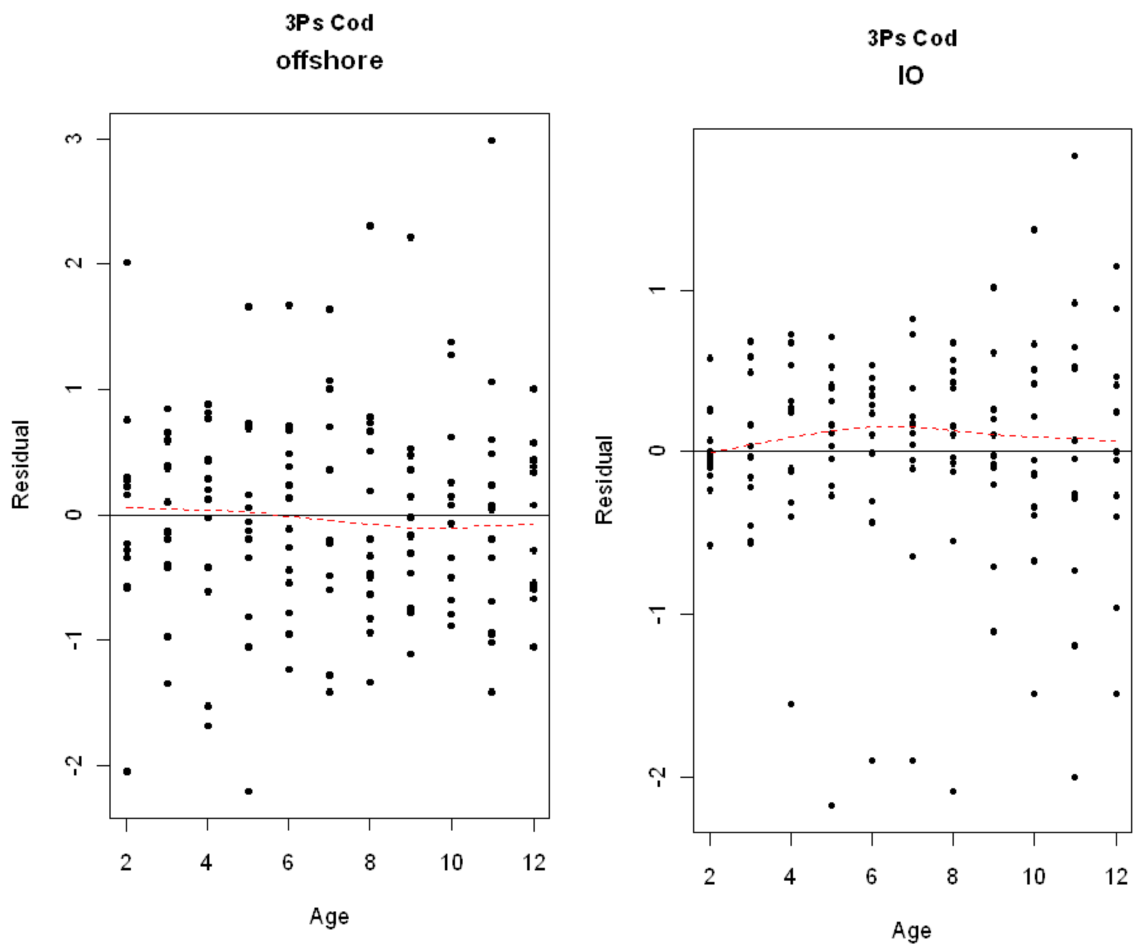

Figure 5. Residual variation in the VPA fit to the two survey series plotted against age. The broken line is a Lowess smoother.

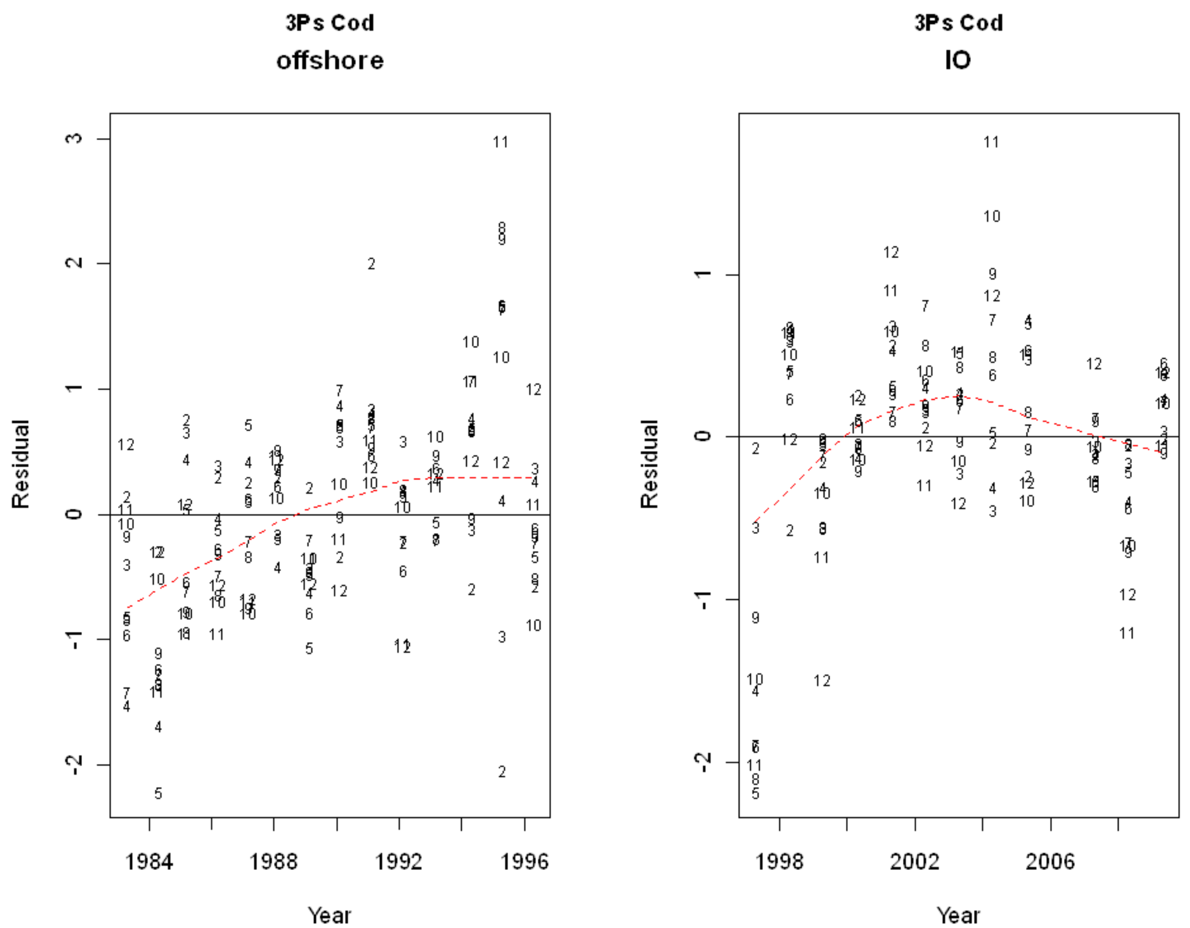

Figure 6. Residual variation in the VPA fit to the two survey series plotted against year. The broken line is a Lowess smoother.

Figure 7. Estimated total biomass age 2+ for 3Ps cod from the ADAPT VPA.

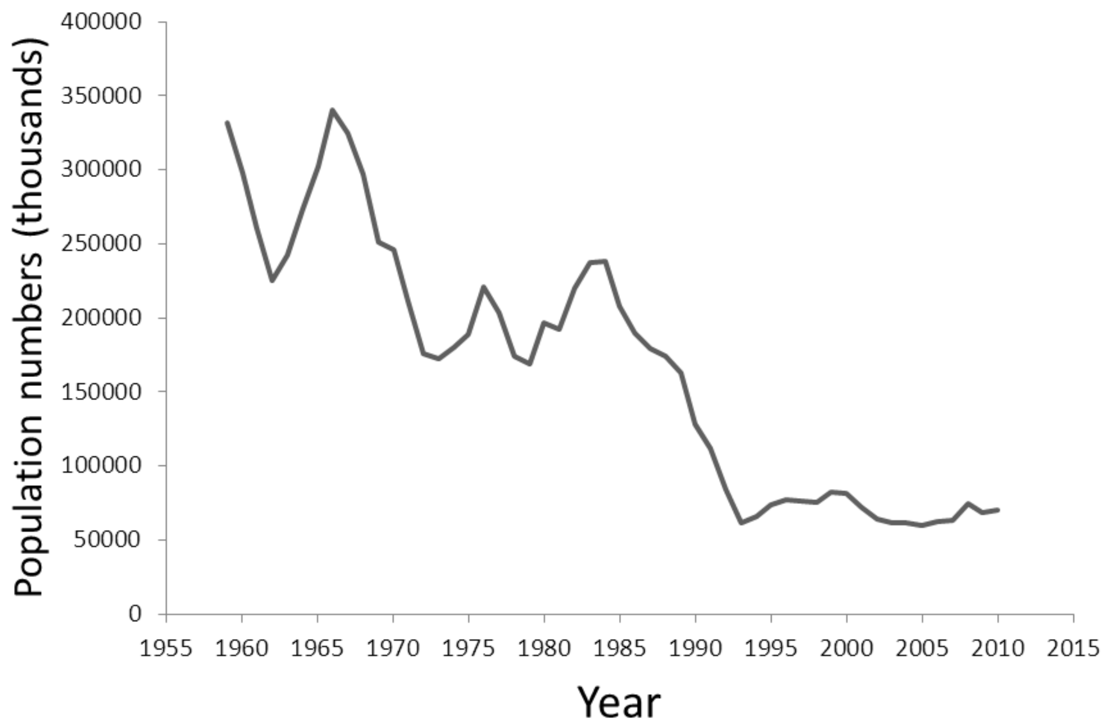

Figure 8. Estimated total 2+ numbers for 3Ps cod from the ADAPT VPA.

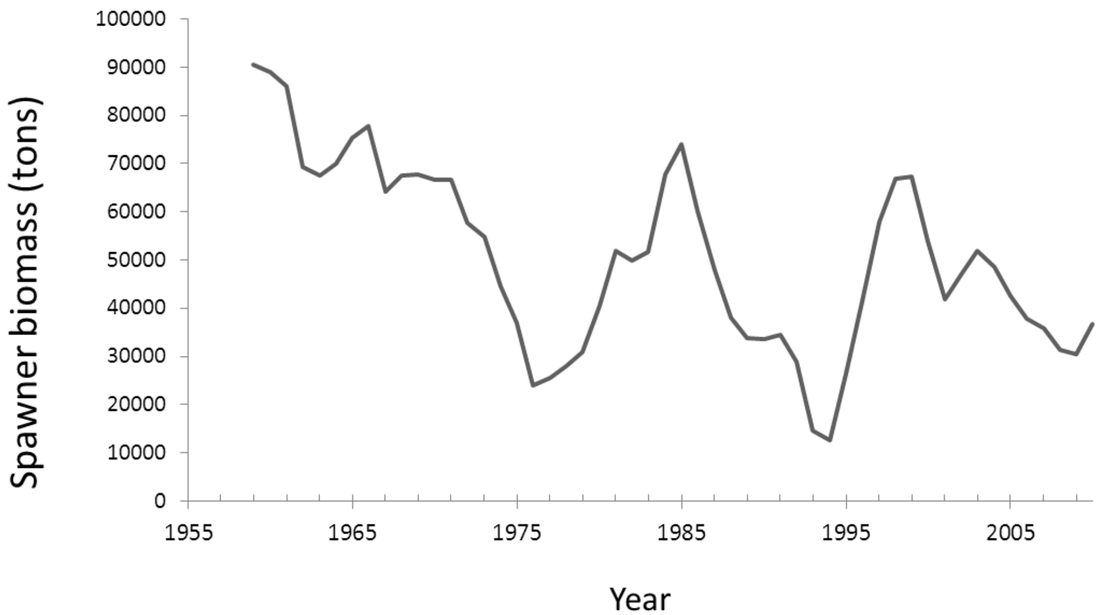

Figure 9. Estimated spawning stock biomass for 3Ps cod from the ADAPT VPA.

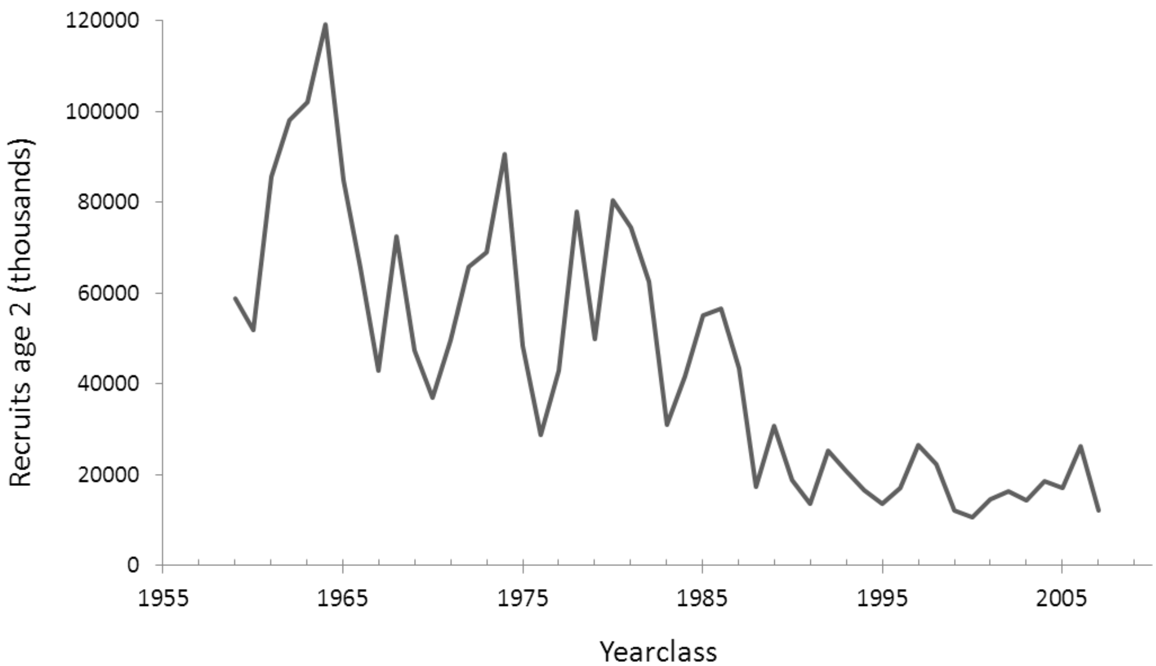

Figure 10. Estimated recruitment at age 2 for 3Ps cod from the ADAPT VPA.

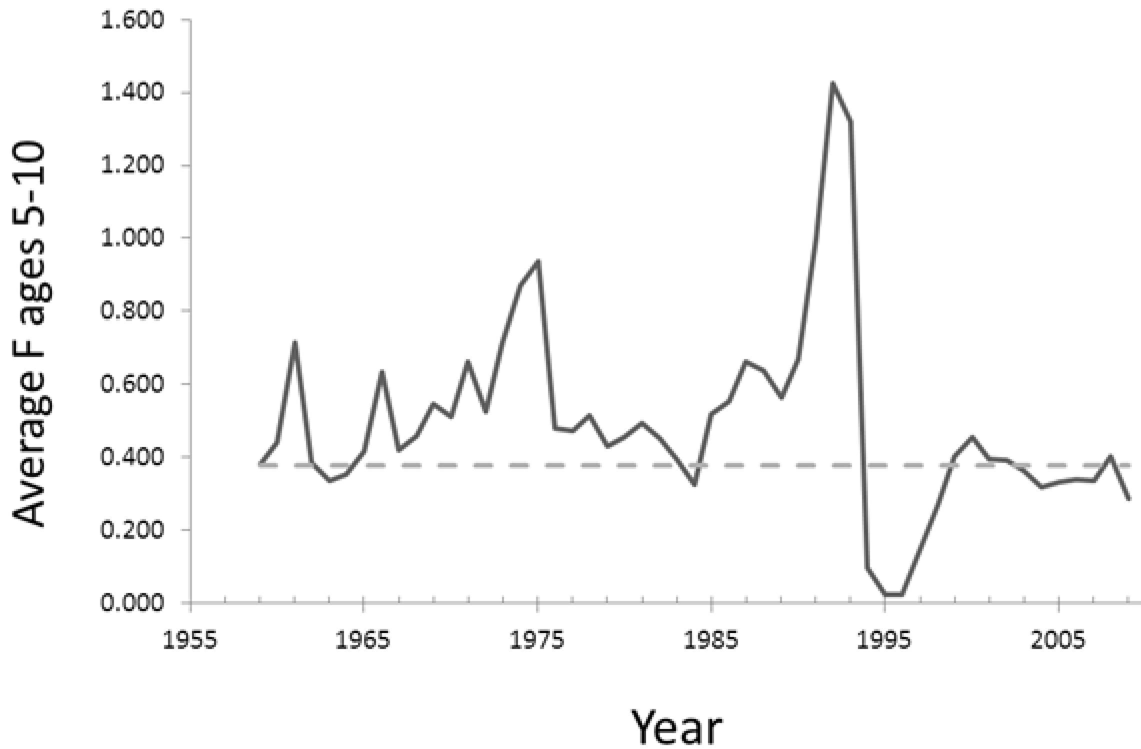

Figure 11. Estimated fishing mortality (average age 5-10) for 3Ps cod from the ADAPT VPA. The horizontal broken line indicates the Fmsy level.

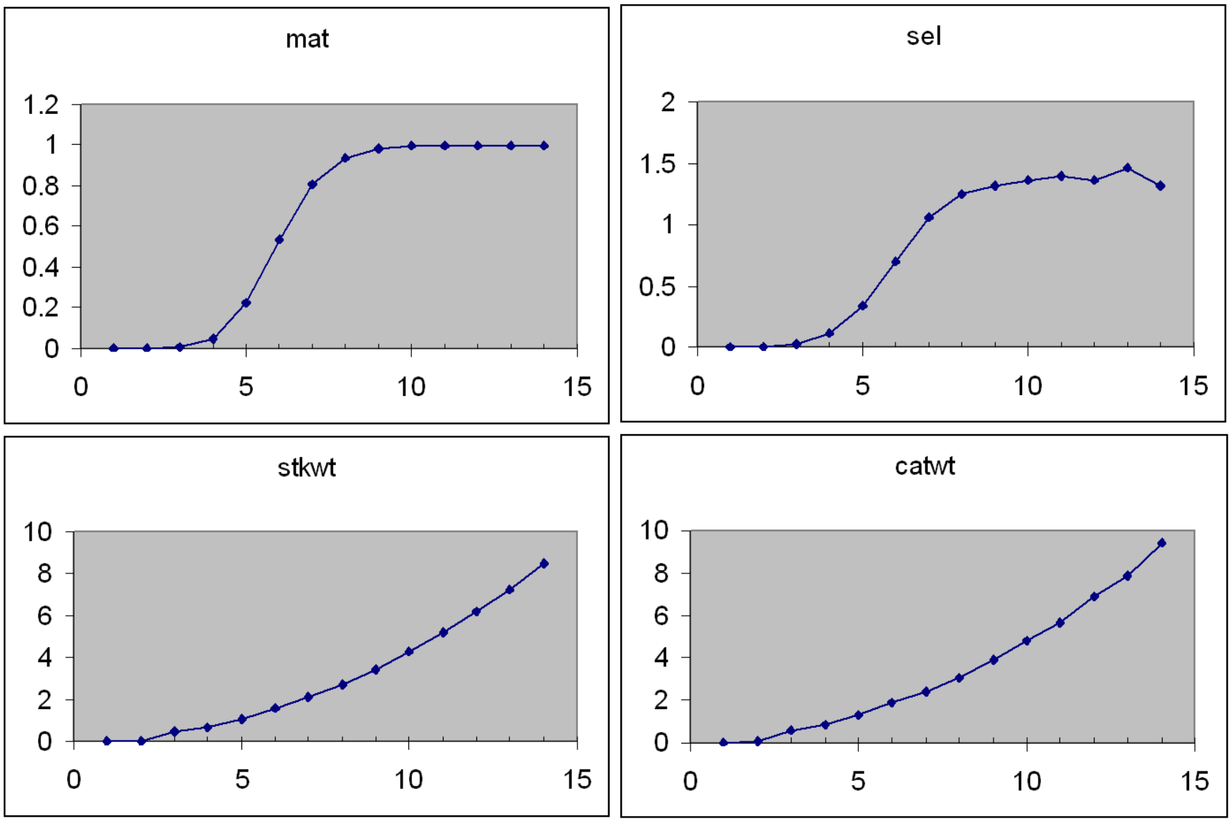

Figure 12. Average values of maturity, selectivity (rescaled to the average over ages 5-10), stock weight and catch weight used as inputs in the computation of biological reference points.

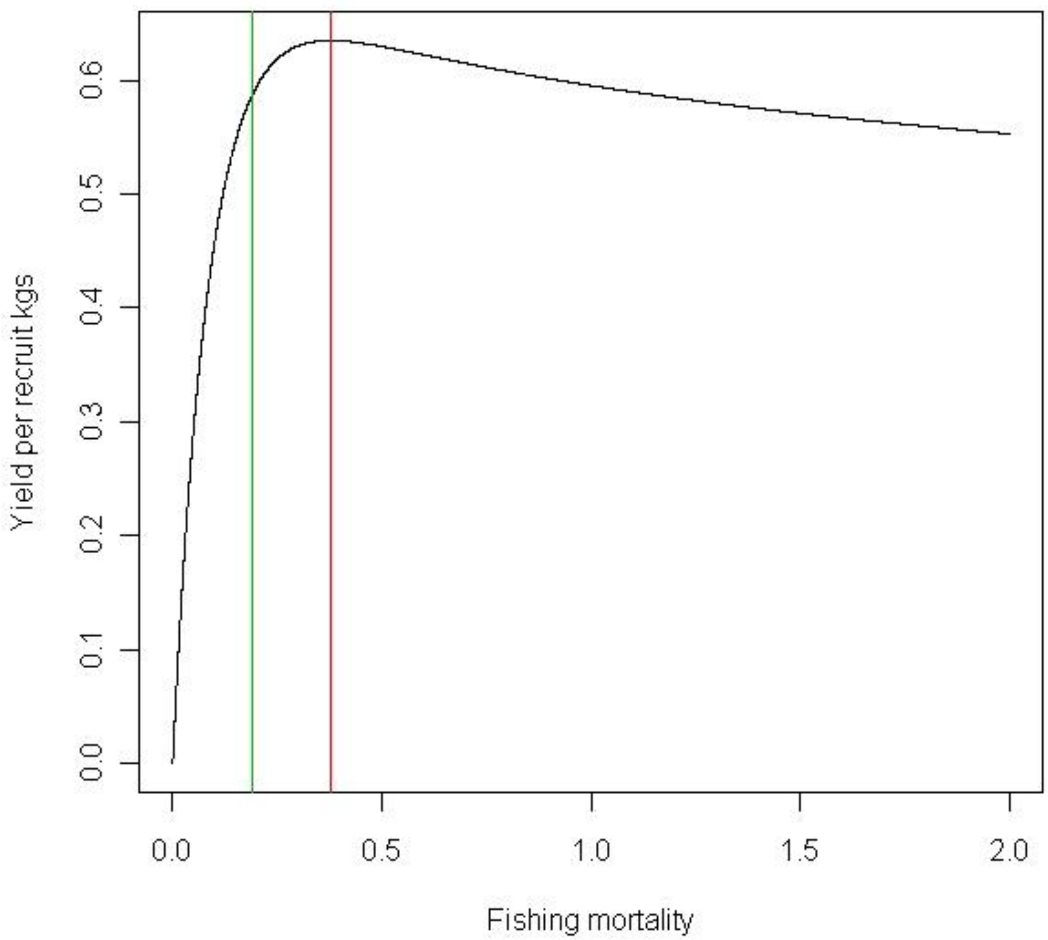

Figure 13. Yield per recruit for 3Ps cod. The vertical line on the right corresponds to Fmax and the vertical line on the left to F0.1.

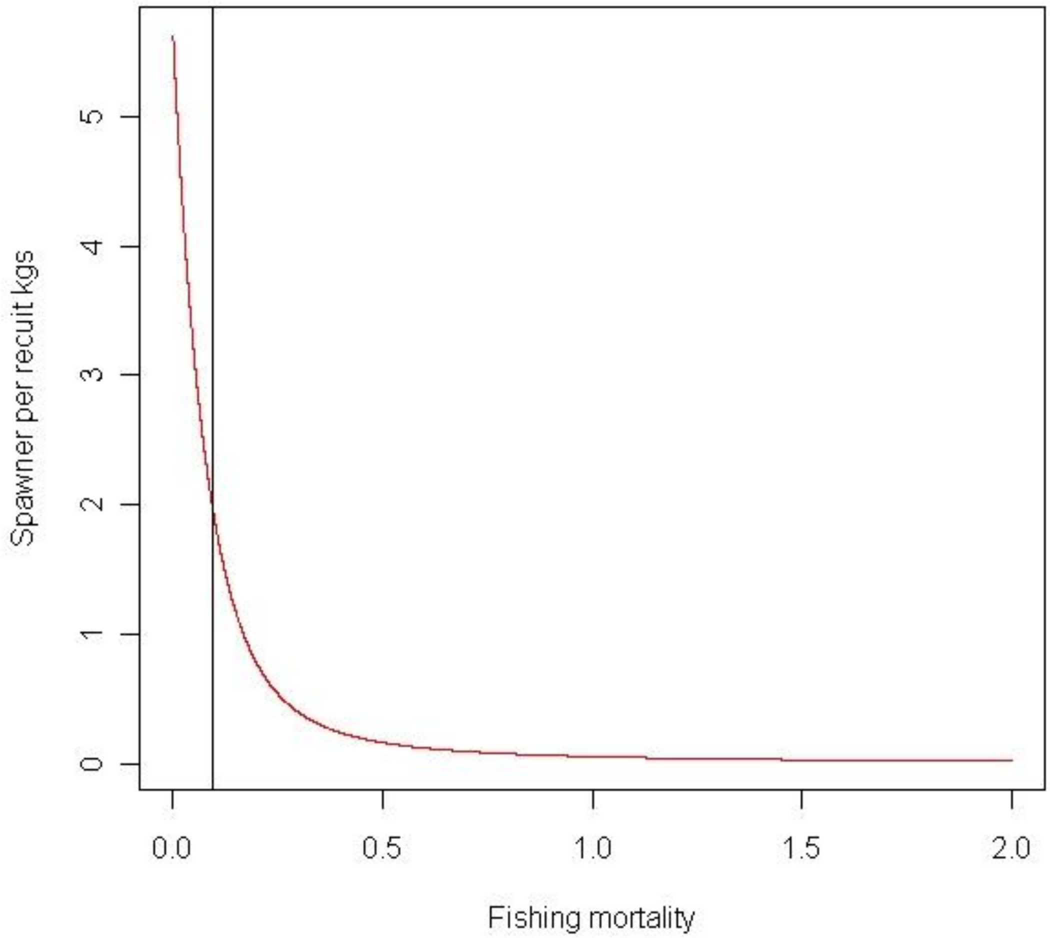

Figure 14. Spawning biomass per recruit for 3Ps cod. The vertical line gives the F that corresponds to 35% of the SPR that is achieved in the absence of fishing.

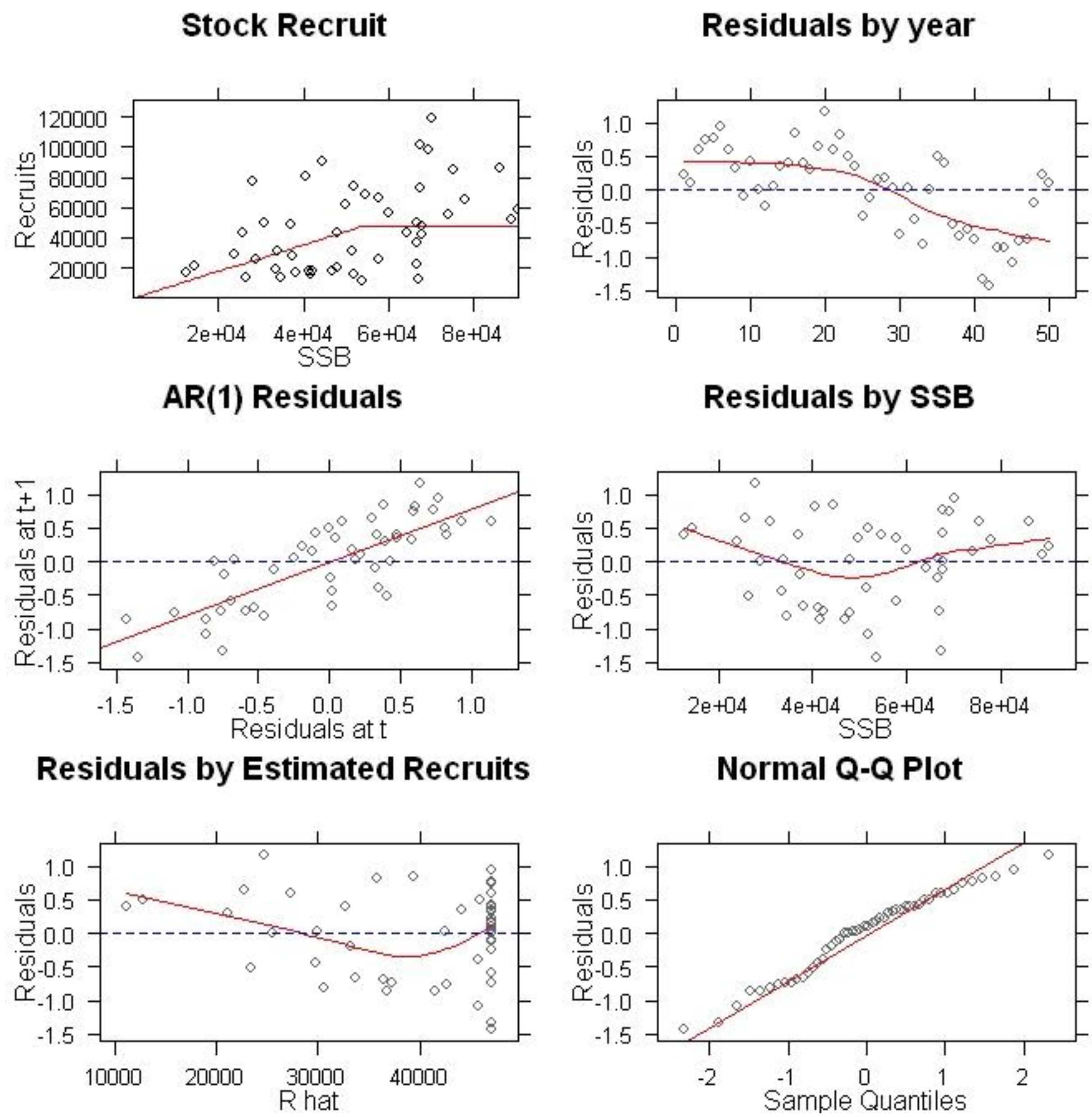

Figure 15. Segmented or hockey stick stock–recruit model fit using the Julious Algorithm along with associated diagnostic statistics.

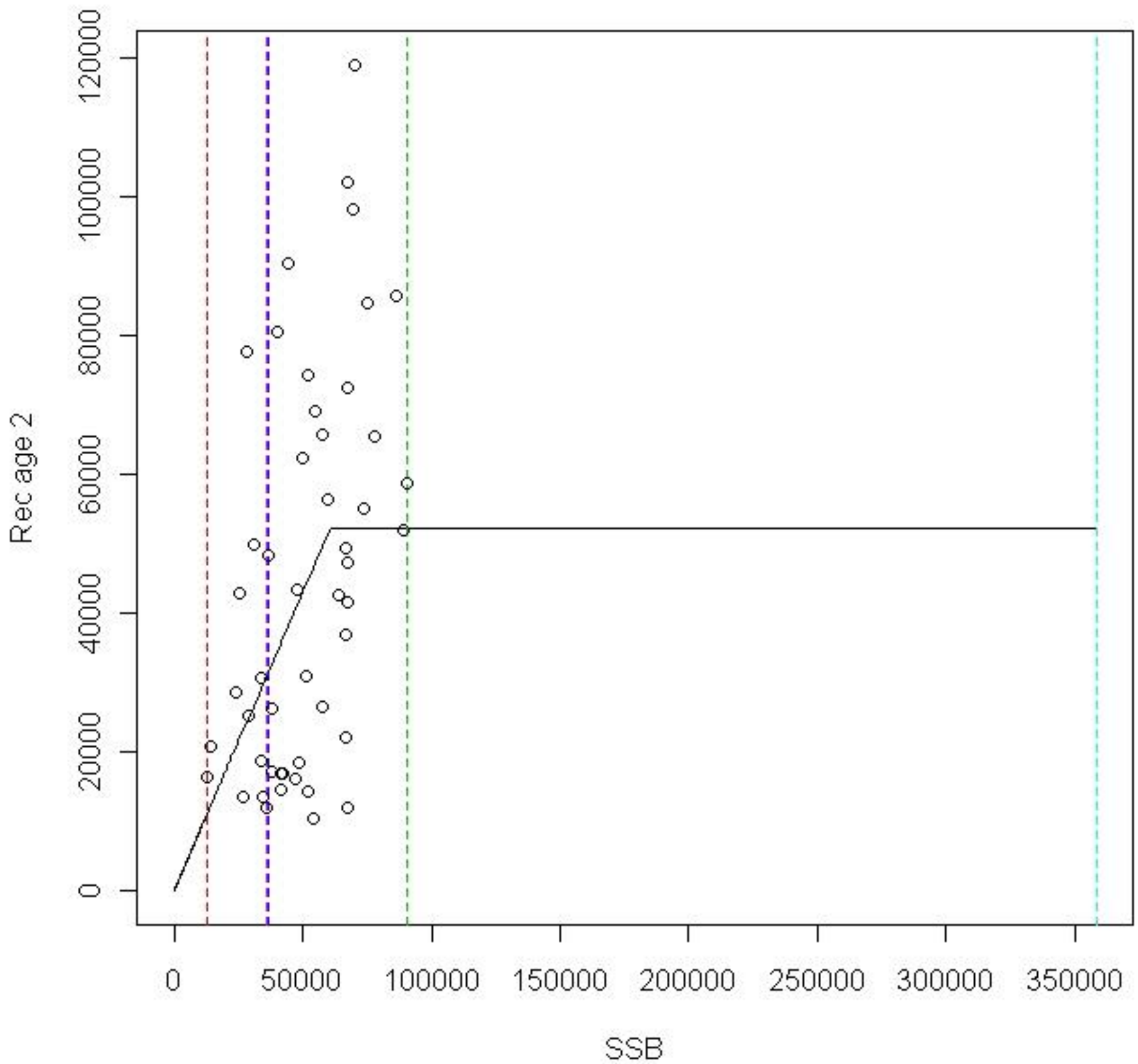

Figure 16. Recruitment scatter, segmented stock-recruit model fit and MSY-based reference points. Vertical broken lines are from right to left, B0, Bmsy, 40%Bmsy overlaid by Bcurr (current SSB) and Brecov.

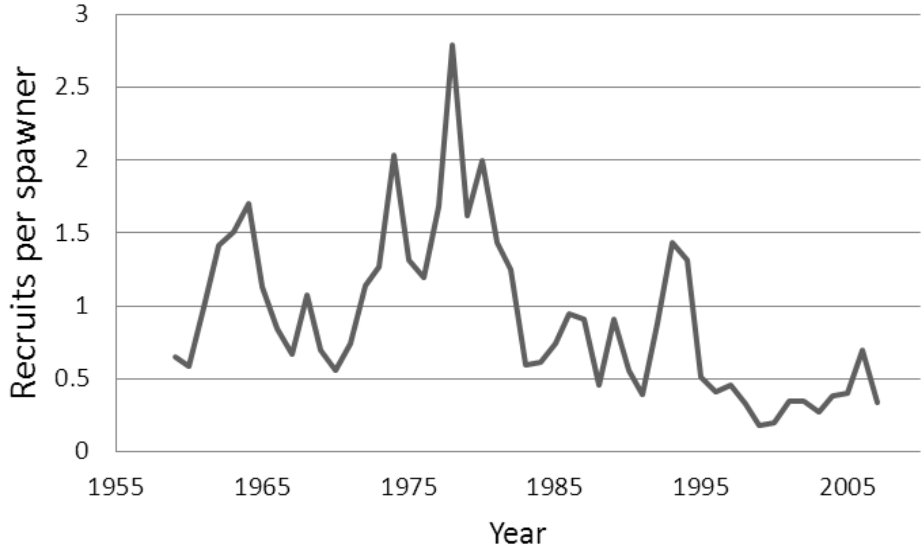

Figure 17. Recruits (age 2) per spawner for 3Ps cod based on VPA estimates.

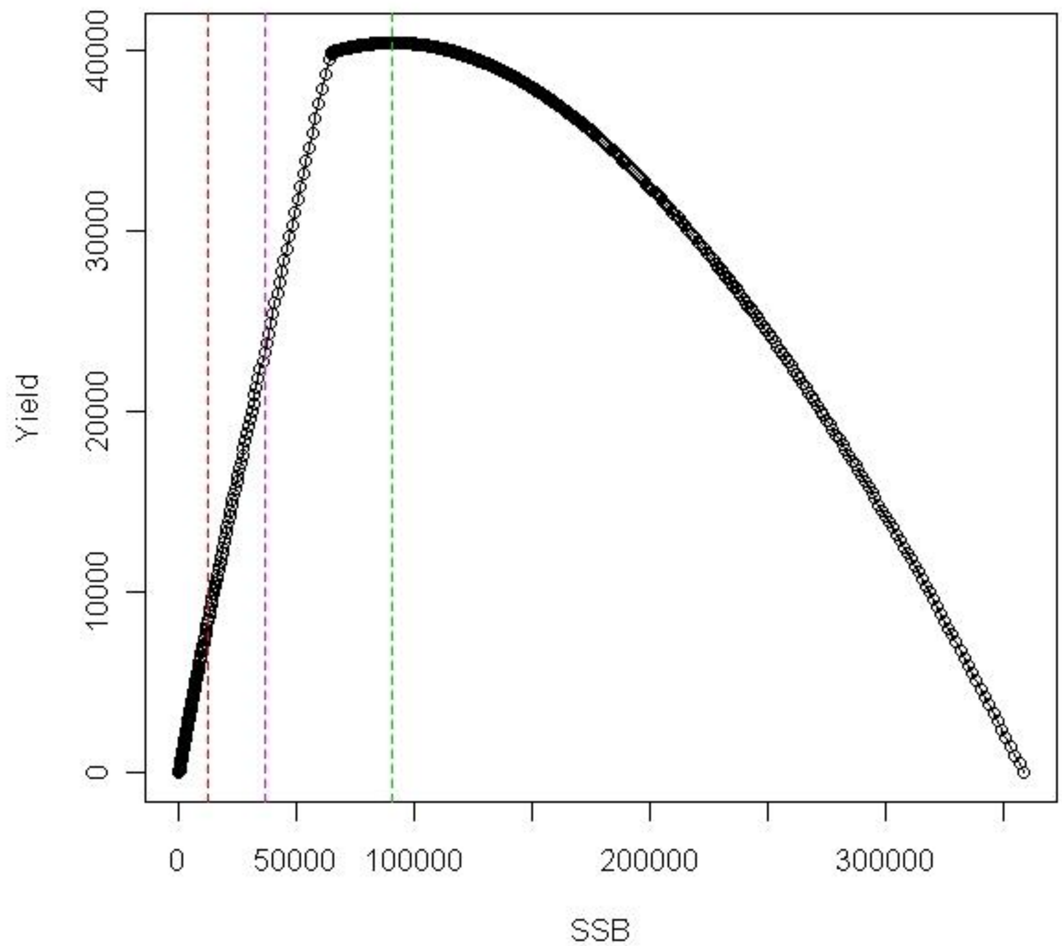

Figure 18. Equilibrium yield plot generated by applying a range of F levels. The vertical broken lines are, from right to left, Bmsy, Bcurr and 40%Bmsy overlaid, and Brecov.

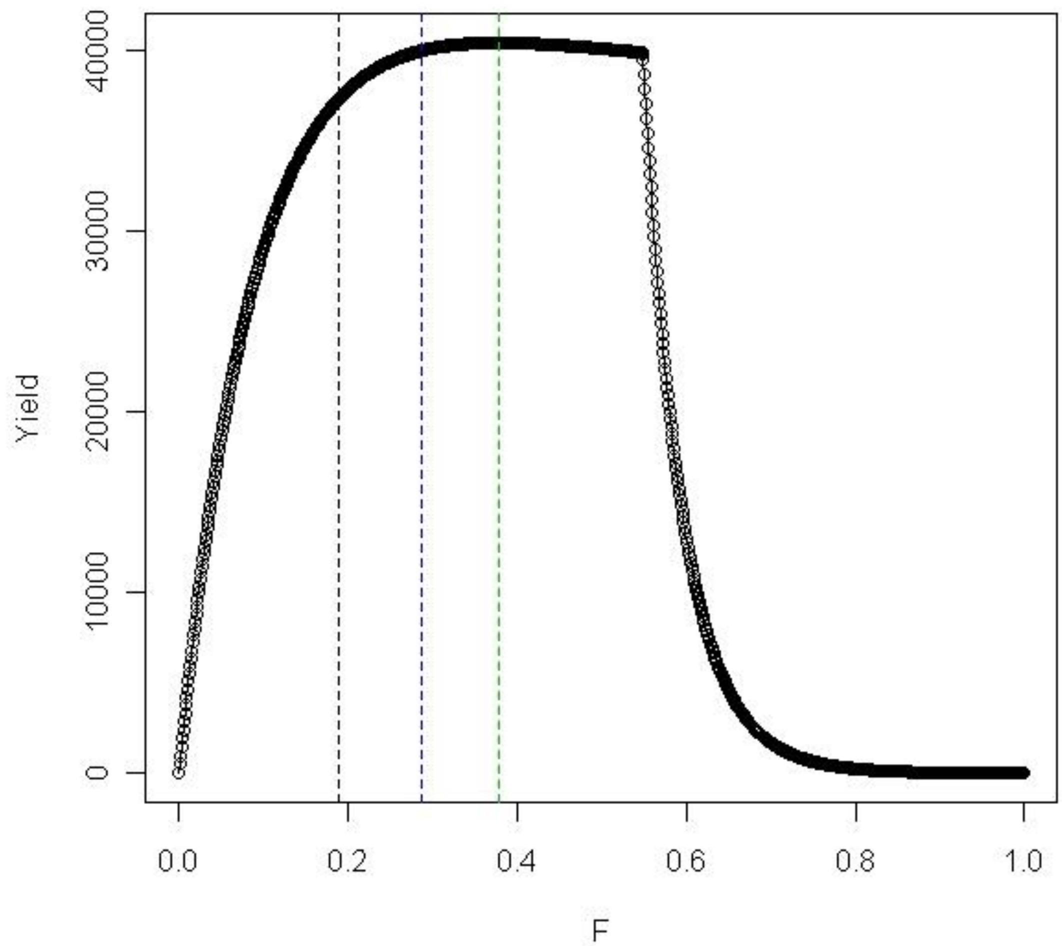

Figure 19. Equilibrium yield plotted against F. The vertical lines are, from right to left, Fmsy, Fcurr and F0.1.

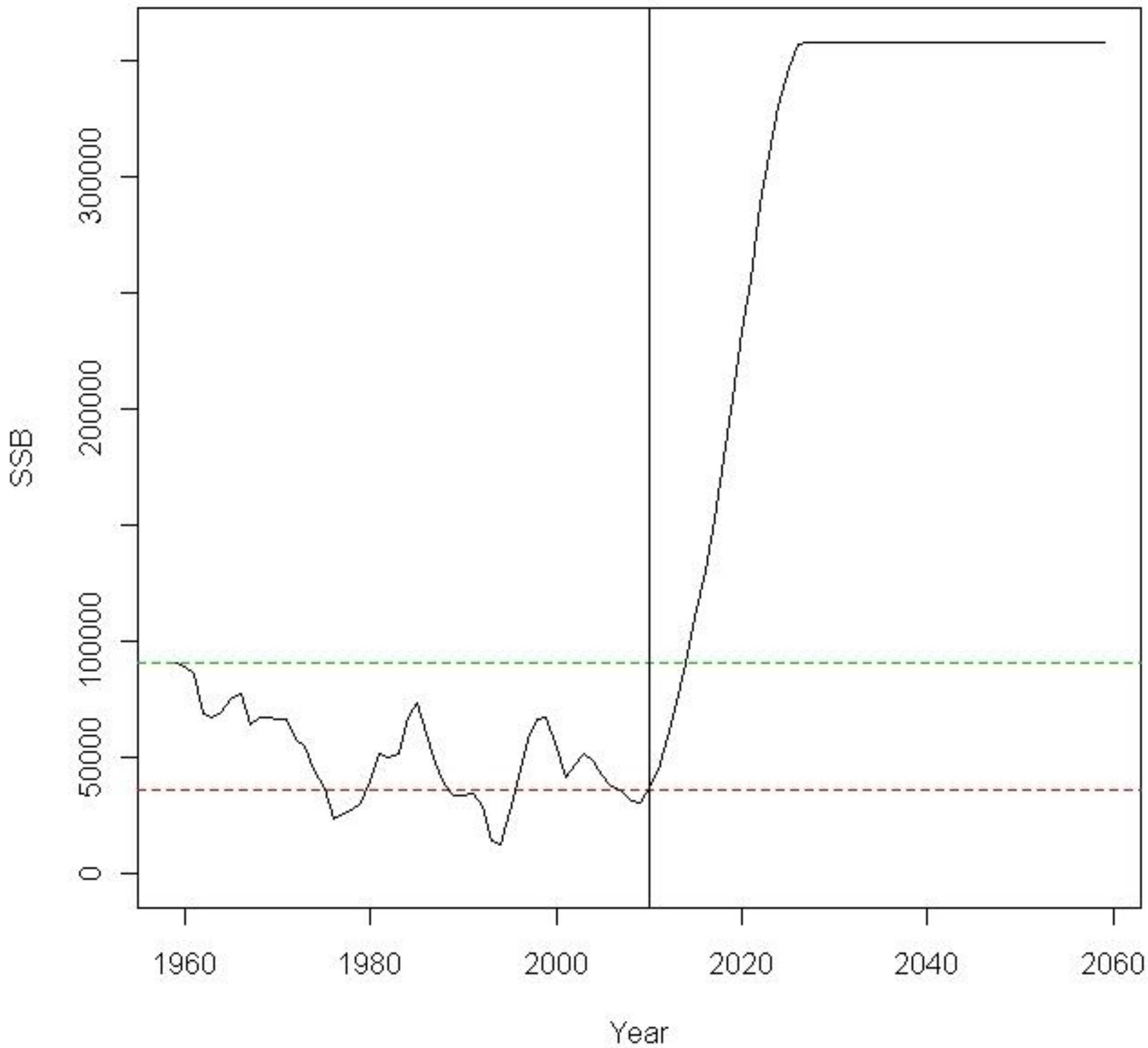

Figure 20. A 50 year projection of 3Ps cod SSB under no fishing. The horizontal broken lines are Bmsy on top and 40%Bmsy below.

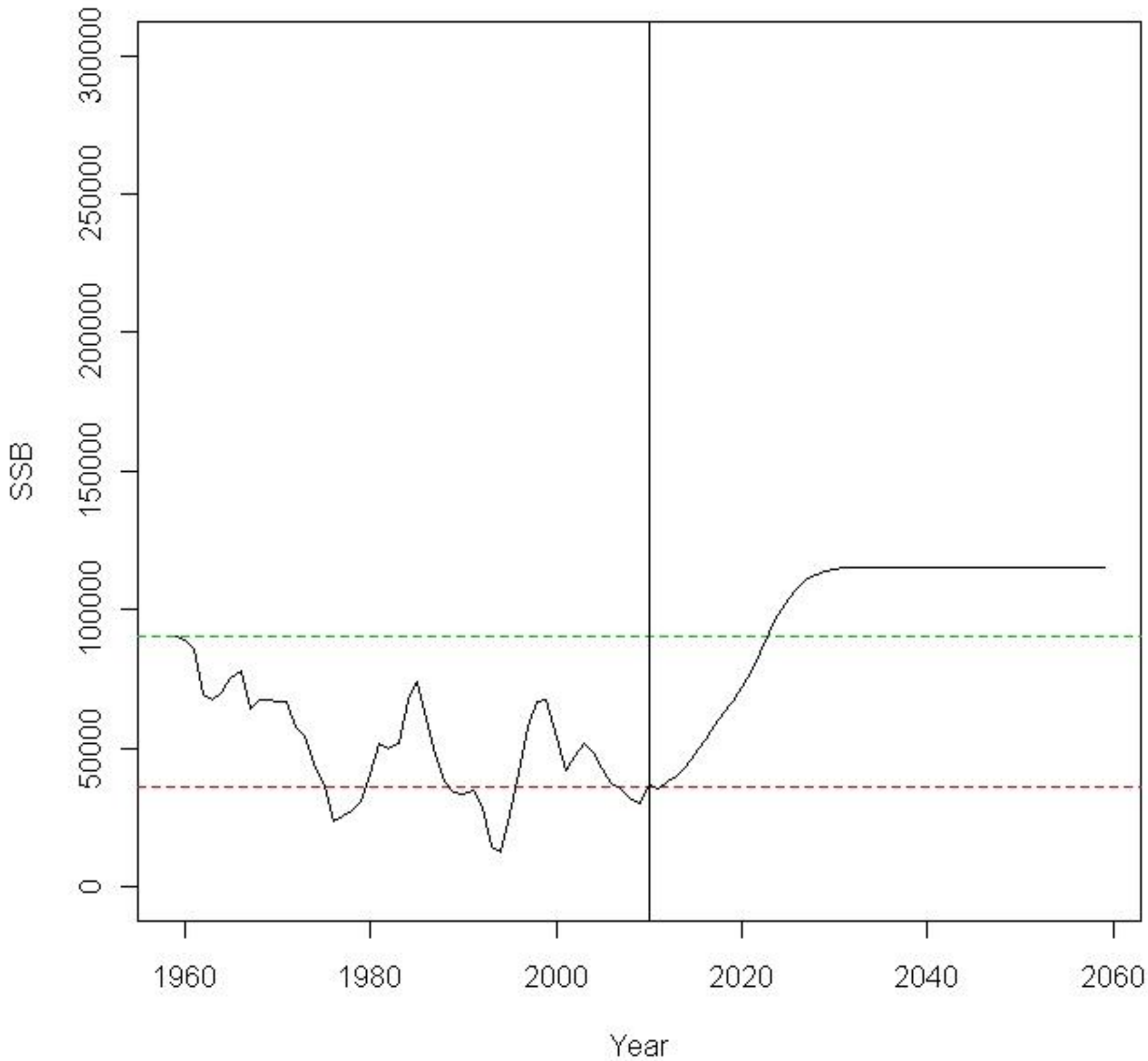

Figure 21. A 50 year projection of 3Ps cod SSB at the current F level (0.286).

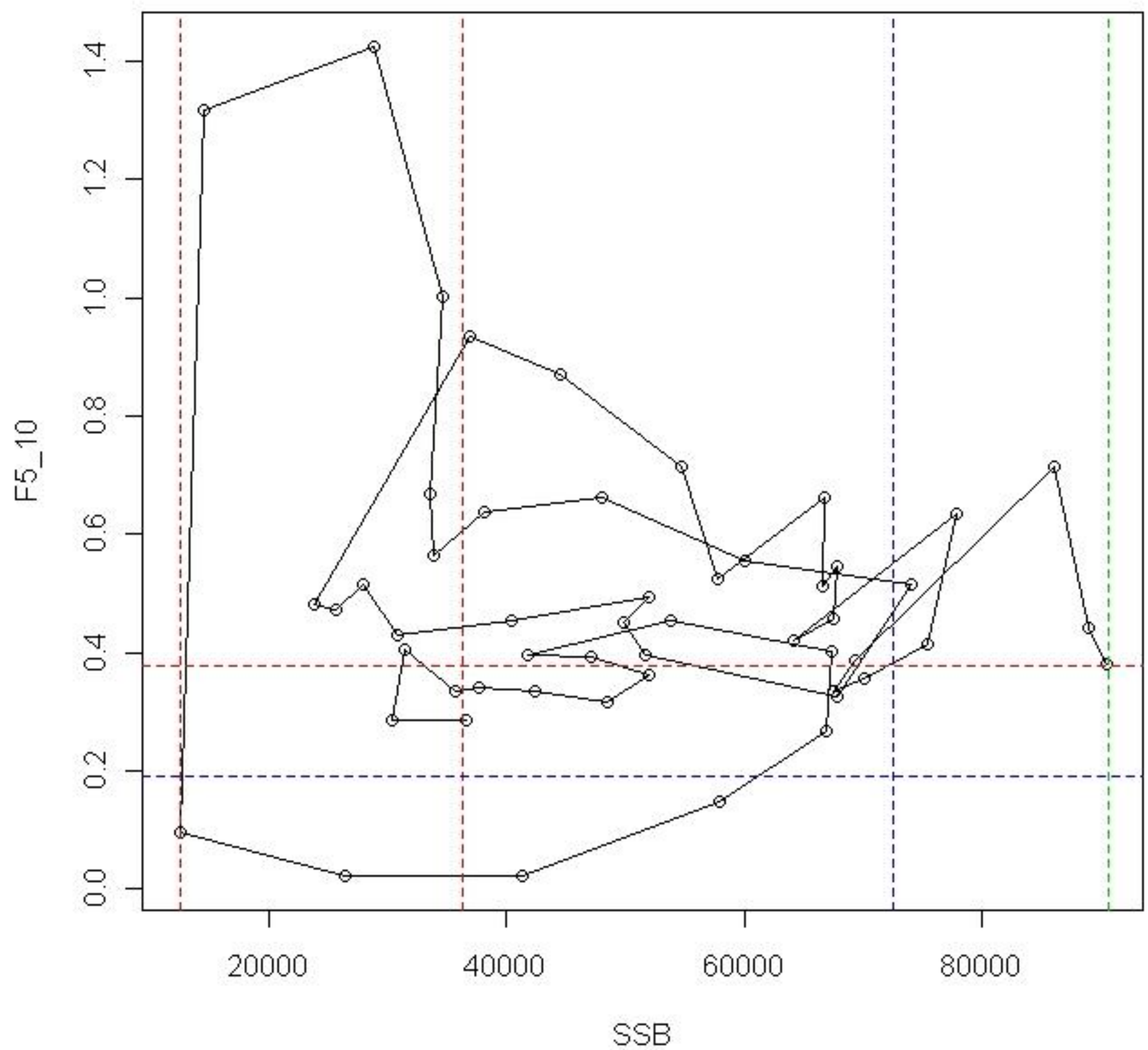

Fig. 22. Trajectory of fishing mortality against spawning stock biomass from the VPA estimates.

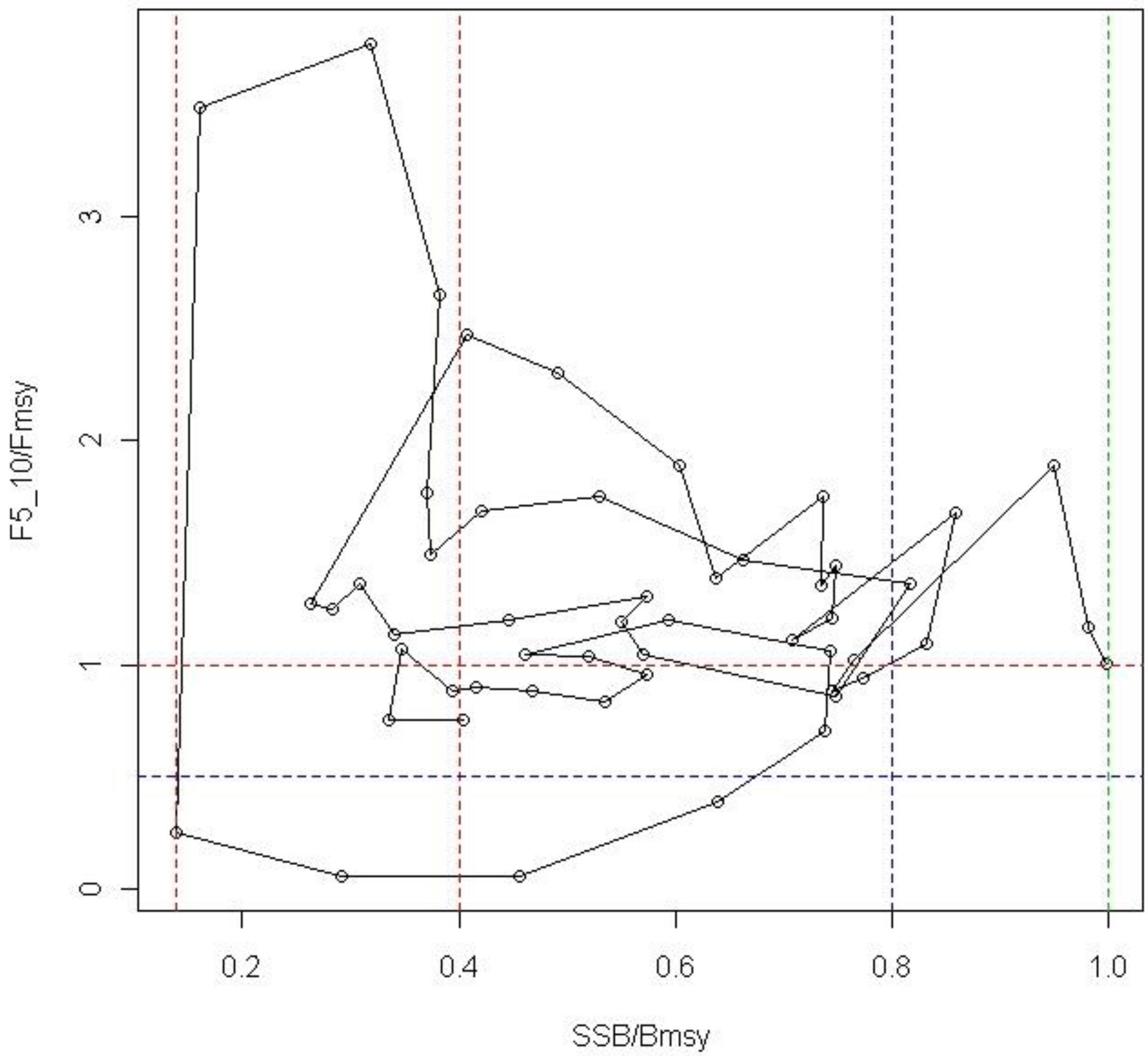

Fig. 23. Trajectory of F/Fmsy against SSB/SSBmsy from the VPA estimates.

APPENDIX 1. R-code for computing biological reference points for 3Ps cod.

```
#3Ps cod  SR and Biol Refs
#Set up to do multiple runs incrementing F to find Fmsy and Bmsy
#No plus group in 3Ps cod, age at recruitment is 2
#PR method is to calculated the PR in each year, take the average, and then rescale
the vector to have a maximum of 1
#Aug_2011

rm(list=ls(all=T))              #will remove all objects from R-Workspace
setwd("C:/Documents and Settings/sheltonp/My Documents/Work/Stock
Assessments/3Ps cod/Assessment 2011/Ref points")


#DATA
SRdata<-read.table("3Ps_cod_sr.txt", header=T, nrows = 50, colClasses = "numeric",
comment.char = "")
projparm<-t(as.matrix(read.table("proj_parm_3Ps_cod.txt", header=T, nrows=15,
colClasses = "numeric", comment.char = "" )))


#sort by SSB
SRdata <- SRdata[order(SRdata$SSB) , ]

age<-projparm[1,]
pop<-projparm[2,]
sel<-projparm[3,]
catwt<-projparm[4,]
stkwt<-projparm[5,]
mat<-projparm[6,]

#Last year pop estimates from ADAPT is 2010 - need to provide age 1 and 2 nums for
this vector
#2010 age 2 from 2008
#2010 age 1 from 2009
# Historic SSB vector for 2008 to 2009 (rage years previous to current year) in order of
most recent first
HSSB<-c(30347, 31455)

MaxSSB<-max(SRdata$SSB)
MinSSB<-min(SRdata$SSB)

#Input projection parameters
m<-0.2
nages<-14
rage<-2
nyrs<-100
```

```
SSBlim<-12533 #SSB 1994
nruns<-1000
F<-(0-1/nruns)

#segmented regression parameters
#recruits age 2
alph<-0.864292
bet<-52199.420005
brkpt<-bet/alph
#sigma2<-3.753019e-01

#Set up some matrices
MSYREFS<-matrix(0,nruns,4)
PopAge<-matrix(0,nyrs,nages)
PopAge[1,]<-pop
CatchAge<-matrix(0,nyrs,nages)
SSB<-matrix(0,nyrs,1)
Catch<-matrix(0,nyrs,1)

#Fill recruits for ages 1-rage in first year from segreg allowing for M
for (a in 1:rage)
{
if (HSSB[a]<brkpt) PopAge[1,a]<-alph*HSSB[a]*exp(m*(rage-a)) else Pop[1,a]<-
bet*exp(m*(rage-a))
}

for (i in 1:nruns)
{

F<-F+1/nruns
MSYREFS[i,1]<-F

#do projection loops for years and ages
for (y in 1:(nyrs)){

for(a in 1:(nages)){

if(y<nyrs)
{
#project ages
if(a<nages){
PopAge[y+1,a+1]<-PopAge[y,a]*exp(-(m+(F*sel[a])))
propdie<-((1-exp(-(m+(F*sel[a])))))
CatchAge[y,a]<-PopAge[y,a]*propdie*(F*sel[a]/(m+F*sel[a]))
}

}#end loop for y<nyrs
```

```
if(y==nyrs){
#Catch at age for the last year
propdie<-((1-exp(-(m+(F*sel[a])))))
CatchAge[y,a]<-PopAge[y,a]*propdie*(F*sel[a]/(m+F*sel[a]))
}

}#end age loop

#store catch at age
Catch[y]<-sum(CatchAge[y,]*catwt)

#Do Stock-recruit
SSB[y]<-sum(PopAge[y,]*stkwt*mat)
if(y<nyrs){
if (SSB[y]<brkpt) PopAge[y+1,1]<-alph*SSB[y]*exp(m*(rage-1)) else PopAge[y+1, 1]<-
bet*exp(m*(rage-1))
}

}#end year loop


Year<-(1:nyrs)

MSYREFS[i,2]<-Catch[nyrs]
MSYREFS[i,3]<-SSB[nyrs]
MSYREFS[i,4]<-PopAge[nyrs,1]*exp(-(m*(rage-1))) #one year mortality to go from age
1 to age 2
}

#find Fmsy
msy<-max(MSYREFS[,2])
point<-which.max(MSYREFS[,2])
Fmsy<-MSYREFS[point,1]
SSBmsy<-MSYREFS[point,3]

#other refs
F0.1<-0.1897 # Recent average mean age 5-10
#F0.1<-0.20 # Long-term average
KSSB<-MSYREFS[1,3]
SSBcurr<-36653
Fcurr<-0.286  #average ages 5 to 10

plot.new()
Perc40Bmsy<-0.4*SSBmsy
plot(MSYREFS[,1],MSYREFS[,2],col=1,type="o", xlab="F", ylab="Yield")
abline(v=Fmsy, col=3, lty=2)
abline(v=F0.1 , col=1, lty=2)
abline(v=Fcurr , col=4, lty=2)
```

```
plot(MSYREFS[,3],MSYREFS[,2],col=1,type="o", xlab="SSB", ylab="Yield")
abline(v=SSBlim, col=2, lty=2)
abline(v=SSBmsy, col=3, lty=2)
abline(v=SSBcurr, col=4, lty=2)
abline(v=Perc40Bmsy, col=6, lty=2)


plot(MSYREFS[,3],MSYREFS[,4],col=1,type="l",
ylim=c(0,max(SRdata$R,MSYREFS[,4])), xlab="SSB", ylab="Rec age 2")
abline(v=SSBlim, col=2, lty=2)
abline(v=Perc40Bmsy, col=6, lty=2)
abline(v=SSBmsy, col=3, lty=2)
abline(v=SSBcurr, col=4, lty=2)
abline(v=KSSB, col=5, lty=2)
points(SRdata$SSB,SRdata$R)

BMSYtoK<-SSBmsy/KSSB
Perc40Bmsy<-0.4*SSBmsy
BlimtoK<-SSBlim/KSSB
SSBtoBmsy<-SSBcurr/SSBmsy
SSBtoBlim<-SSBcurr/SSBlim

Fmsy<-round(Fmsy, digits = 3)
SSBlim<-round(SSBlim, digits = 0)
SSBmsy<-round(SSBmsy, digits = 0)
KSSB<-round(KSSB, digits = 0)
BMSYtoK<-round(BMSYtoK, digits = 3)
Perc40Bmsy<-round(Perc40Bmsy, digits = 3)
BlimtoK<-round(BlimtoK, digits = 3)
SSBtoBmsy<-round(SSBtoBmsy, digits = 3)
SSBtoBlim<-round(SSBtoBlim, digits = 3)
msy<-round(msy, digits = 3)

out<-data.frame(F0.1, Fmsy, SSBlim, SSBmsy, KSSB, BMSYtoK, Perc40Bmsy,
BlimtoK, SSBtoBmsy, SSBtoBlim, msy)
#write stock-recruit data to file
write.table(out, file = "3ps_cod_msy_refs.txt", append = FALSE, quote = FALSE, sep = "
",
         eol = "\n", na = "NA", dec = ".", row.names = FALSE,
         col.names = TRUE, qmethod = c("escape", "double"))
```