PRECISION IN RECRUITMENT ESTIMATES AND ITS IMPLICATIONS FOR MANAGEMENT OF DEMERSAL FISH STOCKS

by

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ABSTRACT

Errors in abundance indices of recruiting year-classes will affect stock predictions. The contribution of recruiting year-classes to the predictions of catch and spawning stock biomass for the stocks of Northeast Arctic cod, haddock and saithe is investigated. The effect various levels of error in the recruitment indices would have had on the predictions during the last two decades is calculated. The error in the index has frequently gone in the same direction for consecutive year-classes and errors of less than 30% have been relatively rare. Longer time series and new methodology will probably reduce the errors in the future, but substantial errors in the stock predictions must therefore be anticipated, even in the short term. Management aimed at moderate exploitation and stability can minimize the problem and the use of risk-analyses is desirable. Medium-term predictions rely to a large extent on assumptions of average recruitment and must be used with great caution.

INTRODUCTION

In age-based stock assessments, one age has to be given as the age of first recruitment to the fishery. This will then be the reference age for recruitment. However, for long-lived species recruitment to the fishery usually is a gradual process, extending over more than one year. Which age of recruitment is used for a given stock is to some extent a subjective choice. Thus, in some cases there may be some individuals caught before the age defined as the recruiting age, in other cases the catches at the age of recruitment are too small to be of any significance.

Estimates of abundance of the year-classes recruiting to the fishery are necessary inputs to predictions of catch and stock biomass. In the predictions recruiting year-classes can be defined as those year-classes where the abundance estimates are not based on any information from the commercial catches. While the abundance of the year-classes in the VPA (virtual population analysis) is estimated by combining information from research vessel surveys and commercial catches, the methods for estimating abundance of the recruiting year-classes rely

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only on surveys. It is, however, not unusual in predictions that abundance indices are not available for one or more of the recruiting year-classes. When no index of abundance exists, some historical mean level (recent or long-term, arithmetic or geometric) of year-class strength is used.

Even in the cases where survey indices are available, some error in the recruitment estimate must be expected. Such errors are not necessarily only measurement errors, but may also be the result of variable mortality between year-classes in the time interval between establishing a survey index and the recruitment to the fishery. The resulting error in the predictions will be dependent on the catch and biomass of the recruiting year-classes relative to the total catch and stock biomass, which again is dependent on growth, mortality, exploitation pattern and variation in recruitment. The error is potentially largest for short-lived, heavily exploited stocks with high variation in recruitment. However, a lot will still depend on the precision of the abundance estimates.

The present paper deals with the stocks of Northeast Arctic cod, haddock and saithe and examines the potential for errors caused by lack of precision in the recruitment estimates. The three species are all relatively long-lived, but with a different degree of variation in recruitment. The exploitation has historically been mostly above a sustainable level (Anon. 1994, Jakobsen 1992).

Short-term projections are used as basis for setting the TAC (total allowable catch). The normal procedure in the biological advice given by ICES is to present to the managers tables giving a number of options for the catch in the year for which the TAC is to be decided and the corresponding spawning stock biomass the year after, while predictions for the total biomass are ignored.

In some cases, medium-term projections are also considered, as basis for decisions on management strategies covering longer periods than one year.

MATERIALS AND METHODS

For Northeast Arctic cod and haddock, age at first recruitment is defined as 3 years. Catches at age 2 occur, but contribute only a negligible part of the total. In these stocks a number of abundance indices are available for ages 0-3 years from both Norwegian and Russian surveys. Practice for accepting or rejecting the results of the VPA on the youngest year-classes has varied, but in the present exercise the current practice of taking estimates for age 4 and older from the VPA is assumed. The year for which a TAC is to be decided upon is normally two years after the last year included in the VPA. This means that in the catch predictions for the TAC, the number of individuals at age 3-5 in the TAC year will be based on the recruitment indices and it is the effect of the error on these age groups which is examined.

For the Northeast Arctic saithe the age at first recruitment is set to 1, although catches at age 1 are negligible. There are survey estimates available for both age 2 and 3, but the time series is short and there is still uncertainty about the precision of the estimates (Anon. 1994). Although VPA estimates of abundance at age 3 have normally been used in the predictions, recent examination of the data indicates that this may not be appropiate. For this exercise it was therefore chosen, as for cod and haddock, to consider the ages up to 5 in the TAC year as being based on recruitment estimates.

The standard predictions used as basis for management decisions represent the starting point for the present exercise. All the data are taken from the ICES Report of the Arctic Fisheries Working Group (Anon. 1994).

To examine the potential for error in predictions caused by errors in the recruitment estimates, the contribution by weight of these age groups to the total catch and spawning stock biomass in the last two decades was calculated. Both short-term (2 years ahead) and medium-term (6 years ahead) predictions were considered. For cod and haddock the relevant ages are 3-5 and 3-9 in the catches for short-term and medium-term, respectively, and correspondingly the ages 3-6 and 3-10 for the spawning stock biomass. For saithe the ages 1 and 2 are also included, although age 1 can be ignored for all practical purposes.

In the simulations, the most recent estimates of historical year-class strength (Anon. 1994) are assumed to represent actual recruitment. The potential error in prediction from recruitment indices is dependent on the fishing mortality, which for all three stocks has been considerably reduced in recent years. Therefore, to simulate a pattern of errors representing the present exploitation rate, a fishing mortality of 0.4 throughout and prior to the period examined has been assumed. The exploitation patterns, weights at age and maturity ogives are taken from the most recent predictions (Anon. 1994). When average recruitment has to be assumed, the long-term arithmetic mean is used. The label "true" on the y-axis in the figures refers to the values that would have been obtained in the predictions using the recruitment figures from the most recent VPA.

In order to find appropriate levels of errors to use in the simulations, the recruitment estimates for the year-classes 1976-1988 were compared with the final VPA estimates (Table 1). The deviations are given in both relative and absolute terms. Starting with the 0-group, there are four estimates in consecutive years. In some cases, especially the early estimates for saithe year-classes, an average recruitment figure has been used.

It is evident that the relative error can be very large for cod and haddock. However, the extremes are linked to small year-classes and are not so dramatic in absolute terms.
Also, some of the largest errors for cod occurred in the mid-1980s when the capelin stock collapsed and abundant year-classes were rapidly reduced during the first couple of years by cannibalism (Bogstad *et al.* 1994) and possibly other mortality. Nevertheless, the errors on cod and haddock have been substantial also in more normal circumstances. The errors on the saithe have been less extreme, which reflects the use of average recruitment as estimates and a relatively small variation in the recruitment level for this stock.

It is difficult from this table to infer what can be expected in terms of errors in recruitment estimates in the furture. If the mid-1980s are considered as abnormal and ignoring the errors on the smallest year-classes, errors up to 50-60% are still quite frequent. Furthermore, errors of less than about 30% are rare. As basis for the simulations of predictions over the last 20 years, it was therefore chosen to use 30% and 60% error, up or down.

A closer examination of Table 1 reveals that there is a tendency, at least for cod and haddock, to either over- or underestimate all recruiting year-classes in a given assessment. Thus, in the simulations all recruiting year-classes are assumed to be over- or underestimated by the same percentage.

RESULTS

Each of the figures comprise the results for cod, haddock and saithe. Figure 1 shows the contribution of ages up to 5 in the historical catches, corresponding to the recruiting year-classes in short-term predictions. For all three species the contribution has been substantial in some years. For cod it has varied from 4% to 76%, and for haddock from 11% to 97%. For saithe the contribution has been more stable, from 40% to 80%.

Figure 2 shows the corresponding contribution, of ages up to 6, to the spawning stock biomass. The pattern for haddock is slightly less variable, ranging from 13% to 90%, but otherwise similar to that of the catch. The contribution to the cod stock is also variable but generally smaller, from 4% to 46%. For the saithe, with assumed knife-edge maturity at age 6, the level was fairly stable at about 20% for a long period, but has increased considerably in more recent years, with a maximum value of 78%.

Figures 3 and 4 show the contribution of the recruiting year-classes corresponding to a medium-term prediction, i.e. ages up to 9 in the catch and ages up to 10 in the spawning stock. The contributions are very large, mostly in the range 80-100%. The exception is the earliest period for the cod where the contribution both to catch and spawning stock was considerably smaller.

Figures 5-8 and Figures 9-12 show the results of the simulations in relative and absolute terms, respectively. In the short-term predictions of catch and spawning biomass (Figures 5, 6, 9, 10), the effect of simulating over- and underestimates of recruitment by the same percentage is to create a symmetrical pattern for cod and haddock, but not for saithe. This difference is caused by the use of average recruitment for the youngest age groups of saithe.

The effect of using average recruitment is clearly pronounced in the medium-term predictions (Figures 7,8,11,12). In the long periods of poor recruitment in recent years the use of average recruitment in the predictions leads to large overestimates of both catch and spawning stock.

Figure 5 shows errors in the catch predictions of up to 29% for cod, 57% for haddock and nearly 47% for saithe. In absolute terms, maximum errors are 344,000 t for cod, 77,000 t for haddock and 62,000 t for saithe (Figure 9).

The errors in relative terms in the predictions of spawning stock biomass of haddock and saithe are of a similar magnitude as in the catch predictions, but for cod the errors are smaller, not exceeding 20% (Figure 6), and this is reflected also in the absolute errors (Figure 10).

The discrepancy between the observed recruitment and the long-term average creates most of the errors in the medium-term predictions (Figures 7,8,11,12) and the tendency to periodicity in the recruitment is clearly illustrated. The figures also reflect the fact that recruitment in this period has been mostly below average.

In relative terms the medium-term prediction error is in some cases very large for haddock, with both catch and spawning stock biomass predictions at more than 4 times the "true" level in the most extreme year.

The relative error is large also for cod where future catch is overestimated by up to 100% and spawning stock biomass by a slightly lower percentage.

The error in spawning stock biomass of saithe exceeds 100% in one year, more than twice the maximum error in catch prediction.

In absolute terms, the maximum errors in medium-term catch and spawning biomass predictions, respectively, are: Cod 471,000 t and 645,000 t; haddock 135,000 t and 185,000 t; saithe 58,000 t and 96,000 t.

Figure 13 shows how the average error from recruitment indices in short-term catch predictions depends on the fishing mortality. Thus, reduction of fishing mortality from historical high levels of exploitaion, (about 1.0 for cod, 0.9 for haddock and 0.7 for saithe) to current levels at about 0.4, reduces the average error to approximately half. The effect on short-term predictions of spawning stock biomass is similar. Errors in medium-term predictions, however, are less dependent on the fishing mortality.

DISCUSSION

There are substantial errors in the recruitment estimates used in the assessment. These are large enough to cause considerable errors in short-term predictions of catch and spawning stock. Recruitment indices from surveys are of little importance to medium-term predictions where the crucial factor is the actual level of recruitment compared to the historical mean level assumed for year-classes not born or measured.

The errors in the recruitment estimates for cod and haddock reflects to some extent measurement errors in the surveys. However, the abnormal development of some year-classes in the mid-1980's and a relatively short time series of survey data create at present problems in the estimation of recruitment figures from the survey indices. During more stable periods and with a longer time series the recruitment estimates should be more reliable. Nevertheless, there are few indications that it will be possible in the near future to restrict potential errors to less than about 50% on abundant and average year-classes. For poor year-classes, the likelihood of large relative errors is higher.

The severity of errors in the recruitment estimates are worsened by the tendency to go in the same direction for all the recruiting year-classes. What causes this tendency is not clear, but it may be due to periodical variation in natural mortality and in catchability and area coverage of the surveys.

Because of the large variation in the errors in earlier estimates, improved data series and development of new methodology, it is difficult to assess what errors in predictions should be expected in the future. In short-term predictions, it must probably be expected that errors in the catch and spawning stock corresponding to 30% error in all the survey indices will occur relatively often. This would mean that errors in the catch predictions of 10-15% for cod and 20-30% for haddock and saithe should be considered as "normal". In absolute terms, this translates into errors of up to 100,000 t for cod and 40,000 t for haddock and saithe. The errors on the spawning stock will be of a similar magnitude.

Medium-term predictions are mostly based only on the assumption of some sort of average recruitment. Thus, the error will depend largely on how much the actual recruitment deviates from the average. The tendency for periodicity in the recruitment considerably increases the potential for errors in the predictions. For all three stocks, recruitment in the period simulated comprise the worst periods of bad recruitment on record. The maximum errors shown in the figures therefore demonstrate how large overestimates can be expected in periods of very poor recruitment. However, the distribution of year-class size is not symmetrical and in periods of very good recruitment deviation from the average level can be larger. This would create errors, in the form of underestimates, which are higher than the errors shown in the figures.

Because of the periodical variation in recruitment it is not very meaningful to define some "normal" error in the medium-term predictions. The large potential error in these predictions shows that one must be extremely cautious to use them as basis for management decisions.

The recruitment indices is not the only source of error in catch and stock predictions. The total stock and its age structure, growth and (for the spawning stock) sexual maturation, are some of the factors which may cause errors in the predictions. These errors may add to the errors in recruitment or they may tend to cancel them. Which source of error is most important in a given assessment varies, but in recent years recruitment and growth have been the most problematic factors in the predictions.

The large potential errors caused by recruitment alone might indicate that the reliability of the predictions is too poor to be used as basis for setting a TAC. Clearly, it is not possible to keep the exploitation rate at an exactly fixed level, but this is not necessarily desirable. All three species are relatively long-lived, which means that there is some time to correct for errors before they produce significant losses in long-term yield. Furthermore, good management can minimize the effect of the errors by aiming at low exploitation and stability in yield, where the first is a necessity in order to achieve the other. As shown in Figure 13, this will also limit the prediction error caused by the recruitment indices.

In view of the uncertainties, management based on risk analyses would be desirable, and if medium-term predictions are considered, necessary. Such analyses will usually define the risk of something "bad" happening to the stock, e.g. that the spawning stock falls below a certain level. Risk analyses are developed and available for use. They require, however, knowledge about the likely distribution of error on the varios parameters in the predictions, and there is need for a careful examination of historical data and assessments to decide on the input to the models.

Medium-term predictions have at present limited value as basis for management decisions. However, there is scope for improvement if better models for environmantal influence on the recruitment can be developed and predictions of changes in the environment can be improved. Ongoing development of multispecies interaction models will also gradually improve these projections.

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Table 1. Year class strength from VPA compared with recruitment estimates

NORTHEAST ARCTIC COD

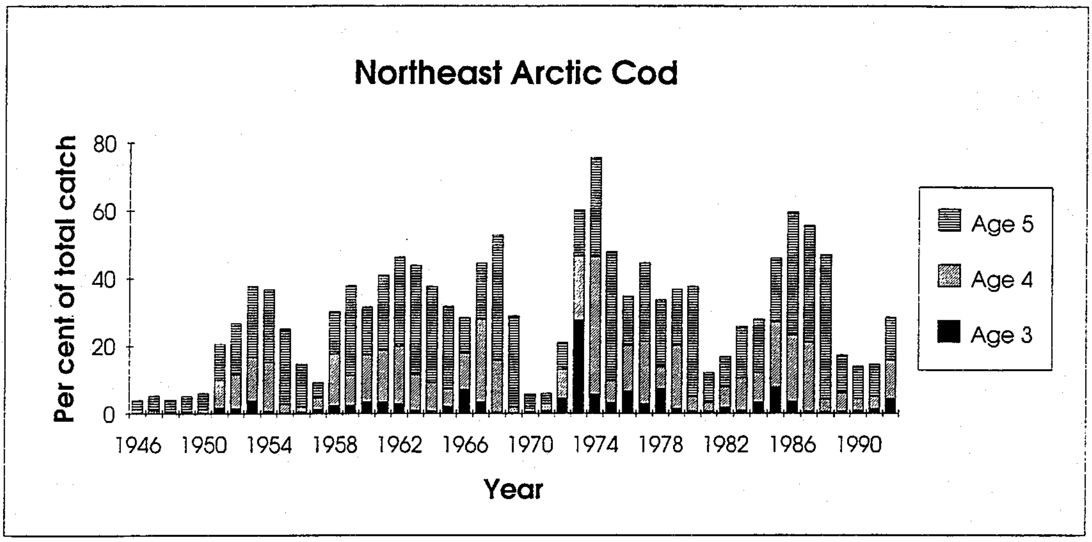
year-	vpa	recruitment estimates				relative error				absolute error (mill.)			
class	age 3	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1976	201				325				1.62				124
1977	142			195	81			1.37	0.57			53	-61
1978	160		100	100	257		0.63	0.63	1.61		-60	-60	97
1979	159	100	100	191	108	0.63	0.63	1.20	0.68	-59	-59	32	-51
1980	171	100	100	30	69	0.58	0.58	0.18	0.40	-71	-71	-141	-102
1981	398	100	30	66	144	0.25	0.08	0.17	0.36	-298	-368	-332	-254
1982	499	400	400	800	678	0.80	0.80	1.60	1.36	-99	-99	301	179
1983	952	1500	1500	1500	1000	1.58	1.58	1.58	1.05	548	548	548	48
1984	288	1600	800	430	443	5.56	2.78	1.49	1.54	1312	512	142	155
1985	243	1100	346	384	136	4.53	1.42	1.58	0.56	857	103	141	-107
1986	159	391	258	199	175	2.46	1.62	1.25	1.10	232	99	40	16
1987	162	186	171	146	136	1.15	1.06	0.90	0.84	24	9	-16	-26
1988	363	222	184	240	227	0.61	0.51	0.66	0.63	-141	-179	-123	-136

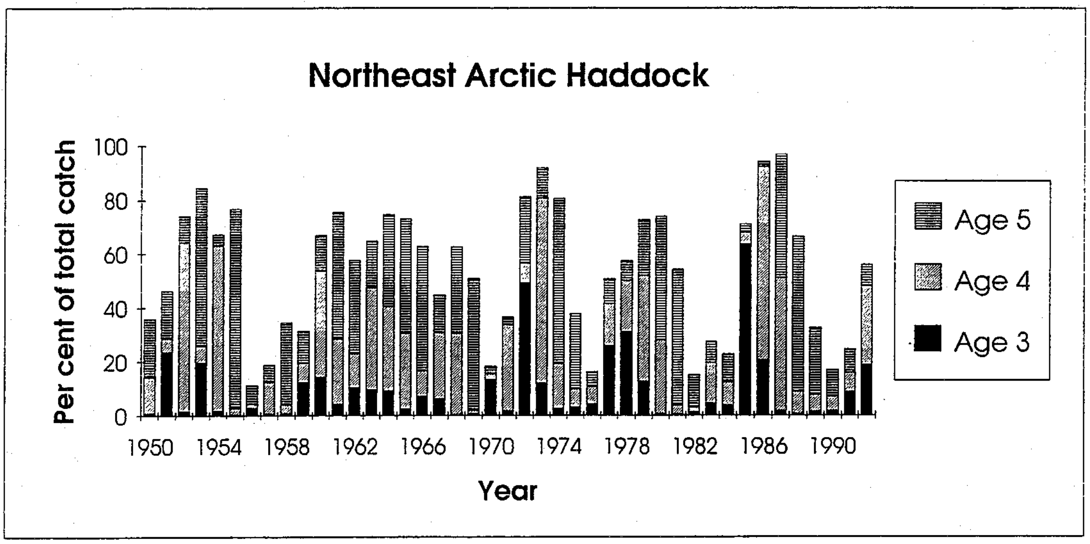
NORTHEAST ARCTIC HADDOCK

year-	vpa	recruitment estimates				relative error				absolute error (mill.)			
class	age 3	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1976	135				225				1.67				90
1977	19			50	50			2.63	2.63			31	31
1978	6		50	50	21		8.93	8.93	3.75		44	44	15
1979	8	50	50	55	18	6.25	6.25	6.88	2.25	42	42	47	10
1980	5	50	50	14	21	10.87	10.87	3.04	4.57	45	45	9	16
1981	8	50	20	23	10	5.95	2.38	2.74	1.19	42	12	15	2
1982	257	165	200	300	424	0.64	0.78	1.17	1.65	-92	-57	43	167
1983	333	300	400	700	591	0.90	1.20	2.10	1.77	-33	67	367	258
1984	82	75	200	162	140	0.91	2.44	1.98	1.71	-7	118	80	58
1985	28	100	31	25	32	3.57	1.11	0.89	1.14	72	3	-3	4
1986	13	30	14	14	11	2.31	1.08	1.08	0.85	17	1	1	-2
1987	18	8	9	9	10	0.42	0.50	0.47	0.54	-11	-9	-10	-8
1988	72	10	25	30	130	0.14	0.35	0.42	1.81	-62	-47	-42	58

NORTHEAST ARCTIC SAITHE

year-	vpa	recruitment estimates				relative error				absolute error (mill.)			
class	age 1	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1976	346				342				0.99				-4
1977	207			342	184			1.65	0.89			135	-23
1978	436		342	334	327		0.78	0.77	0.75		-94	-102	-109
1979	187	342	334	183	151	1.83	1.79	0.98	0.81	155	147	-4	-36
1980	171	334	332	229	113	1.95	1.94	1.34	0.66	163	161	58	-58
1981	145	332	337	133	144	2.29	2.32	0.92	0.99	187	192	-12	-1
1982	169	337	318	170	332	1.99	1.88	1.01	1.96	168	149	1	163
1983	327	318	200	190	139	0.97	0.61	0.58	0.43	-9	-127	-137	-188
1984	245	200	200	200	158	0.82	0.82	0.82	0.64	-45	-45	-45	-87
1985	119	200	200	270	99	1.68	1.68	2.27	0.83	81	81	151	-20
1986	105	200	270	161	174	1.90	2.57	1.53	1.66	95	165	56	69
1987	123	270	200	200	273	2.20	1.63	1.63	2.22	147	77	77	150
1988	358	200	200	200	460	0.56	0.56	0.56	1.28	-158	-158	-158	102





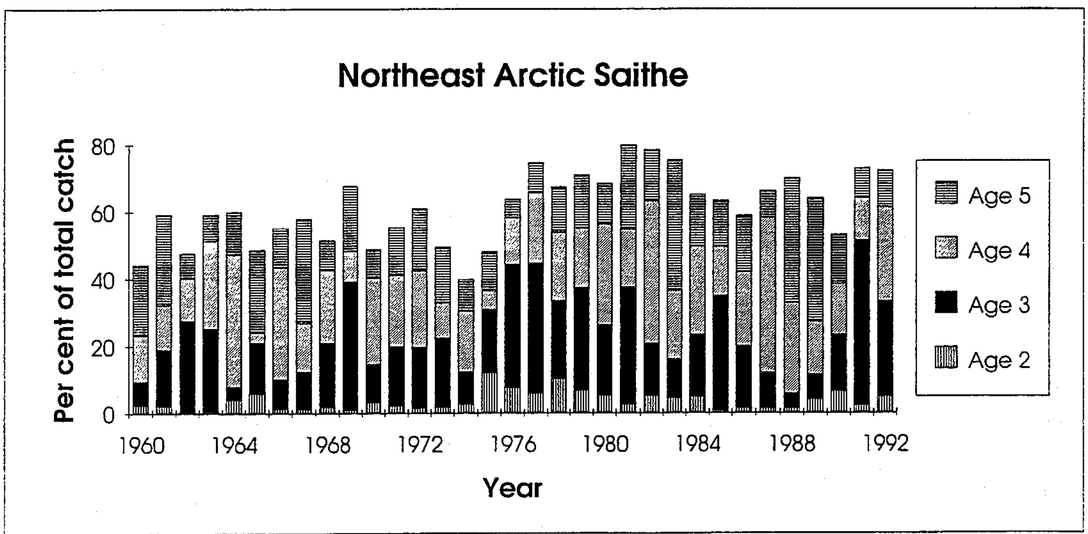


Figure 1. Contribution (%) to the catch (in weight) of the age groups 3-5 of cod and haddock and 2-5 of saithe.

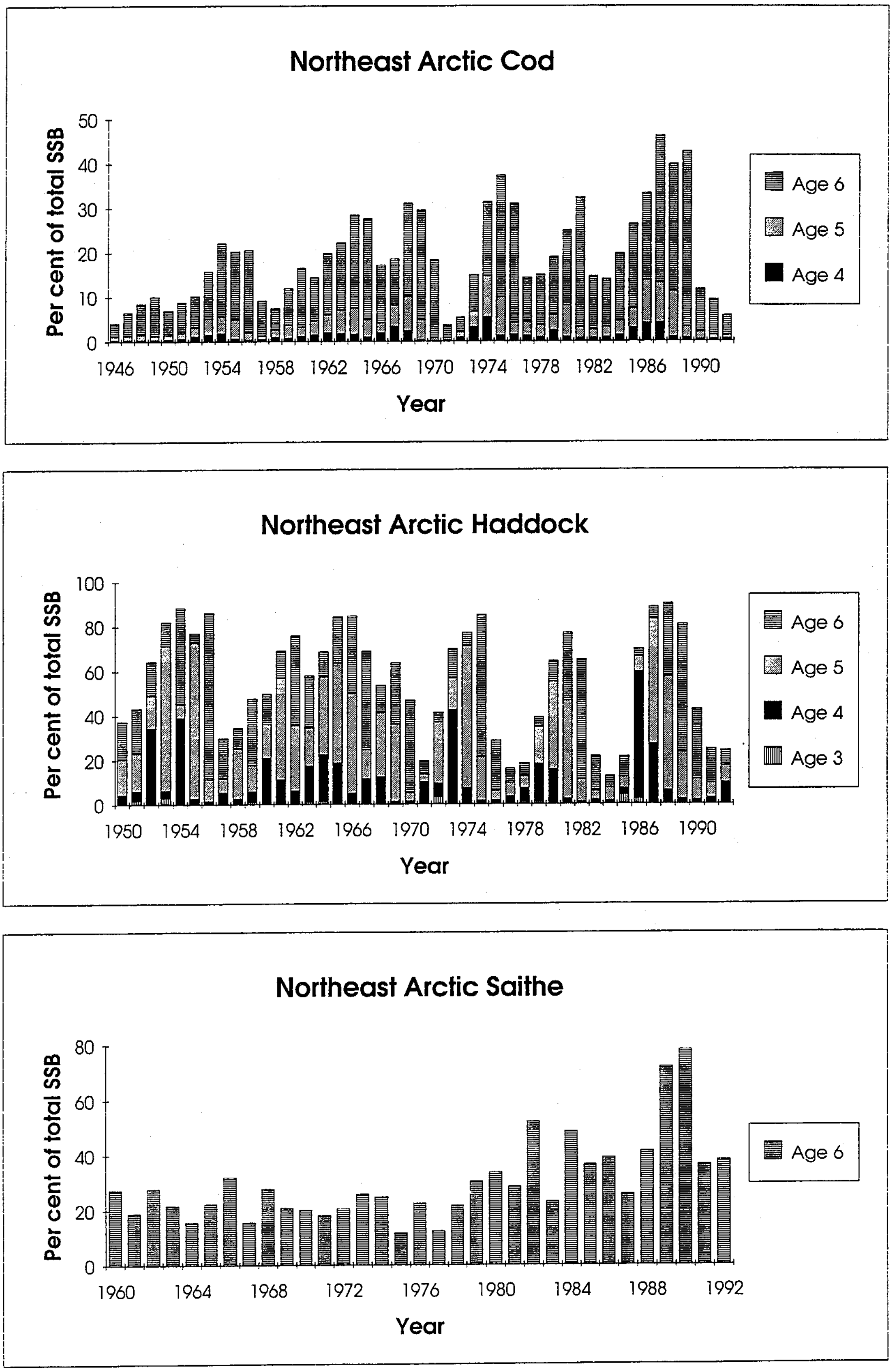


Figure 2. Contribution to the spawning stock biomass of the age groups 4-6 of cod, 3-6 of haddock and 6 of saithe.

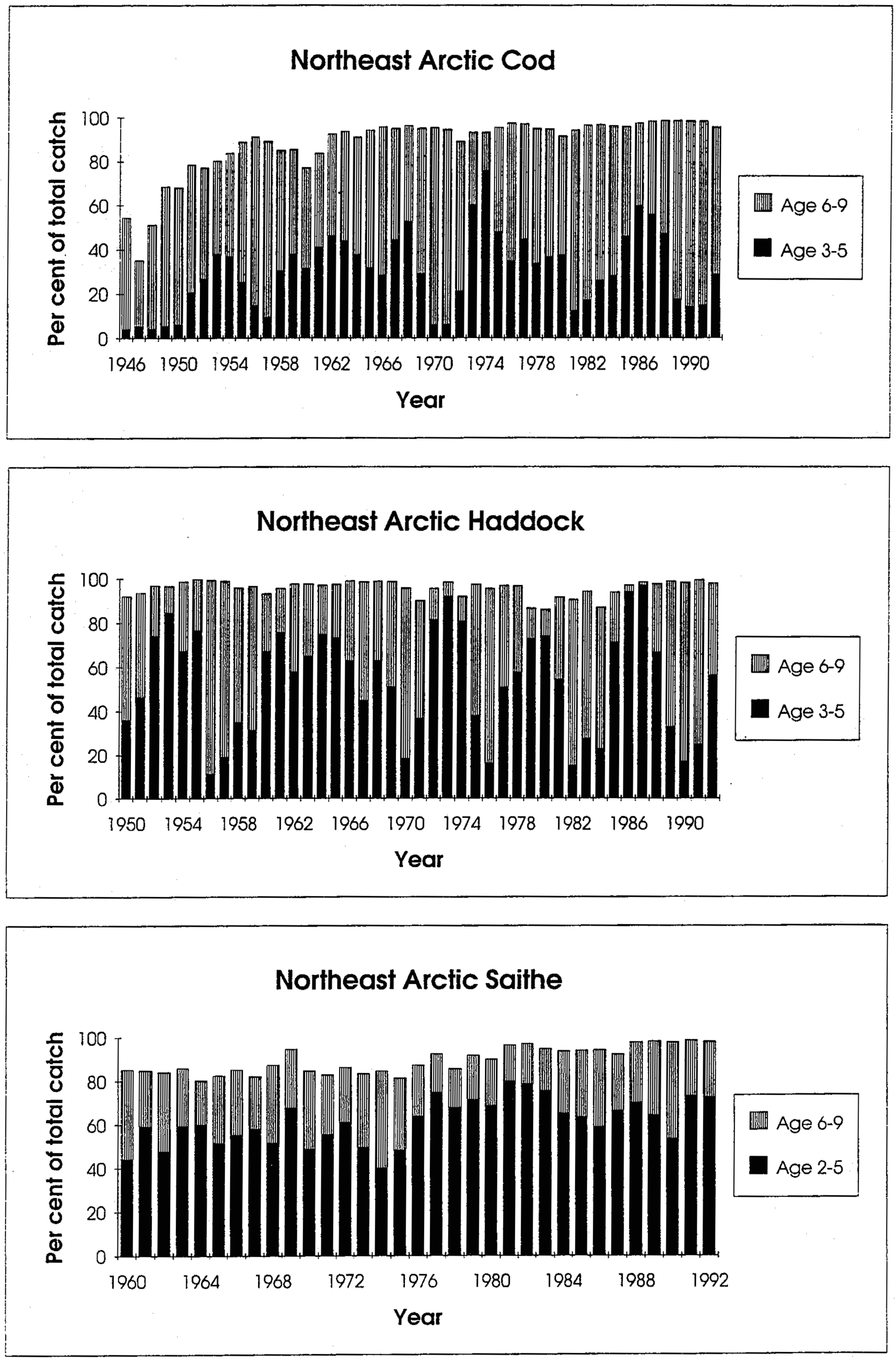


Figure 3. Contribution (%) to the catch (in weight) of the age groups 2-5 and 6-9 of coc and haddock and 2-5 and 6-9 of saithe.

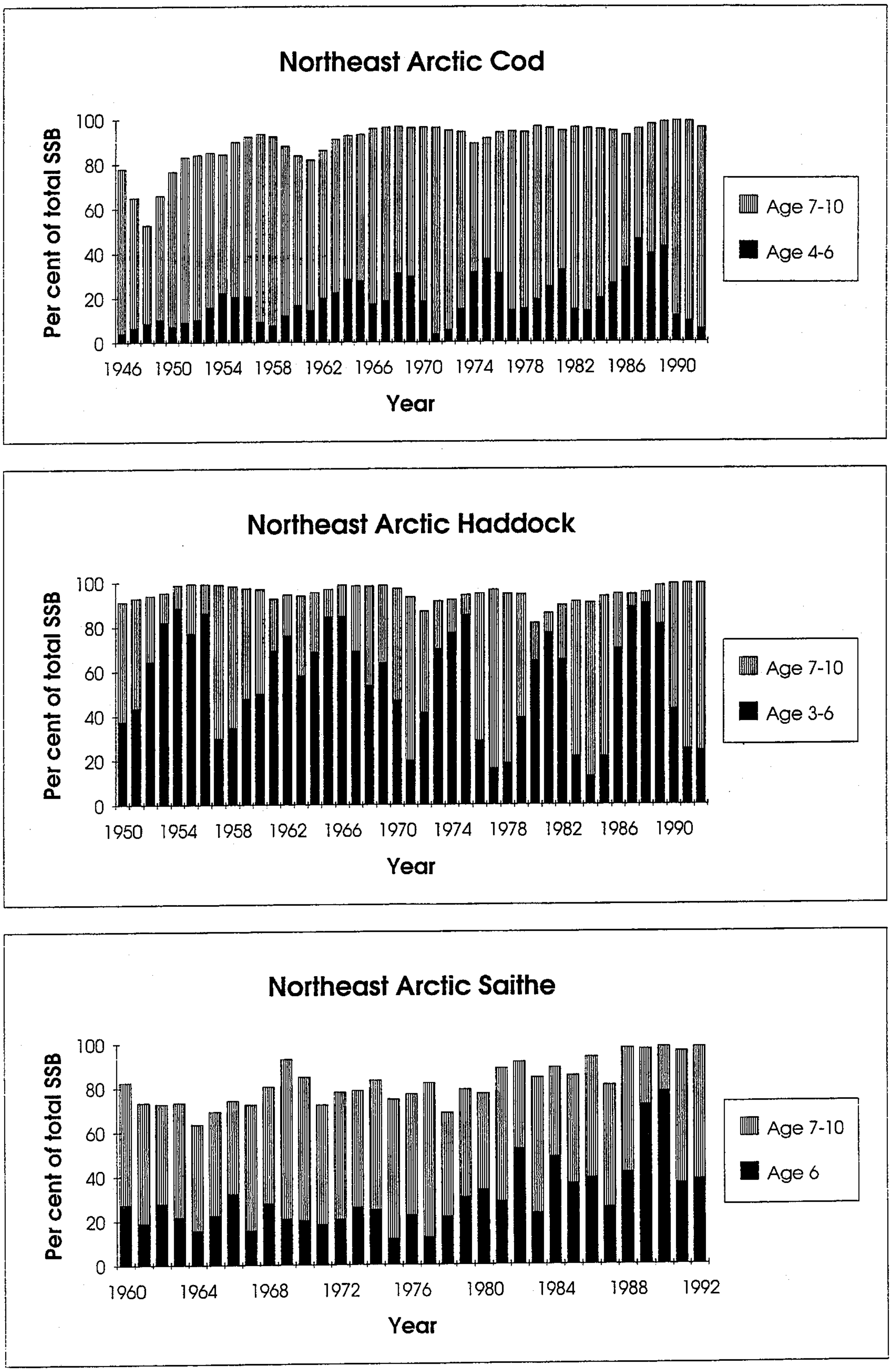


Figure 4. Contribution to the spawning stock biomass of the age groups 4-6 and 7-10 of cod, 3-6 and 7-10 of haddock and 6 and 7-10 of saithe.

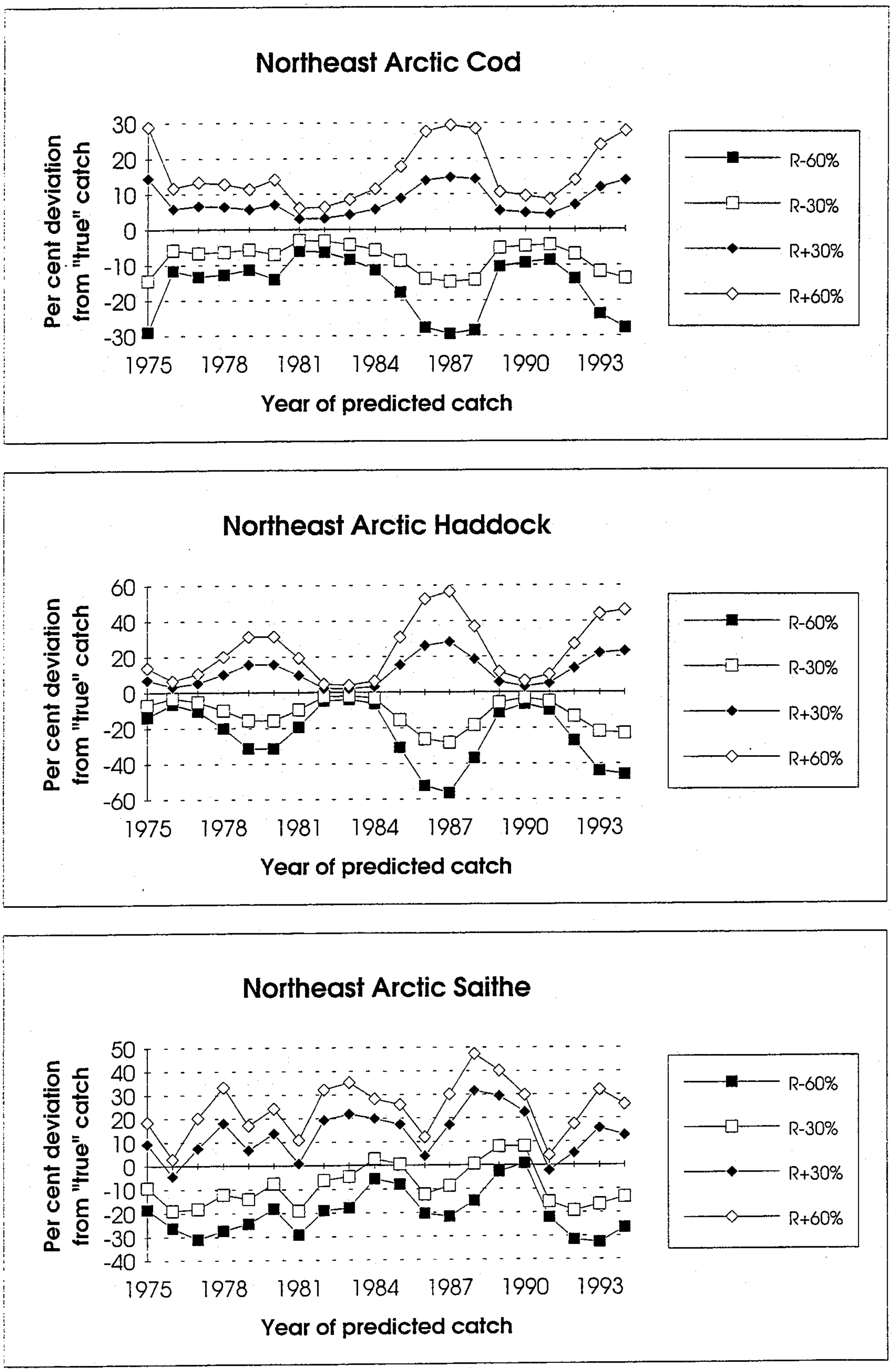
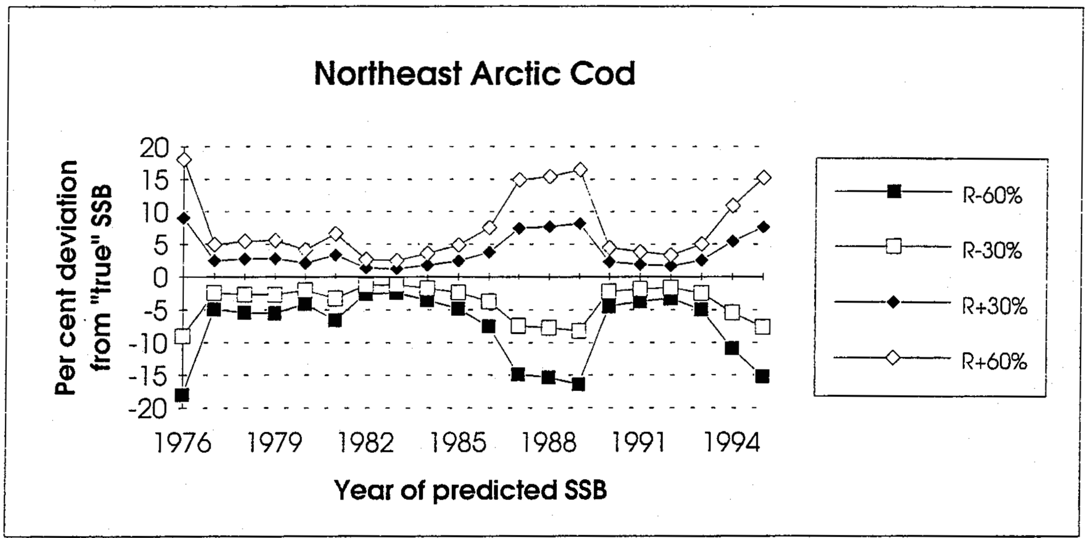
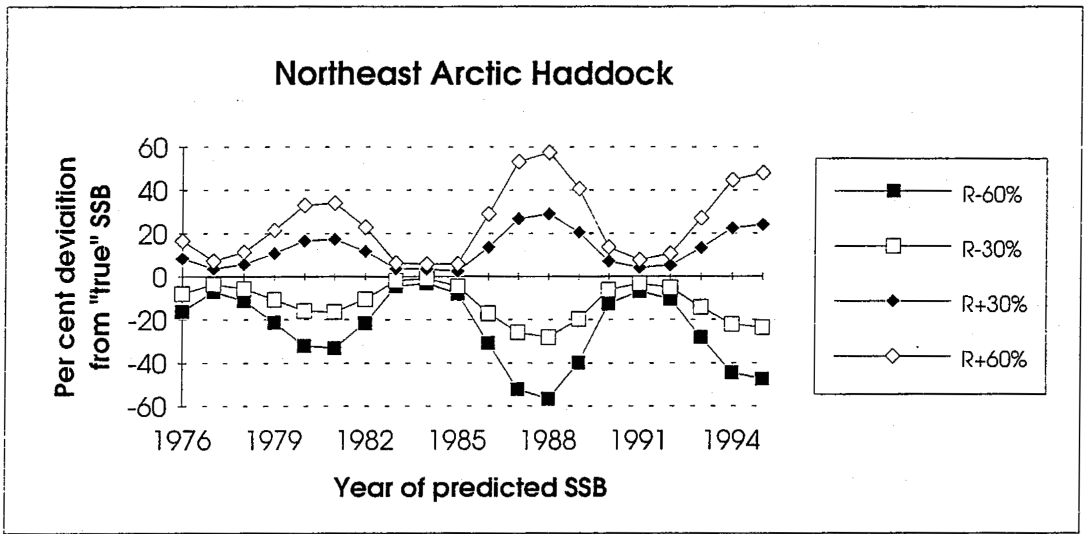


Figure 5. Per cent deviation over the last 20 years in short-term prediction of catch (in TAC year) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





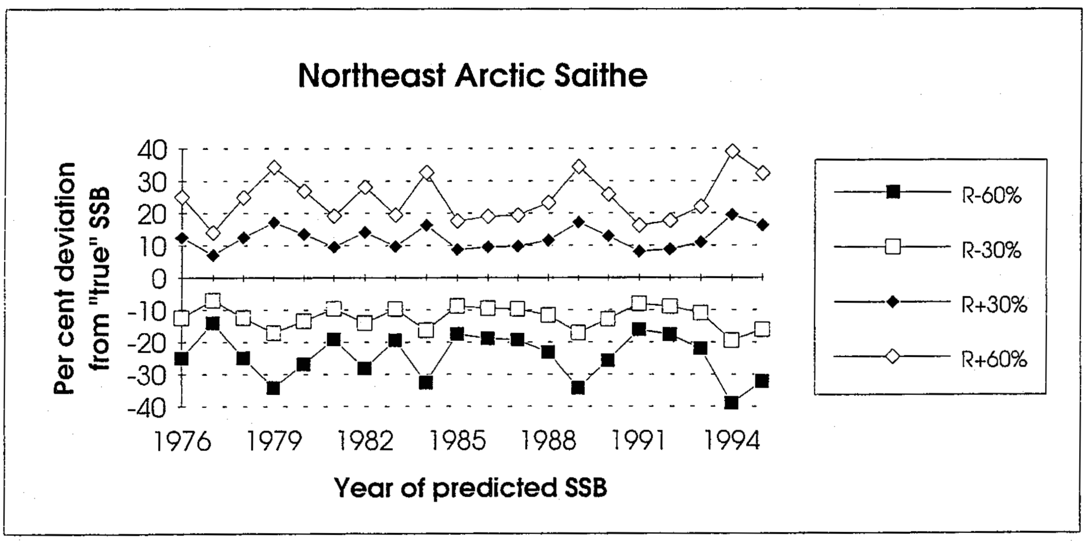
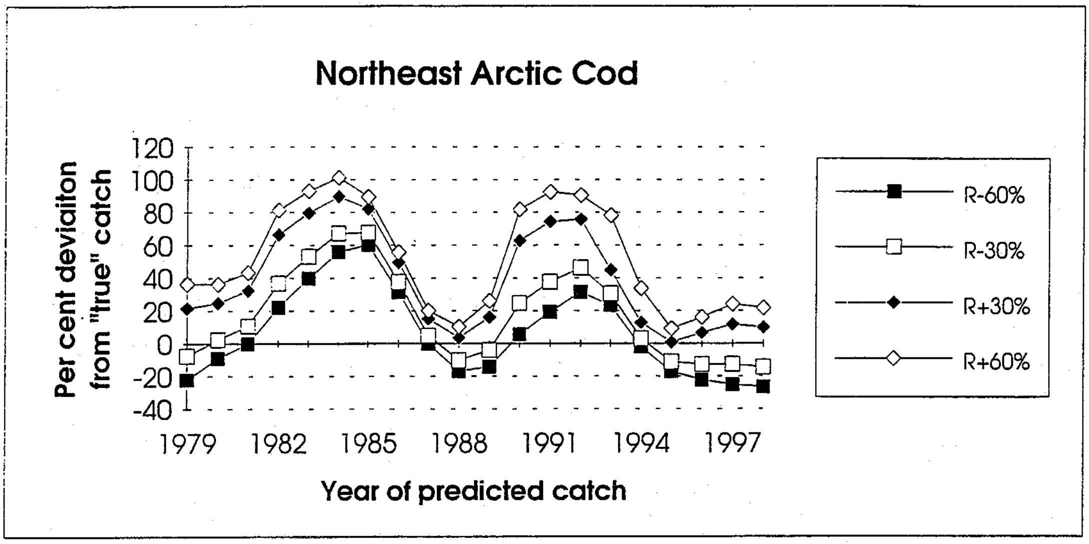
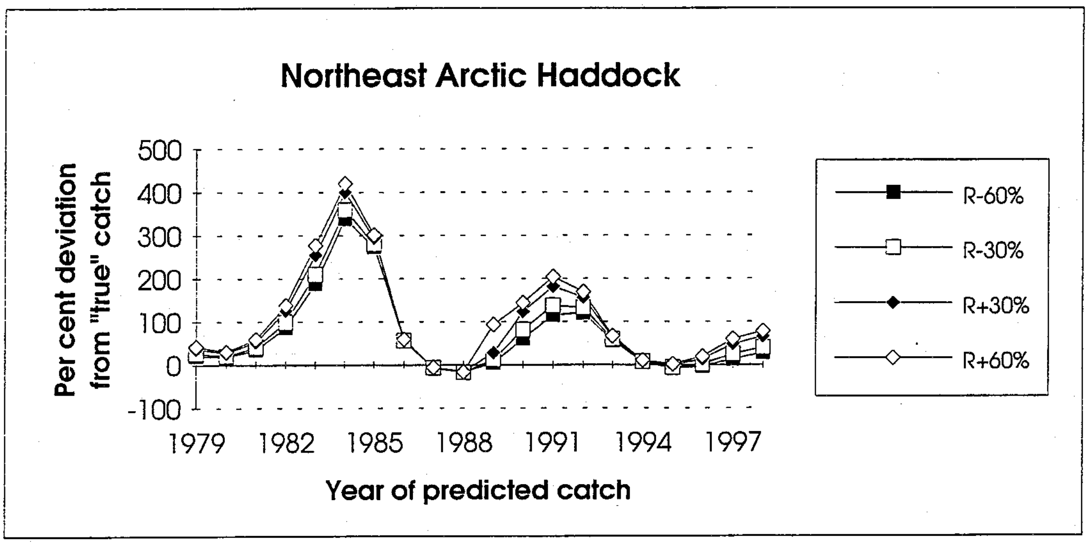


Figure 6. Per cent deviation over the last 20 years in short-term prediction of SSB (in TAC year + 1) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





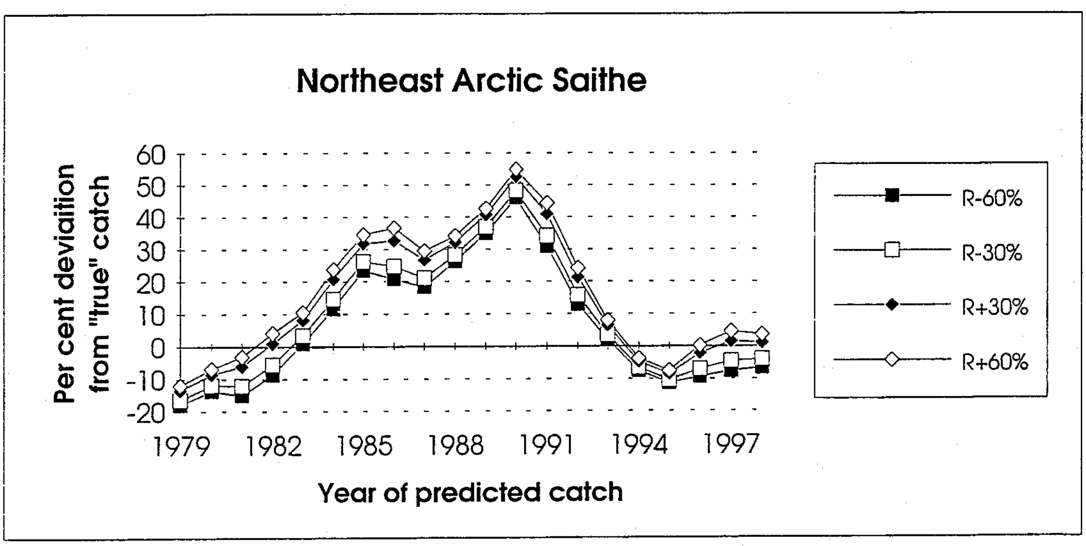


Figure 7. Per cent deviation over the last 20 years in medium-term prediction of catch (in TAC year + 4) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)

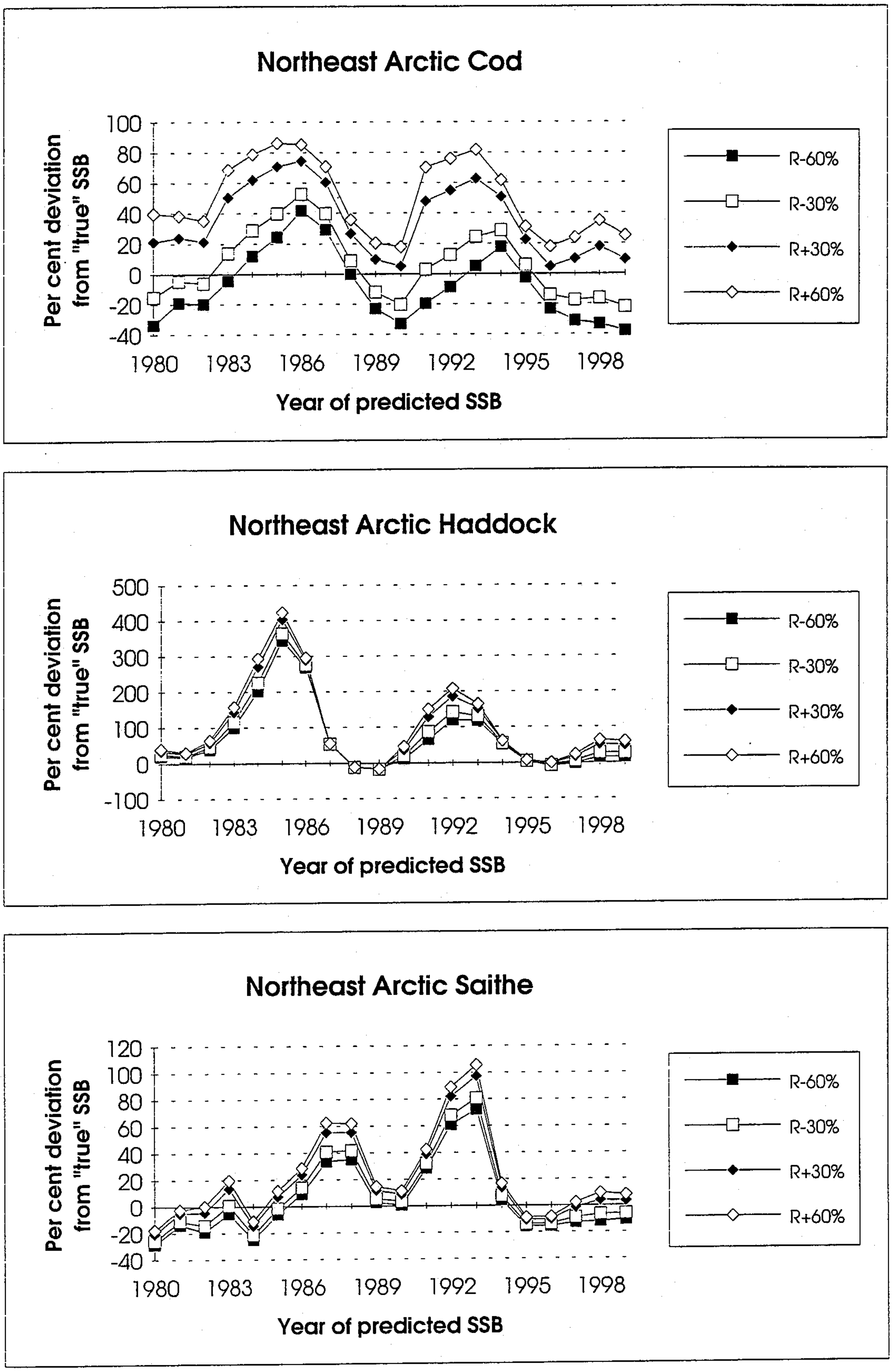


Figure 8. Per cent deviation over the last 20 years in medium-term prediction of SSB (in TAC year + 5) caused by errors in the range -60% to +60% in the indices of recruitment (R).
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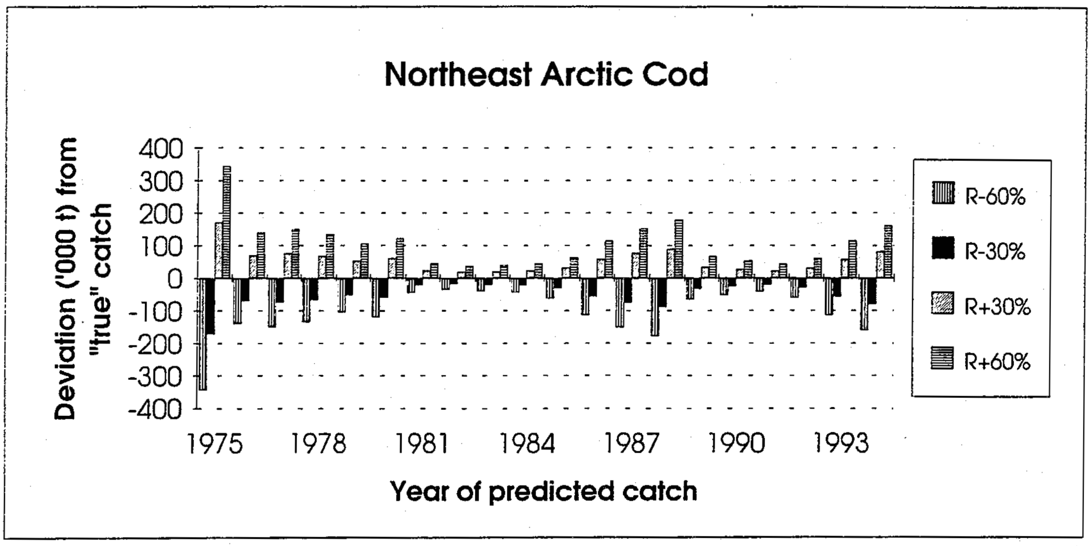
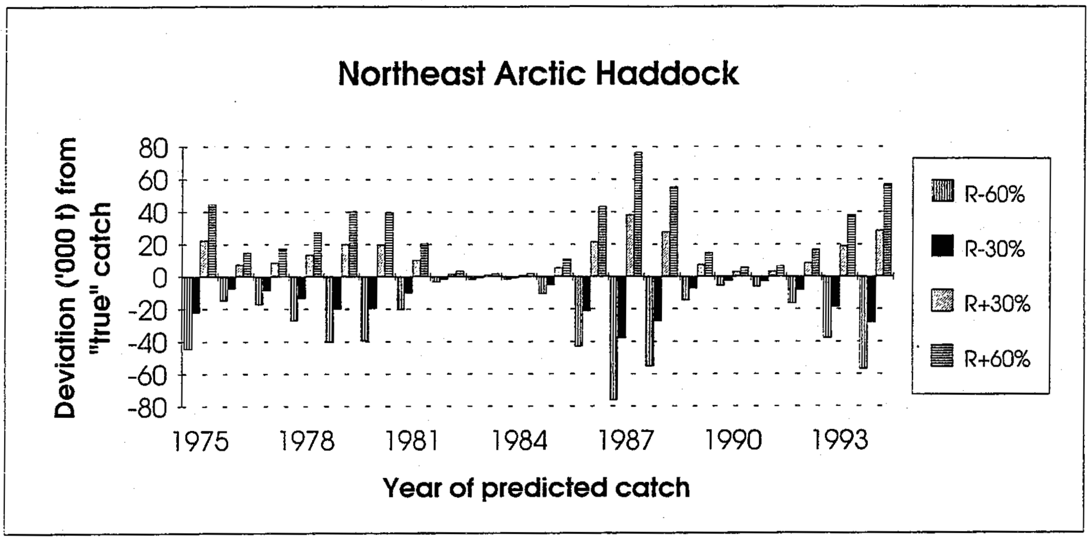




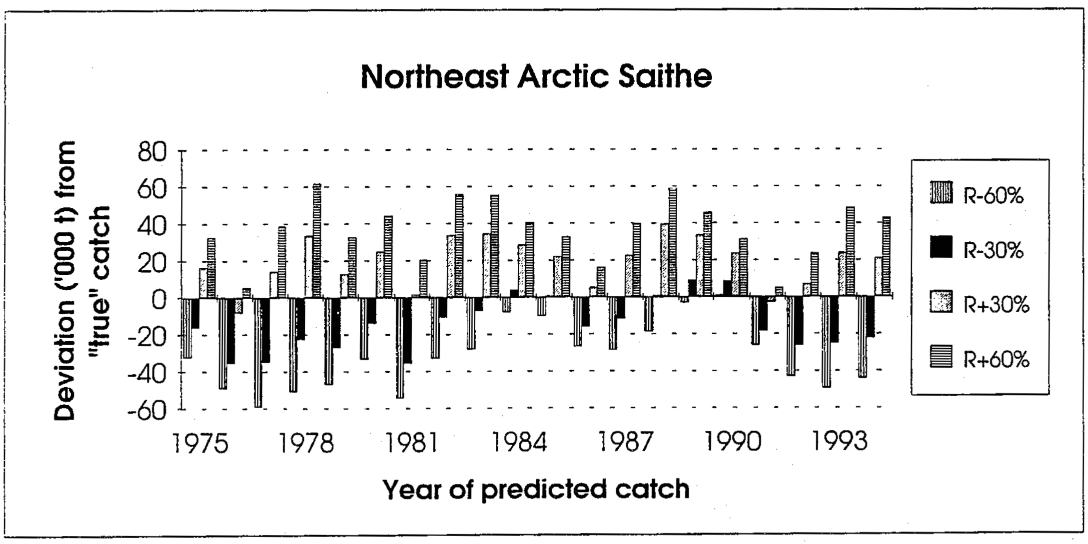
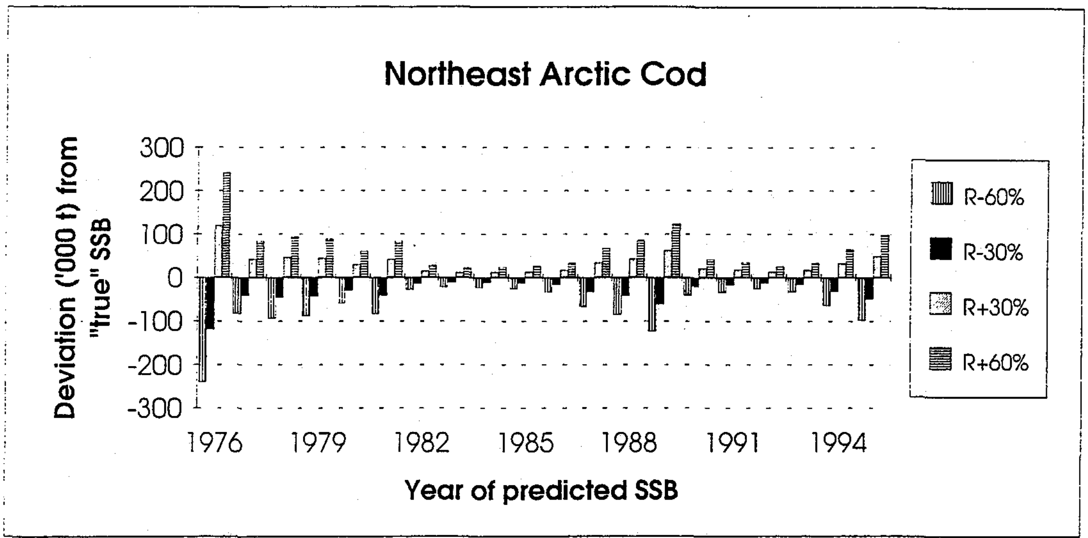
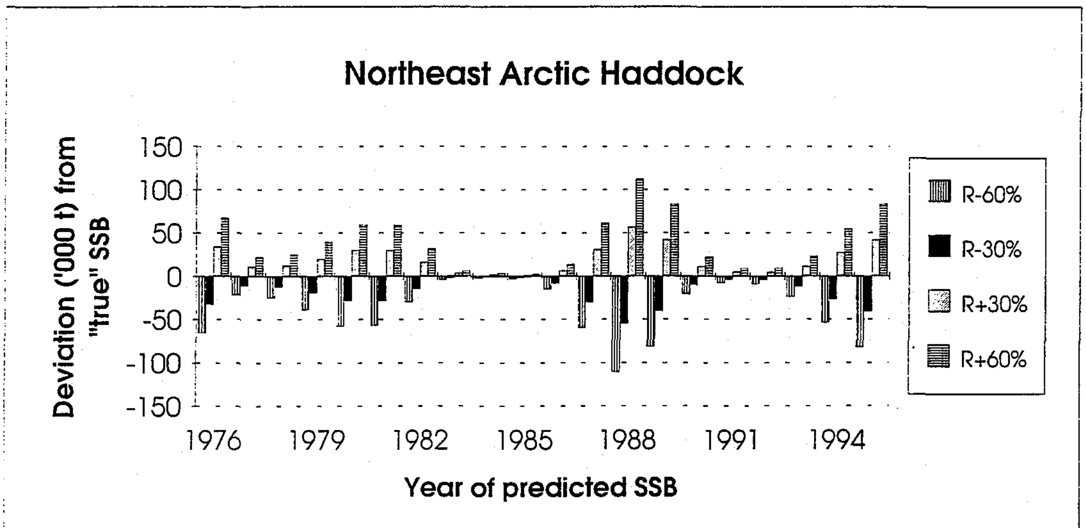


Figure 9. Deviation ('000 t) over the last 20 years in short-term prediction of catch (in TAC year) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





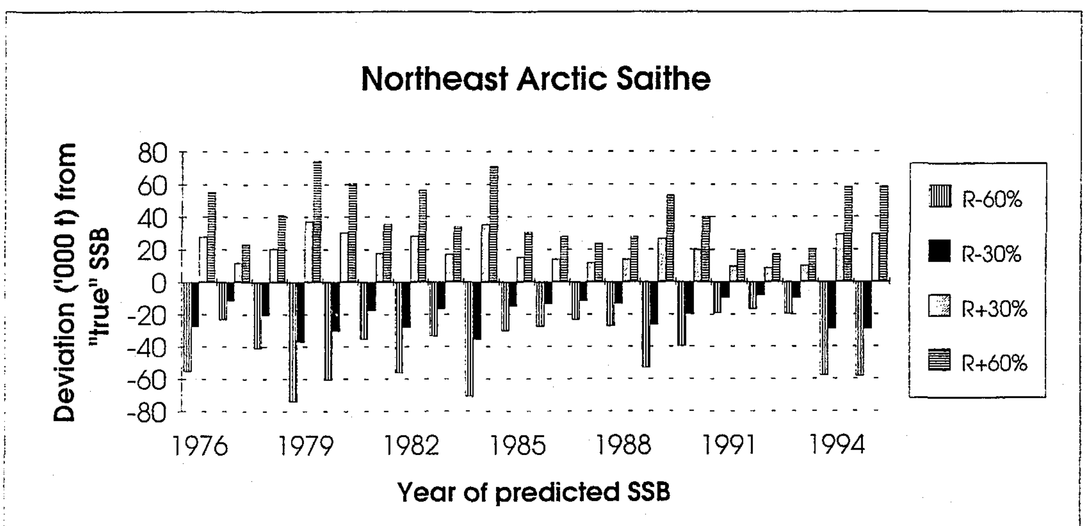


Figure 10. Deviation ('000 t) over the last 20 years in short-term prediction of SSB (in TAC year + 1) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)

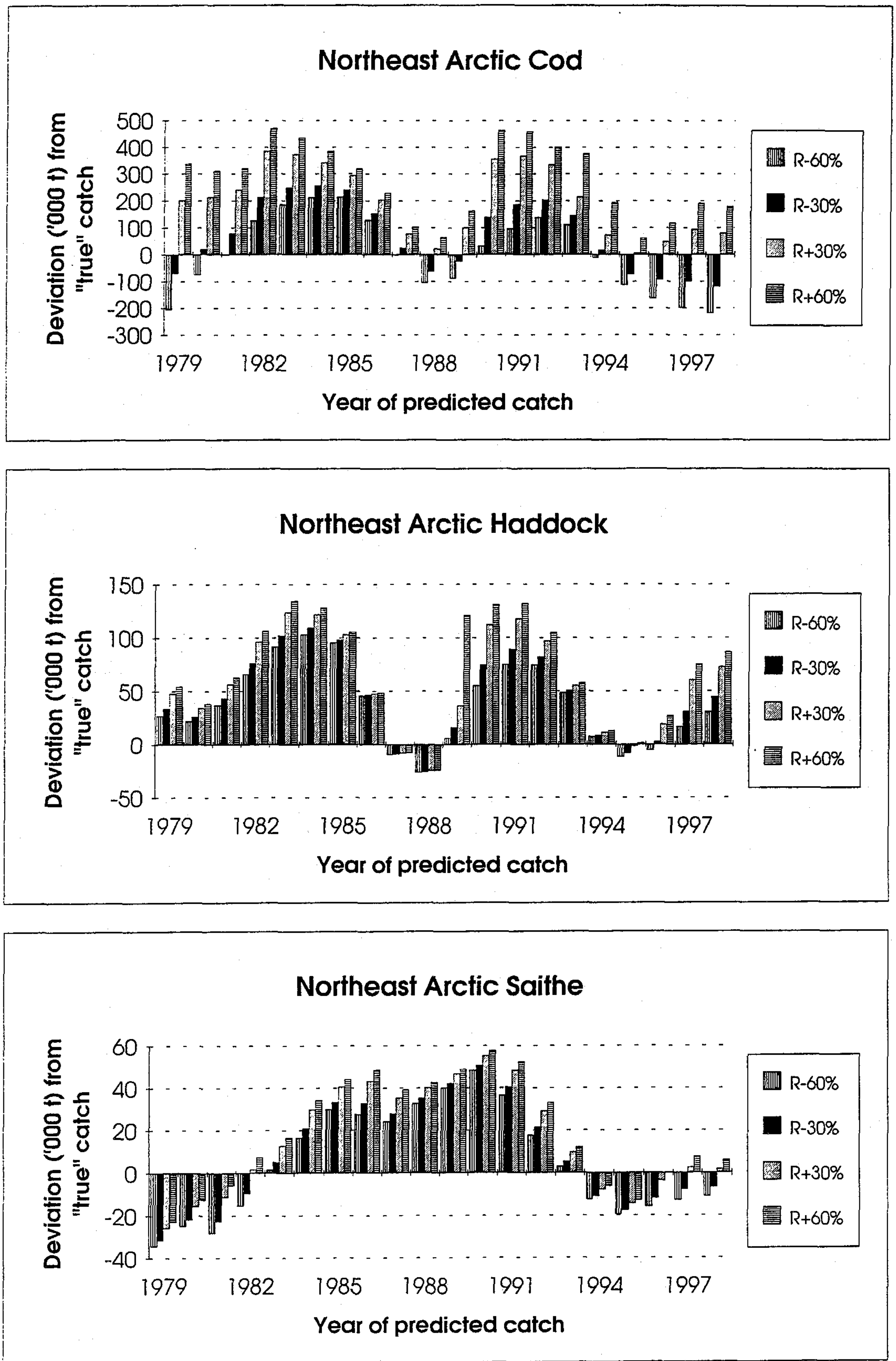
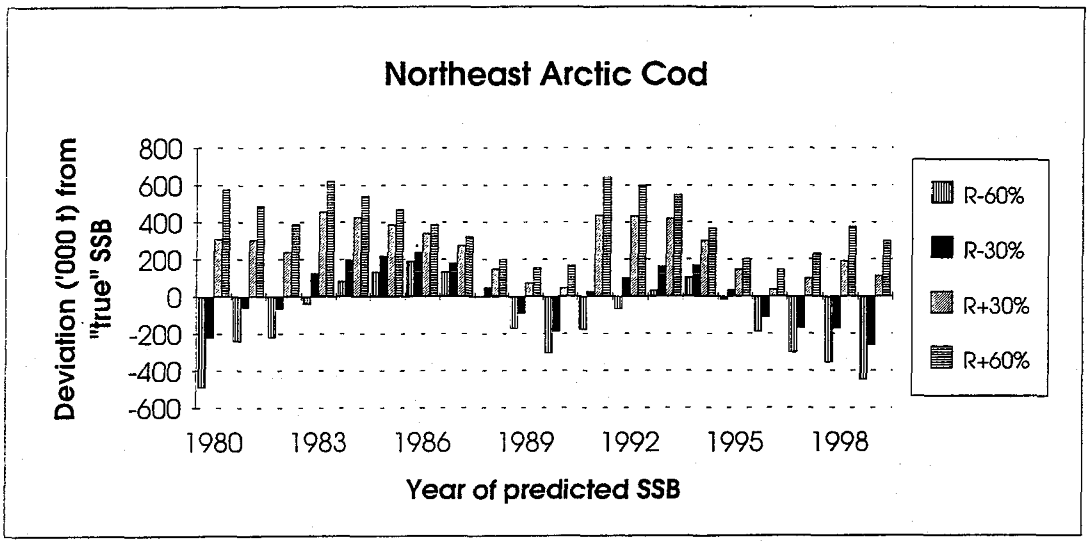
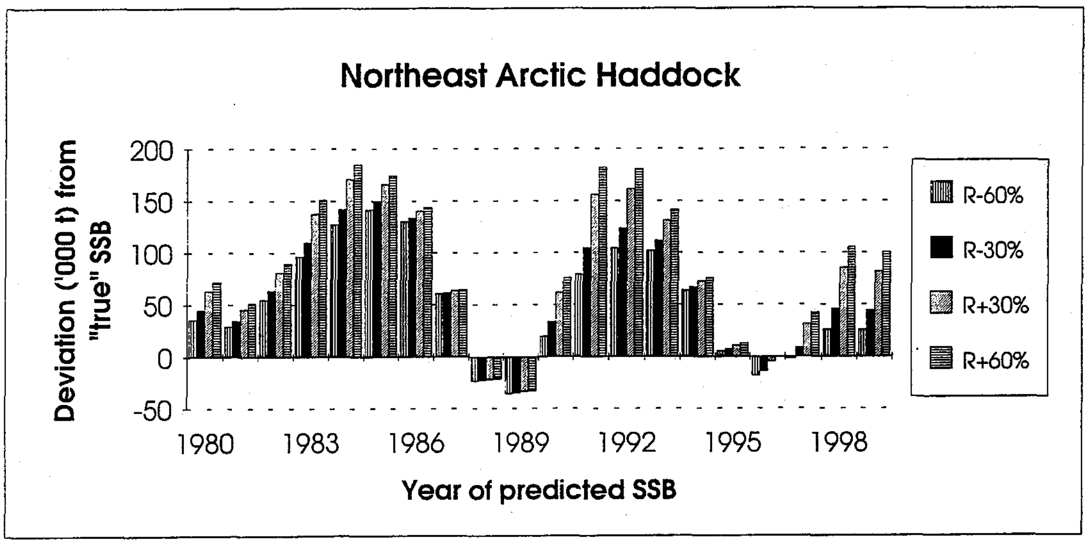


Figure 11. Deviation ('000 t) over the last 20 years in medium-term prediction of catch (in TAC year + 4) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)





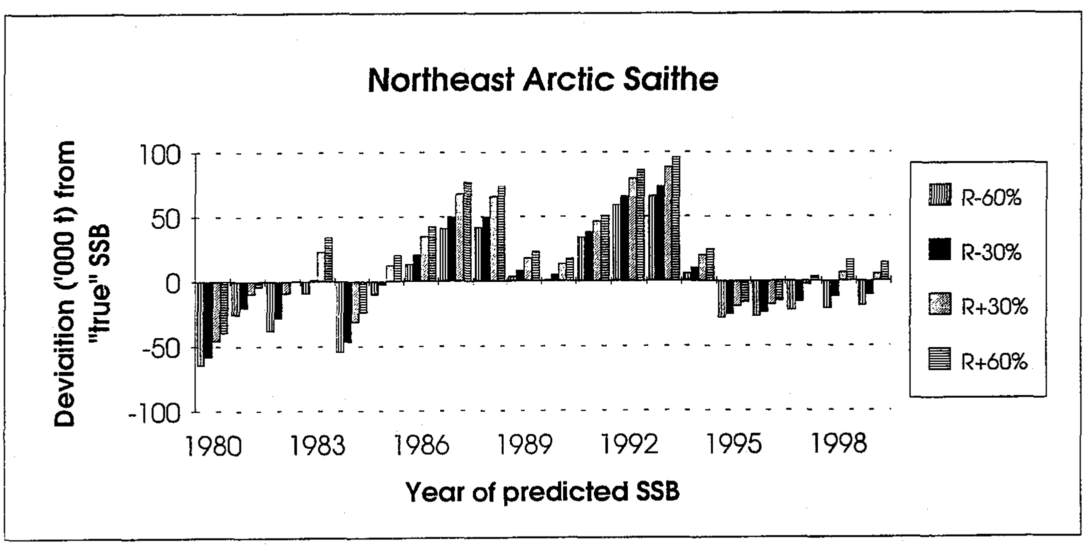
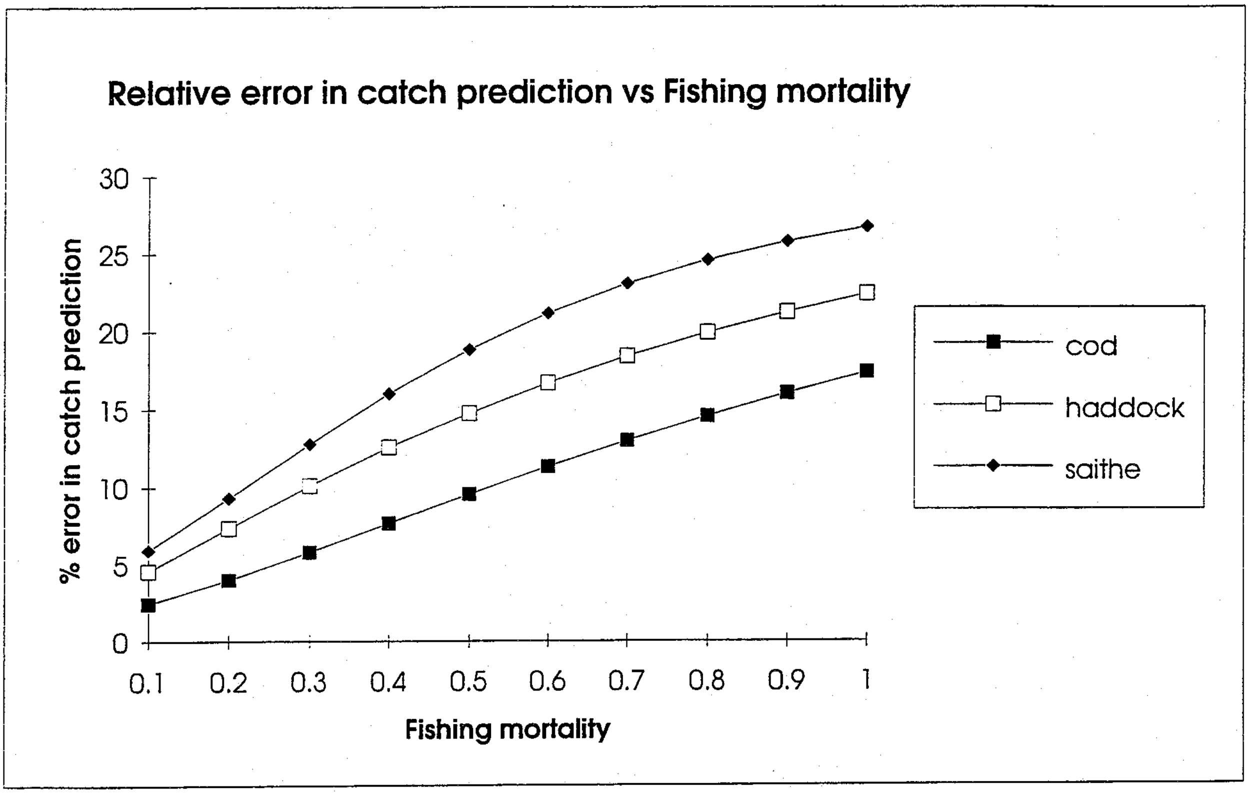


Figure 12. Deviation ('000 t) over the last 20 years in medium-term prediction of SSB (in TAC year + 5) caused by errors in the range -60% to +60% in the indices of recruitment (R).
(Simulation based on actual recruitment and F=0.4)



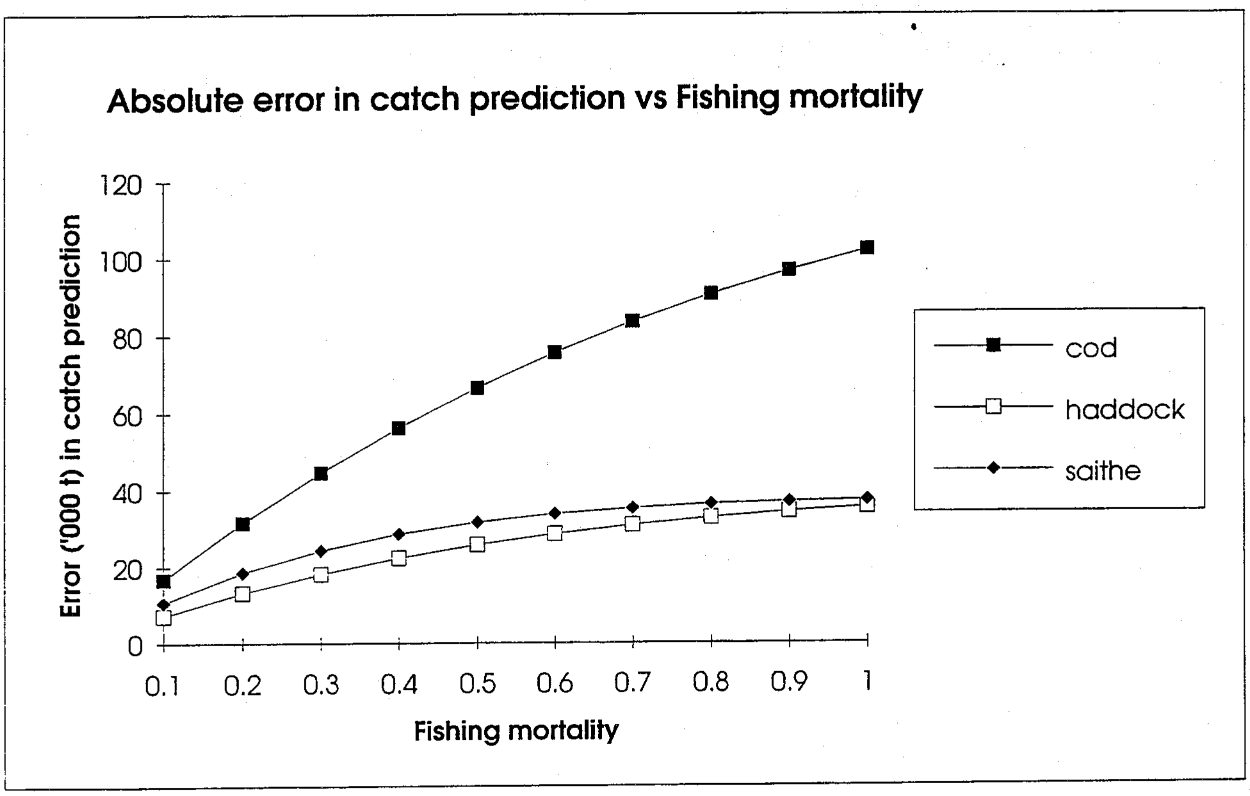


Figure 13. Relative and absolute error in short-term catch prediction as a function of fishing mortality, assuming 30% error in the recruitment indices.