NAFO Sci. Coun. Studies, 18: 27–31

Testing Non-parametric Methods to Estimate Cod (*Gadus morhua*) Recruitment in NAFO Divisions 3NO

J. Paz
Instituto Español de Oceanografía, Cabo Estai Canido
Aptdo. 1552, 36280 Vigo, Spain

and

M. G. Larrañeta
Instituto de Investigaciones Marinas, Eduardo Cabello 6
36208 Vigo, Spain

Abstract

Recognizing that non-parametric methods to estimate fish stock recruitment are generally simple and they do not need to be based on ecological hypotheses, four non-parametric methods; the probability transition matrix and three algorithms to estimate recruitment probability density functions were tested on cod (*Gadus morhua)* data from NAFO Div. 3NO. The transition matrix method was inadequate because the cod stock failed to meet the primary Markovian assumption: the transition probability must be constant and depend only on the previous state. Of the three algorithm methods, the fixed-interval, the New England and the Cauchy, only the New England was appropriate for calculating recruitment with these stock data. A regression coefficient of r = 0.556 (d.f. = 23, P = 0.003) was obtained when the observed data were compared with the estimated. The validity of estimates of future recruitment using the New England algorithm depends on biotic and abiotic environmental conditions being similar in both the pre-recruit and the observation periods.

Key words: Cod, *Gadus morhua*, NAFO Divisions 3NO, non-parametric methods, recruitment

Introduction

Difficulties in evaluating parameters of a stock-recruitment relationship, the wide dispersion of points around a stock-recruitment curve, or the parameter variations owing to environmental fluctuations, have induced several authors to propose statistical methods for estimating the most likely recruitment according to available historical data on recruitment when the size of the spawning population was similar to the present. With a statistical approach, the biological knowledge of the stock-recruitment relationships is excluded. Biological approaches are very valuable in order to predict the medium- or long-term evolution of the fishery resource, or to understand extreme fluctuations (e.g. explosion, collapse) in the past, but this kind of approach inspires little or no confidence when a prognosis on immediate or very short-term recruitment is required. This problem is usually reported to fisheries managers by working groups considering the state of resources. In contrast, however, the shorter the term of recruitment prognosis, the more valuable are the statistical approaches.

The simplest statistical method, and really the most used in the working groups recommending TACs, consist of supposing that the next recruitment will be the average of the most recent recruitments. But this has the great disadvantage that the last recruitments in the population analysis methods are usually underestimated, some times seriously so. There is an alternative solution which is to take the spawning populations nearest in size to the present spawning stock, and to predict the next recruitment from them, supposing that environmental conditions have not changed very much.

During the 1980s some attempts were made to give a statistical solution to these non-parametric approaches of the stock-recruitment relationship, as the probability transition matrix models of Getz and Swartzman (1981) and Rothschild and Mullen (1985), and most recently the use of an analysis of spawning stock biomass per recruit (Gabriel et al., 1989). The probability transition matrix methods need a very long data series, and needs even more the use of the spawning stock biomass-recruitment diagrams. In contrast, the use of algorithms seems to allow one to work with shorter data series.

In this paper we test for the cod (*Gadus morhua*) population in Div. 3NO, the utility of the probability transition matrix method proposed by Rothschild and Mullen (1985), and the use of algorithms to select stock-recruitment couple, according to Evans and Rice (1988). This procedure assumes that the environment in which the estimated recruitment was developed is similar to the environment of the remaining year-classes. In this way, if the resulting estimation is not accurate compared to the past using favourable assumptions, it would be apparent that very little confidence could be placed on the prediction of the future recruitment.

Materials and Methods

Cod recruitment numbers at age 3 (N_3) and stock biomass at age 6+ (B_{6+}) data were taken from Bishop et al. (MS 1990). Recruitment estimates for the period 1986-89 were not included because the Virtual Population Analysis (VPA) tended to underestimate recent recruitment values. The year-classes of 1956 to 1982 were considered and the stock biomasses were for the period 1959-82 (Table 1).

Recruitment was higher for the 1959 to 1969 year-classes than for the 1970 to 1982 ones (Fig. 1). With logarithmic transformation it was apparent that only recruitment of the 1963 year-class falls outside

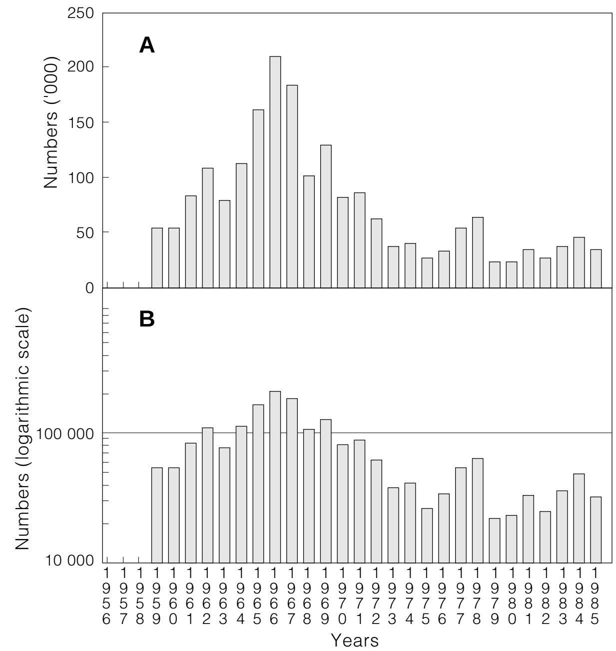


Fig. 1. Cod year-class recruitment observed in Div. 3NO. (**A**) recruitment number and (**B**) recruitment logarithm.

TABLE 1. Population numbers ('000) and biomass (tons) for cod in Div. 3NO from Bishop et al. (MS 1990).

Year-class	Recruitment year	Population number ('000)	Biomass (tons) (B_{6+})
1956	1959	53 698	–
1957	1960	53 179	–
1958	1961	82 134	–
1959	1962	107 755	89 220
1960	1963	78 284	72 956
1961	1964	112 516	90 018
1962	1965	162 762	80 480
1963	1966	210 243	88 029
1964	1967	183 387	112 830
1965	1968	101 714	120 660
1966	1969	128 599	104 875
1967	1970	80 905	93 820
1968	1971	86 121	83 341
1969	1972	63 163	81 217
1970	1973	37 594	82 481
1971	1974	41 586	90 799
1972	1975	26 552	81 758
1973	1976	33 510	61 446
1974	1977	52 753	60 994
1975	1978	61 688	27 912
1976	1979	21 747	23 903
1977	1980	23 345	35 541
1978	1981	33 823	42 314
1979	1982	24 673	52 004
1980	1983	35 426	103 667
1981	1984	47 223	157 436
1982	1985	32 581	172 654

the normal distribution at $P < 0.05$, though inside the $P < 0.03$ level. For this reason we considered that every recruitment value was within a significantly probable limit of the normal variation.

To test the algorithms, a series of annual recruitment values as predicted by each algorithm was calculated. To obtain the recruitment value for each year corresponding to the reported stock biomass for that year, the full stock-recruitment data available were used excluding the figure of that year.

Results and Discussion

Transition matrix

In general, stock values can be ordered and classified by m-tiles. Likewise recruitment values can be ordered and classified by n-tiles. The classification partitions the stock recruitment plane into m by n regions. Each stock-recruitment point may be classified as belonging to one of the m by n regions. The classification thus utilizes the median stock and the median recruitment to partition the stock recruitment plane into four regions or "states". In this way cod recruitment (N_3) and spawning biomass (B_{6+}) for each year-class (1959 to 1982) was classified as high or low as two similar series, and included in one of the following "states".

S1 = low stock/low recruitment,

S2 = low stock/high recruitment,

S3 = high stock/high recruitment,

S4 = high stock/low recruitment.

Year-classes were placed in chronological order, and the number of transitions between states were observed, resulting in the following matrix:

State	1	2	3	4
1	5	1	0	2
2	2	0	2	0
3	0	3	5	0
4	1	0	0	2

As the total number of transitions is 23, the mean frequency in each cell will be 23/16 = 1.44. To test the observed frequency distribution for heterogeneity, a Chi-square test was used and the value, χ^2 = 20.43, (d.f. = 15, $P > 0.05$) obtained. The heterogeneity hypothesis was rejected.

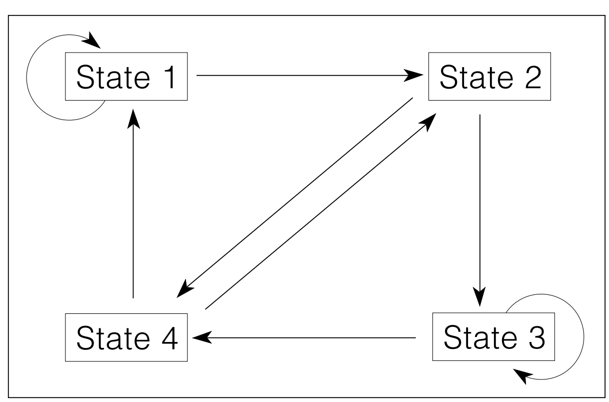
Dividing the number of transitions of the ijth element of the above matrix by the total number of transitions in the jth row, the probability transition matrix was obtained among all four states:

State	1	2	3	4
1	0.625	0.125	0.00	0.25
2	0.50	0.00	0.50	0.00
3	0.00	0.375	0.625	0.00
4	0.333	0.00	0.00	0.667

The transitions 1-1, 3-3 and 4-4 showed higher probabilities. This suggested a spawning biomass autocorrelation (which is reasonable because it is composed of several year-classes) with recruitment in successive years. In fact, Myers, Blanchard and Thompson (1990) obtained a high autocorrelation function (ACF = 0.749) between cod recruitment in Div. 3NO. We also obtained significant autocorrelations with lag of 1, 2 and 3 years: ACF_1 = 0.80, ACF_2 = 0.66 and ACF_3 = 0.59. This signifies that the factors determining recruitment in consecutive years are similar. If the VPA did not underestimate the last recruitment, these would provide a reliable estimate for the next recruitment.

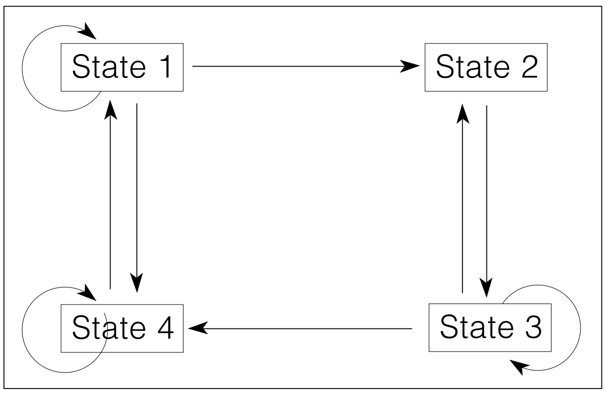
If it is assumed that these stock-recruitment transitions are Markovian, then further deductions regarding future observations of the stock-recruitment relationship can be made. The primary Markovian assumption is that transition probabilities are constant and only depend on the previous state. This Markovian condition will depend both on the prevailing physical environment, including fishing, and the ecological niche remaining constant during the projection time.

One method to test these probabilities is to draw a theoretical transition diagram according to the adopted classification. The result was as follows:



It was supposed that each state depends only on the previous state. Then, since with constant natural mortality the change from low recruitment to high stock is not possible, this transition was eliminated from the diagram. The real problem is the transition between stock and the recruitment with variable natural mortality.

According to the probability transition matrix the following pattern corresponding to the empirical transition diagram was obtained:



A comparison of the two diagrams revealed fundamental differences, not because of the missing transitions (transitions 3-4, 2-4 and 4-2 are absent in the empirical matrix) which may have been due to insufficient data, but because the theoretical diagram had extra transitions such as the 4-4, 2-1, 3-2 and 1-4. These features indicated that the primary Markovian assumption was not valid for this cod stock. In fact, cod mature at about 6 years of age, so that spawning stock depends on recruitment six or more years earlier.

Non-parametric algorithms

The fixed interval algorithm. Following Evans and Rice (1988), the stock biomass axis was divided into a chosen number of intervals, each containing as nearly as possible the same number of the past observations. The year's stock biomass was in one of the intervals. It was assumed that only recruitment from past observations in that interval were possible, and they were of equal probability. In this case the spawning stock biomasses were divided into seven groups with four in each, in increasing order. In a given stock, its recruitment was estimated choosing the recruitment of the average stock biomass of the three adjacent stocks. The correlation coefficient between estimated and observed recruitment values was r = 0.260 (d.f. = 23, and P = 0.224), which was not significant.

The New England algorithm. The stock biomass and recruitment axes were divided subjectively into convenient intervals. The probability density function was constant within each recruitment interval and proportional to the number of past observations; those in the stock interval containing the previous years stock. The stock biomass series ranging from 20 000 to 200 000 tons was divided into six intervals of 30 000 tons each. Recruitment values corresponding to the year-class in each interval were put in ascending order and the median selected. As an example, Fig. 2 shows the ogive of the recruitment probability density function (pdf) for the 1959 and 1972 year-classes. The ordinate axis was divided into as many regular steps as there were stocks in the interval, and the abscissa represented increasing values of recruitment. The recruitment selected was that corresponding to the 50% level of each step. The correlation coefficient between the estimated recruitment values and the observed values was r = 0.556 (d.f. = 23, P = 0.03). This correlation was considered significant.

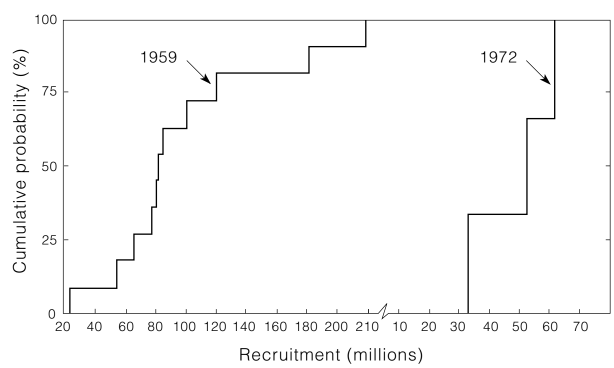


Fig. 2. The step function of cumulative probability of Div. 3NO cod recruitment: The New England algorithm using three stock intervals for recruitment of 1959 and 1972 year-classes.

The Cauchy algorithm. The pdf was weighted according to the algorithm $y = 1/(1+(x/D)^2)$, where D is a chosen characteristic width (stock size), and x is the absolute difference between the past stock size and the stock size of the current year. When x = 0, the recruitment probability corresponding to selected stock has a maximum. The pdf ogive should be also drawn in increasing order of recruitment. As an example Fig. 3 shows the pdf ogive of the 1959 and 1972 year-classes. When the one which has a higher y value was taken as a more probable recruitment value, the correlation between the estimated and observed recruitment values was: r = 0.279 (d.f. = 23, P = 0.178); the correlation was not significant. In a new attempt following Fig. 1, all

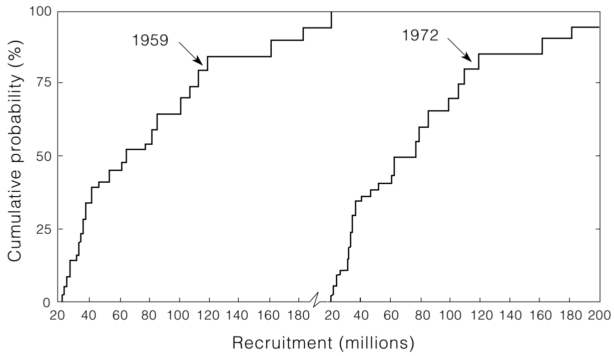


Fig. 3. The step function of cumulative probability of Div. 3NO cod recruitment: The Cauchy algorithm using a characteristic width for stock units.

periods studied were divided into two subperiods, one with high 1959-69 year-class recruitment and the other with lower 1970-82 year-class recruitment. The correlation in this case was r = 0.496 (d.f. = 23 and P = 0.013).

Conclusions

The use of the New England algorithm was the only non-parametric method which gave reasonable estimates of recruitment to the cod stock in Div. 3NO by employing the remaining year-classes in the period 1959-82. The results obtained using the transition matrix, the fixed interval algorithm and the Cauchy algorithm were unsuitable for this cod stock. The validity of the algorithm in future will depend on the biotic and abiotic conditions being similar to those experienced by the pre-recruitment phase and the observed stock-recruitment period.

References

BISHOP, C. A., J. W. BAIRD, and E. F. MURPHY. MS 1990. The assessment of cod stock in NAFO Div. 3NO. *NAFO SCR Doc.*, No. 73, Serial No. N1795, 35 p.

EVANS, G. T., and J. C. RICE. 1988. Predicting recruitment from stock size without the mediation of a functional relation. *ICES J. Cons.*, **44**: 111-122.

GABRIEL, W. L., M. P. SISSENWINE, and W. J. OVERHOLTZ. 1989. Analysis of spawning stock biomass per recruit: An example for Georges Bank haddock. *North Amer. J. Fish. Manag.*, **9**: 383-391.

GETZ, W. M., and G. L. SWARTZMAN. 1981. A probability transition matrix model for yield estimation in fisheries with highly variable recruitment. *Can. J. Fish. Aquat. Sci.*, **38**: 847-855.

MYERS, R. A., W. BLANCHARD, and K. R. THOMPSON. 1990. Summary of North Atlantic Fish Recruitment 1942-1987. *Can. Tech. Rep. Fish. Aquat. Sci.*, **1743**: iii+108 p.

ROTHSCHILD, B. J., and A. J. MULLEN. 1985. The information content of stock and recruitment data and its non-parametric classification. *ICES J. Cons.*, **42**: 116-124.