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A non-equilibrium production model for Divisions 4RST redfish.

by

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Abstract

A non-equilibrium stock production model is derived for redfish in the Gulf of Saint-Lawrence using historical data on the commercial fishery during the 1959-1985 period. An examination of the residuals suggests that the sudden decline in the standardized catch rates for 1985 cannot be completely explained by the dynamics of the stock. Other factors, such as changes in fish availability and/or catchability, must be invoked to explain such a decline in commercial catch rates. The impact of the large 1956 and 1958 year-classes on the trajectory of the transient (non-equilibrium) yield is examined; that trajectory follows the expected behavior of the transient points in a typical stock production analysis. The authors discuss management implications for this redfish stock.

Résumé

On élabore ici à partir de l'analyse des séries de données sur la pêche commerciale, de 1959 à 1985, un modèle de production en situation de non-équilibre pour le sébaste dans le golfe du Saint-Laurent. L'examen des valeurs résiduelles suggère que le déclin subit des taux de capture standardisés en 1985 ne peut s'expliquer uniquement par la dynamique de ce stock. D'autres facteurs, comme des changements dans la disponibilité ou la capturabilité du poisson, doivent être invoqués pour expliquer un tel déclin dans les taux de capture commerciaux. L'impact des grosses classes annuelles de 1956 et 1958 sur la trajectoire décrite par les captures transitoires (i.e. à l'état de non-équilibre) est examiné; cette trajectoire suit le patron normal des points transitoires dans une analyse type du rendement d'un stock. Les auteurs discutent les implications pour la gestion de ce stock de sébaste.

Introduction.

Historical data on the redfish fishery in the Gulf of Saint-Lawrence are given by Rubec *et al.* (1986). The purpose of this paper is to provide estimates of surplus production from the analysis of the commercial catch and effort data and to study the response of this redfish stock to exploitation.

Catch and effort data.

Catch and effort data from NAFO Statistical Bulletins for the period 1959-1983 were combined with provisional data for 1984 and 1985 and analysed by Rubec *et al.* (1986) with a multiplicative model (Gavaris, 1980) to derive a standardized catch rate and effort series. Before analysis, adjustments were made to compensate for an increase in catchability when the Engel high lift trawl was used. Such adjustments were made to TC-4 Maritimes and Quebec vessels for the period 1981-1985. The nominal catch, standardized catch rates and effort used in the present analysis are given in Table 1.

The standardized catch rates show a marked decline in 1985 (Table 1). Such a decline in catch rates cannot be explained on the sole basis of a change in stock abundance: in a species like redfish, which experiences relatively low fishing and natural mortality, catch rate levels may be expected to show some stability over time. Consequently, other factors, such as those affecting fish availability and catchability, must have played a role in this recent decline in commercial catch rates. A possible explanation for the decline in commercial catch rates of redfish during the 1985 fishing season is that the water temperature in the depth range that redfish normally occupy was about 1°C warmer than in 1984 (Dr. P. Rubec, Fisheries Research Branch, Moncton; *pers. comm.*). A preliminary analysis of research survey data suggests that redfish were found in deeper waters, and further west and further north in 1985 compared to 1984.

Production model and estimation procedure.

The non-equilibrium versions of both the Schaefer model and of the generalized stock-production model (Pella and Tomlinson, 1969) were applied to the nominal catches and the standardized effort for the 1959-1985 period. We used the Levenberg-Marquardt method, a non-linear estimation technique that minimizes least squares, to estimate model parameters and we approximated the solution of the non-equilibrium model, which has the form of a system of differential equations, by a Runge-Kutta algorithm for numerical integration (Rivard and Bledsoe, 1978).

Results.

The maximum productivity of the stock (or maximum equilibrium yield, MEY) was estimated at 56,500 t ± (S.E.) 2,800 t with the non-equilibrium version of the Schaefer model. Standard statistics on the estimated parameters are presented in Table 2 and the transient yield levels predicted by the resulting model appear in Table 3. The model has an R^2 of 0.949 (i.e. 95% of the variation in transient yield is explained by the model).

Because factors other than stock size seem to have affected the catch rate series (e.g. in 1985), particular attention has been paid to the "validation" of the results obtained from the stock production model. Attention was thus paid to patterns and outliers in residuals, to trends in the stock sizes implied by the model, to trends in catchability and to the interpretation of the transient trajectory of the fishery in view of known biological events (such as the occurrence of exceptionally large year-classes).

While the parameters of the non-equilibrium model were well estimated, it must be noted that the information content of the data series is limited for the area beyond the maximum of the parabolic Schaefer curve. This observation suggests that the confidence intervals around the underlying equilibrium curve may be large beyond the maximum despite the small variance of the three parameters estimated in the model. The application of the non-equilibrium version of the generalized stock production model (Pella and Tomlinson, 1969) confirmed that the information content of the data series is not sufficient to allow a precise estimation of the location and curvature of the downward limb of the equilibrium curve. In view of these limitations, the Schaefer (non-equilibrium version) model constitutes the best compromise at the present time.

The transient trajectory.

A validation of the Schaefer model was carried out by inspecting the trajectory of the transient (non-equilibrium) yield around the equilibrium curve (Figure 1). As expected, the large 1956 and 1958 year-classes pushed the stock above equilibrium levels for the 1966-1975 period. Because of the gradual depletion of these year-classes through fishing, the stock returned below equilibrium levels in the late seventies and has remained below equilibrium since then. While the 1970 and 1971 year-classes appear to be strong, they have not to date brought productivity to or above the equilibrium level. The transient path described by the observed points follows the expected behavior of the transient points in a typical stock production analysis.

Underlying biomass levels.

The biomass levels underlying the transient production system estimated above are compared, in Figure 2, to the standard mean catch rates calculated from commercial data. Both time series show the same general trends over the 1959-1985 period. It must be noted that the 1985 catch rate value is much lower than that predicted by the model. The non-equilibrium Schaefer model implies a biomass level of 508,000 t (for January 1, 1986). This biomass level is very close to the biomass level of 487,000 t estimated from research surveys for 1985 (Rubec *et al.*, 1986).

Analysis of residuals.

Finally, residuals were inspected for anomalies. While "runs" (resulting from serial correlation) are present in residuals, their presence is expected in a species like redfish. Serial correlation, which may bias parameter estimates when the number of observations is small, is not a major concern here as the number of observations is sufficiently large (27 observations). The value of the residuals for 1985 was particularly large, suggesting that the sudden decline in the standardized catch rates for 1985 cannot be explained by the dynamics of the stock as described by the production model.

Estimates of catchability and of fishing mortality.

The non-equilibrium model produced the following estimates:

$$q = 2.66974 \times 10^{-6} \qquad 2/3\ f_{MEY} = 36{,}846 \text{ hr}$$

From these, the fishing mortality at 2/3 f_{MEY} can be estimated as $F = 2.66974 \times 10^{-6} \times 36{,}846 = 0.098$ and $F_{1985} = q \times f_{1985} = 0.074$.

The yearly catchabilities, derived from the ratio between annual catch rates and biomass estimates, are plotted in Figure 3. In summary, there is no overall trend for the 1959-1984 period but catchability was much below average in 1985.

Management implications

The effort exerted on this stock has been below both the f_{MEY} and 2/3 f_{MEY} in recent years. The results of the non-equilibrium production analysis are:

	MEY	2/3 f_{MEY}
Effort	55,270 hr	36,846 hr
CPUE at equilibrium	1.023 t/hr	1.364 t/hr
Equilibrium yield	56,522 t	50,242 t

The commercial catch rates have been above that to be expected at MEY since 1980 (except 1985) and were slightly below the equilibrium catch rate to be expected at 2/3 f_{MEY} during 1981-1984.

Non-equilibrium projections.

At 2/3 the effort giving MEY, the non-equilibrium yield was estimated at 50,014 t for 1986. This catch would correspond to a fishing mortality rate of 0.10 for 1986. As this yield is very close to equilibrium (see Figure 1), the 2/3 E_{MEY} level for 1987 is also very close to equilibrium, i.e. 50,054 t (the equilibrium level is 50,242 t).

References

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Table 1: 4RST redfish catch rate standardized to Maritimes and Quebec OTB-4, adjusted for the shift to Engle high lift trawls (from Rubec et al., 1986).

Year	Nominal Catch (t)	Standardized Catch Rates (t/h)	Effort (h)
1959	16978	0.749	22668
1960	12218	0.771	15842
1961	10391	0.750	13863
1962	6585	0.557	11820
1963	19794	1.079	18350
1964	29700	1.134	26194
1965	48827	1.254	38947
1966	65215	1.432	45531
1967	70036	1.660	42183
1968	90963	1.579	57607
1969	88875	1.096	81073
1970	87588	0.912	96028
1971	79406	0.873	90962
1972	80329	0.966	83127
1973	130164	0.851	152999
1974	63489	0.611	103883
1975	65401	0.601	108845
1976	37983	0.721	52684
1977	15840	0.603	26281
1978	13591	0.702	19367
1979	15034	0.809	18580
1980	14832	1.132	13102
1981	20549	1.322	15544
1982	26429	1.271	20801
1983	24505	1.289	19004
1984	35780	1.197	29887
1985	27827	0.952	29235

Table 2. Approximate statistics from the linear theory on the parameters of the non-equilibrium version of the Schaefer model estimated from the 1959-85 commercial data.

Parameter	Estimated Value	Standard Error	t-value
$B_{infinity}$	766100	194900	3.93
MEY	56522	2783	20.31
q	2.670E-6	0.348E-6	7.66

Correlation matrix of the estimated parameters:

	$B_{infinity}$	MEY	q
$B_{infinity}$	1.00		
MEY	-0.65	1.00	
q	-0.74	0.52	1.00

Table 3: Comparison of observed yield with the yield calculated from the non-equilibrium Schaefer model for the 1959-85 period.

Year	Yield (t)	Predicted Yield (t)	Residuals (t)
1959	16978	17806	-828
1960	12218	14081	-1863
1961	10391	13880	-3489
1962	6585	13184	-6599
1963	19794	22350	-2556
1964	29700	33633	-3933
1965	48827	51036	-2209
1966	65215	59284	5931
1967	70036	54441	15595
1968	90963	72677	18286
1969	88875	95694	-6819
1970	87588	102229	-14641
1971	79406	87575	-8169
1972	80329	74532	5797
1973	130164	119199	10965
1974	63489	69477	-5988
1975	65401	67096	-1695
1976	37983	32215	5768
1977	15840	17724	-1884
1978	13591	14880	-1289
1979	15034	16193	-1159
1980	14832	12865	1967
1981	20549	16984	3565
1982	26429	24664	1765
1983	24505	24048	457
1984	35780	39466	-3686
1985	27827	39518	-11691

Figure 1. Transient trajectory and equilibrium Schaefer curve for Divisions 4RST redfish. Note that the Schaefer model was estimated under non-equilibrium conditions using the method described in Rivard and Bledsoe (1978).

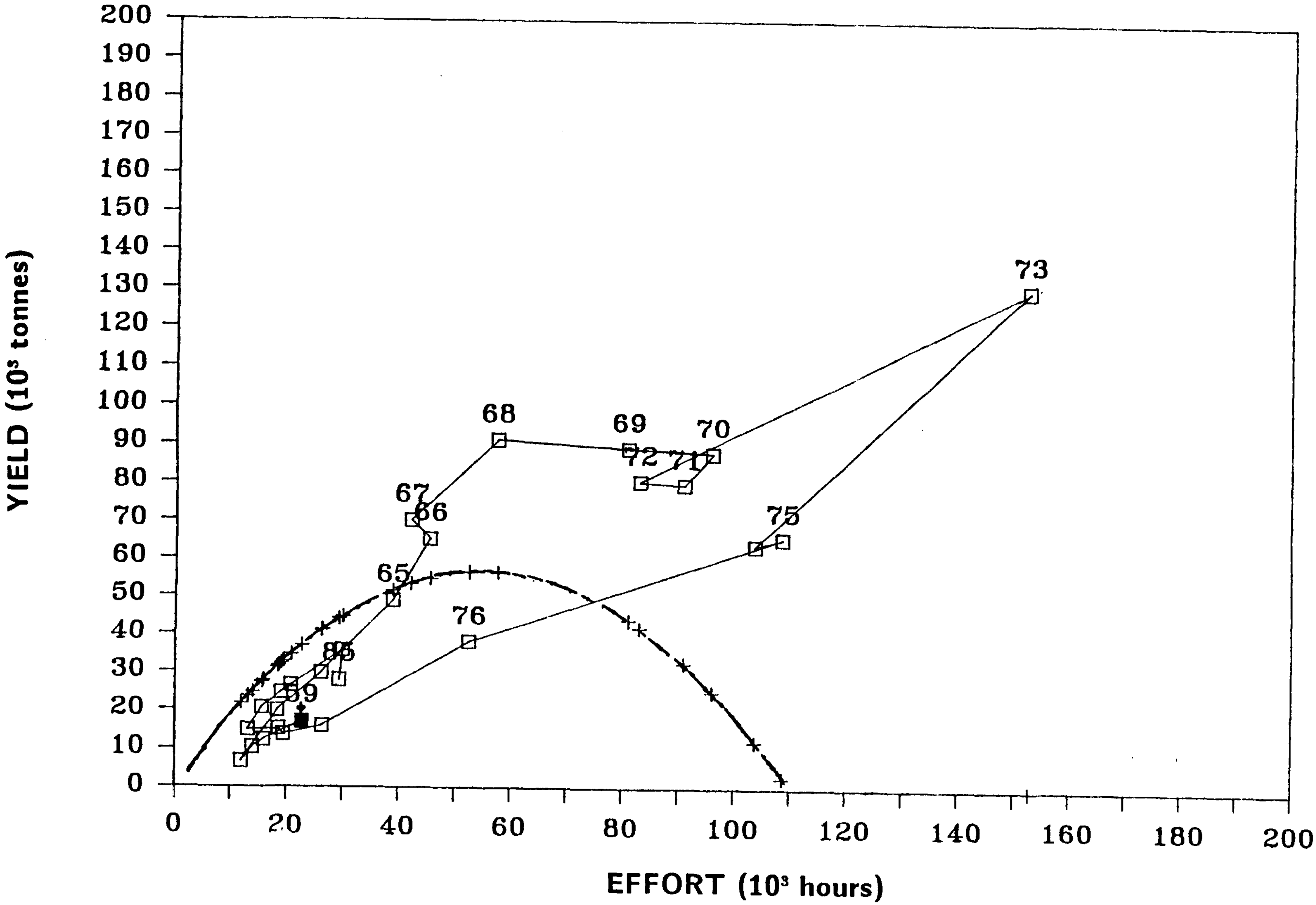

Figure 2. Comparison of standardized commercial catch rates with the biomass levels underlying the Schaefer production model. Both time series were divided by their respective mean for the purpose of this comparison.

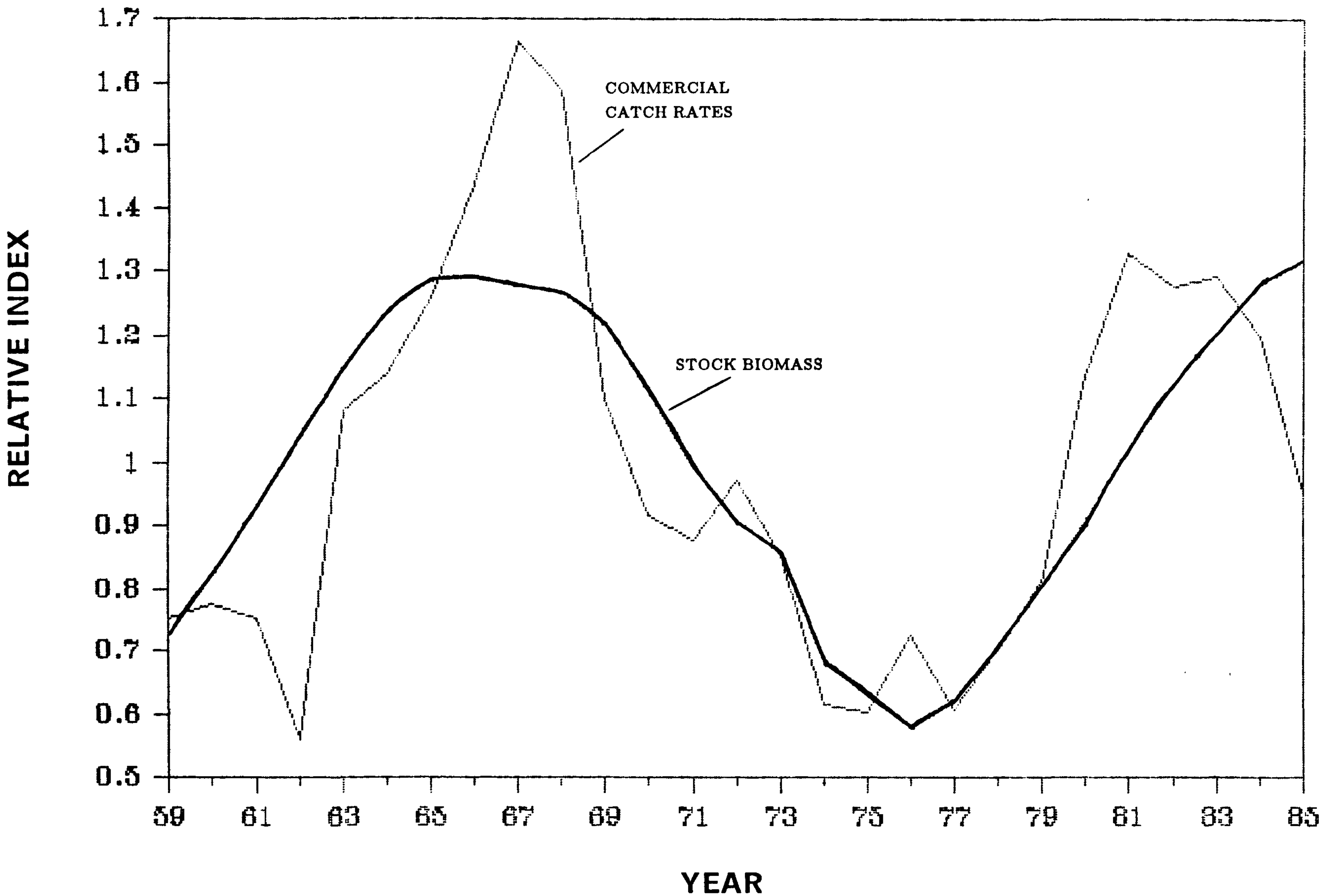

Figure 3. Yearly coefficients of catchability for 4RST redfish. The dotted line represents the coefficient of catchability resulting from the estimation of the Schaefer production model under non-equilibrium conditions.