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Exploitation rate estimates for the 3Pn4RS cod stock based on mark-recapture data

by

Pierre Gagnon

Division des poissons et des mammifères marins
Ministère des Pêches et des Océans
Institut Maurice-Lamontagne
850, Route de la Mer
Mont-Joli, Québec
G5H 3Z4

Fish and Marine Mammals Division
Department of Fisheries and Oceans
Maurice Lamontagne Institute
850, Route de la Mer
Mont-Joli, Quebec
G5H 3Z4

[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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[1]This series documents the scientific basis for the evaluation of fisheries resources in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the secretariat.

Abstract

Data from the mark-recapture programme targeting the 3Pn4RS cod stock in 1983-1986 is analysed using a population dynamics model to provide estimates of exploitation rates. The analysis involves a maximum likelihood procedure for estimating the tag reporting rate, which is made possible because the programme includes multiple tagging sessions. Monthly fishing mortalities are obtained for the 1984 to 1990 period.

Résumé

Les données du programme de marquage et recapture visant le stock de morue de 3Pn4RS durant les années 1983-1986 sont analysées à l'aide d'un modèle de dynamique des populations pour obtenir des estimations des taux d'exploitation. Ces analyses procèdent par maximum de vraisemblance pour estimer le taux de retour des étiquettes, ce qui est possible parce que le programme comportait plusieurs épisodes de marquage. Des taux de mortalité par pêche mensuels sont obtenus pour les années 1984 à 1990.

Introduction

Tagging is a very powerful method for studying the migration and mixing of populations in open sea (see for example Templeman, 1979). Moreover, when tag return rates are known and reasonable assumptions about natural mortality, tagging mortality and the mixing of marked fish can be made, detailed information about absolute exploitation rates can be obtained. In this paper, I present a population model for the mark-recapture data generated by the 1983-1986 3Pn4RS cod tagging programme (Gascon et al., 1990).

Since tags were returned by commercial fishers, the number of tags reported after a fishing season reflects the fishing mortality during the season. The estimation of exploitation rates from this data is complicated by the fact that an unknown number of recaptures were not reported. This is not untypical, Green et al. (1983) showed that some anglers, even when promised a reward for returning tags, chose not to report them. The number of tags returned in such a programme represents only a fraction of the fishing effort so that estimates of harvest rates based only on those would be too low.

Estimates of harvest rates are still possible for programmes involving repeated marking sessions (Brownie et al., 1978). Broadly speaking, this is because each tagging session creates a tagged fish cohort of known initial count. The number of tagged fish that survive to a later date depends on the harvest rate and natural mortality. Assuming a known value for the natural mortality, the concurrent decline of tagged cohorts is entirely driven by the recaptures. This provides a way for estimating the tag reporting rate: the proper value is the one giving the most consistent marked population dynamics for all cohorts exploited together.

Model

A simple model can be used to estimate the tag return rate and to obtain harvest rates. The model requires the following assumptions:

- The natural mortality M is known and constant.
- The tag reporting rate r is constant.
- Fish from different tagging cohorts are exploited together at the same rate.
- The returned tag numbers are independent random Poisson variates.

With these assumptions, the expected number of tagged fish alive after a period where $R_t^{(i)}$ fish from tagging cohort i were returned is given by Pope's approximation:

$$N_{t+1}^{(i)} = N_t^{(i)} e^{-M} - \frac{R_t^{(i)}}{r} e^{-M/2} \qquad (1)$$

where $N_t^{(i)}$ is the number of fish at the beginning of the period. The exact number of fish tagged at each session is known, so that given a value for the tag return rate, all expected population numbers can be calculated.

If the exploitation rate during time period t is H_t, then the expected number of tagged fish recaptures from population (i) is:

$$\mu_t^{(i)} = H_t N_t^{(i)} \qquad (2)$$

and the likelihood that $R_t^{(i)}$ tags will be returned is

$$L_t^{(i)} = \frac{e^{-r\mu_t^{(i)}} (r\mu_t^{(i)})^{R_t^{(i)}}}{R_t^{(i)}!} \qquad (3)$$

combining (2) and (3), taking logs and summing over all tagging cohorts at time t gives the log-likelihood for the return numbers during time period t:

$$l_t = \sum_i -rH_t N_t^{(i)} + R_t^{(i)} \ln(H_t) + R_t^{(i)} \ln(N_t^{(i)}) + R_t^{(i)} \ln(r) - \ln(R_t^{(i)}!) \tag{4}$$

The maximum likelihood value will be attained at

$$H_t = \frac{\sum_i R_t^{(i)}}{r \sum_i N_t^{(i)}} \tag{5}$$

substituting (5) into (4) and ignoring constants we get the log-likelihood

$$l_t = \sum_i R_t^{(i)} \ln(N_t^{(i)}) - \left(\sum_i R_t^{(i)} \right) \ln \sum_i N_t^{(i)} \tag{6}$$

for time period t. This expression depends on the tag return rate r implicitly through equation (1). Note also that the likelihood terms corresponding to time periods where only one tagging cohort is present are constant. The tag return rate can be estimated by maximizing the sum of the log-likelihoods for all time periods.

Refinements

The model can be refined to account for tagging mortality and for increased vulnerability for the first month after tagging. Initial (tagging) mortality can be modeled by correcting the initial cohort sizes prior to first recaptures. Increased vulnerability can be accounted for by dividing the number of reported tags from more vulnerable fish by a *vulnerability* factor in the calculation of the harvest rate (5). Ignoring these phenomenon when they are present would lead to ill-fitting, less credible models with large positive residuals near the tagging months.

The 3Pn4RS cod tagging data

DFO conducted a tagging programme for cod in the northern Gulf of St. Lawrence during the years 1983 to 1986 (Gascon *et al.*, 1990). During the same years, a joint project was conducted by the Ministère de l'agriculture, des pêcheries et de l'alimentation du Québec, but the initial numbers of marked animals from that experiment are not available and therefore these data cannot be combined with the DFO data. The objective of the programme was to study the migration and mixing of the northern Gulf cod. A total of 28727 animals were tagged successfully by DFO (Table 1).

Year	Month	Number of tags
1983	Sept.	6222
1984	May	1509
1984	June	11563
1985	July	2753
1986	June	1263
1986	July	5417

Table 1: Numbers of cod successfully tagged by DFO.

Of those, 3047 usable tags were returned (Table 2) over the years 1983 to 1990. Tags that were returned without some information on the date of capture (at least the year) were not considered usable.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983									**4**	3	2	5
1984	14	18	28	9	**20**	**246**	131	89	49	69	8	2
1985	28	104	57	23	156	152	**210**	102	59	19	8	11
1986	100	105	41	23	47	**32**	**238**	36	1	0	1	0
1987	29	65	22	22	28	66	128	45	15	7	6	4
1988	26	39	37	11	37	11	36	19	6	3	4	0
1989	5	6	3	9	28	14	11	15	4	2	2	0
1990	2	2	6	3	3	1	6	0	0	0	1	8

Table 2: Numbers of tags returned with information on the date of capture. The tagging session months are highlighted.

The maximum likelihood estimate of the tag return rate according to the model described in the previous section is 16.1% and the corresponding harvest rates, converted into the more familiar annual fishing mortalities are given in Table 3. Thus, in June 1984, the 246 tags returns correspond to an estimated 1528 recaptures. These recaptures represent an exploitation rate of 1.264 for a month of the 10985 fish that survived tagging during the same month plus the fish surviving from previous sessions. These estimates of the fishing mortality are independent from research surveys series and catch rate indices. The estimates for the last years are based on very few returns and certainly not very accurate. The fishing mortalities estimated for the periods during or immediately following the tagging sessions are most probably exaggerated because the fish were released close to commercial fishing operations in a vulnerable state that made them more susceptible of being caught than the rest of the stock.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1983									**.052**	.039	.026	.068	
1984	.197	.264	.435	.142	**.253**	**1.264**	.707	.503	.286	.426	.050	.013	.378
1985	.184	.752	.428	.176	1.419	1.588	**1.894**	.970	.588	.192	.083	.117	.699
1986	1.237	1.488	.596	.347	.778	**.431**	**2.041**	.299	.008	.000	.009	.000	.603
1987	.268	.653	.225	.233	.309	.807	1.903	.682	.231	.110	.097	.066	.465
1988	.458	.750	.768	.231	.869	.262	.963	.530	.170	.087	.119	.000	.434
1989	.155	.193	.098	.312	1.106	.575	.475	.703	.189	.096	.099	.000	.333
1990	.103	.106	.335	.172	.177	.060	.382	.000	.000	.000	.068	.589	.166

Table 3: Annual fishing mortalities corresponding to a natural mortality of 0.2, a tagging mortality of 5% and a tag return rate of 16.1%. The tagging session months are highlighted.

Comparison of the deviance residuals (McCullagh and Nelder, 1989, p. 39) from different tagging sessions (Figure 1) indicates that there seem to be a time trend.

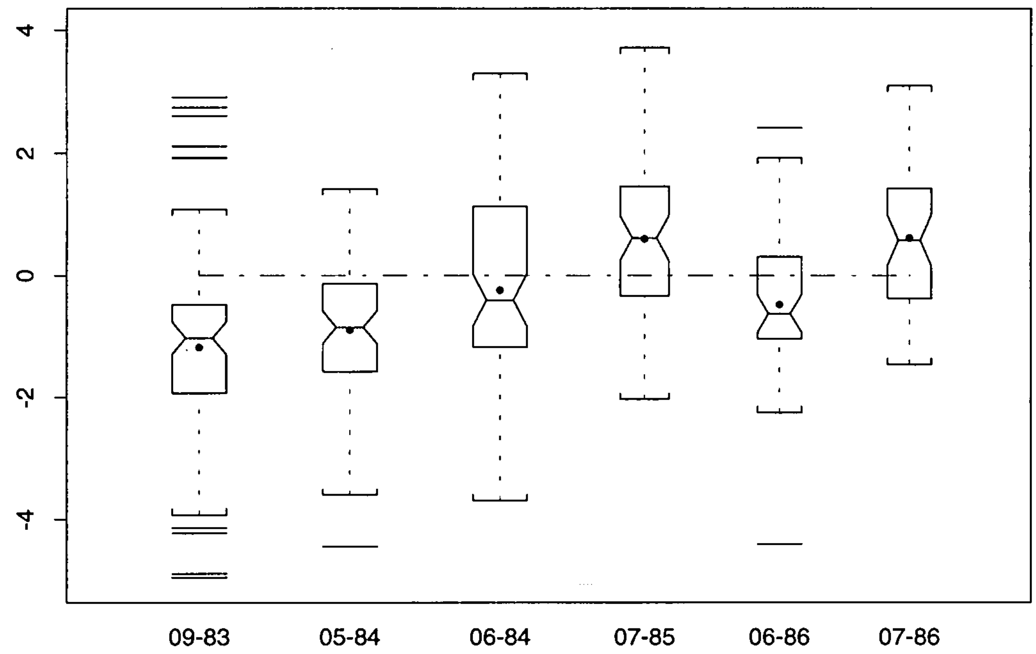

Figure 1 : Box plot of the deviance residuals, natural mortality fixed at 0.2, tag reporting rate estimated at 16.1 % and tagging mortality fixed at 5 %.

The maximum likelihood estimation procedure can be modified to accommodate two extra parameters: an increase in the vulnerability for the first month after release and the initial tagging mortality. The initial tagging mortality is applied only for the fish captured in 1983 and 1984 because it was caught by trawl in warm water which exposes weaker wounded fish to a greater risk of infection than the fish captured in 1985 and 1986 taken from traps and released in colder water (D. Gascon, pers. comm.) The exploitation rate estimates from the modified model are given in Table 4 and the corresponding deviance residuals are illustrated in Figure 2. The fishing mortalities are not modified significantly from the simpler model other than for tagging months but the pattern of residuals is improved.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1983									**.040**	.041	.028	.071	
1984	.207	.278	.459	.150	**.192**	**.643**	.750	.536	.304	.454	.053	.013	.337
1985	.196	.807	.460	.189	1.546	1.751	**1.347**	1.047	.636	.209	.089	.127	.700
1986	1.357	1.652	.663	.385	.874	**.335**	**1.146**	.311	.009	.000	.009	.000	.562
1987	.278	.679	.234	.242	.323	.845	2.011	.721	.244	.117	.102	.070	.489
1988	.487	.799	.822	.248	.936	.282	1.047	.576	.185	.094	.130	.000	.467
1989	.170	.212	.107	.342	1.227	.640	.531	.791	.213	.108	.111	.000	.371
1990	.117	.120	.380	.195	.201	.069	.437	.000	.000	.000	.077	.679	.190

Table 4: Annual fishing mortalities corresponding to a natural mortality of 0.2, a tagging mortality of 11.8%, an initial vulnerability increased by a factor of 2.6 and a tag return rate of 16.6%. The tagging session months are highlighted.

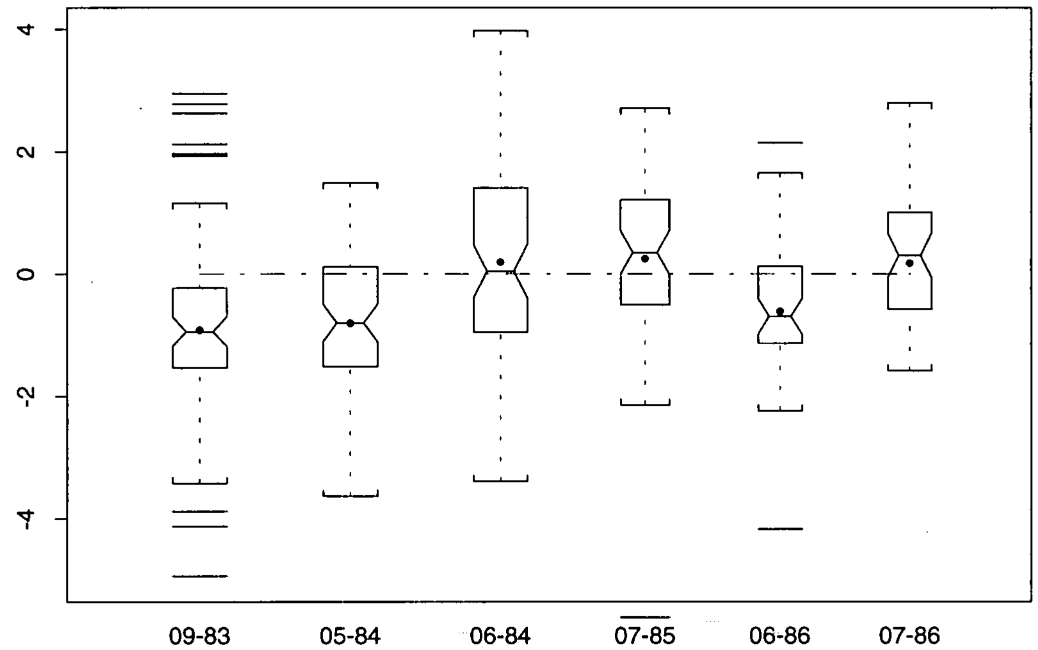

Figure 2: Box plot of the deviance residuals; the natural mortality is fixed at 0.2, the tag reporting rate is estimated at 16.6 %, the tagging mortality at 11.8 % and the vulnerability increase factor for the first month after tagging at 2.6.

Discussion

Model based estimates are only as good as the model assumptions. The model proposed here shares with most SPA models a description of natural mortality which is simplified to the extreme (Megrey, 1989). Exceptional circumstances such as the current cod fishing moratorium could provide the opportunity to estimate natural mortality for this stock. Natural mortality during the period of the moratorium has an effect in our model equivalent to the initial mortality, prior to the beginning of the exploitation period. Thus fish cohorts tagged during the moratorium would be reduced in number at the onset of their exploitation by an amount proportional to the time period since their tagging. After a certain period of exploitation, the natural mortality could be estimated as well as the reporting rate. In the mean time, the exploitation rates of the newly reopened fishery could be assessed using best guesses for natural mortality and reporting rates. These might constitute the only early estimates of fishing mortality available for the critical reopening period as SPA models require many years of catch data to give meaningful results.

Separate studies such as interviews or on-board observer monitoring would be required to refine our description of the tag reporting behaviour of fishers. It should be obvious that higher reporting rates would improve the precision of exploitation rate estimates and could reduce the number of tags required.

The possible presence of relatively separate components (inshore and offshore) within the 3Pn 4RS cod (Anonymous, 1996 and Alain Fréchet, pers. comm.) would require special consideration. If the tagging sessions targeted different stock components and these were not exploited at the same rate or by fishers having the same reporting behaviour, our model would require further refinement.

In summary, the simplified treatment of natural mortality, tag reporting behaviour and fish stock homogeneity could be improved by refining the population model but this would require more tagging data.

It would also be interesting to better characterize the parameter estimates with standard errors. This is not so simple. Equation (4) is the likelihood function at the expected values for the numbers of remaining tags. As such it is not a full likelihood but a profile likelihood, where a large number of nuisance parameters (the harvest rates) have been profiled out. Approximate inferences based on the local properties of this profile likelihood function at its maximum could be very misleading (McCullagh and Nelder, 1989, p. 254). The position of the maximum (the parameter estimates) however coincides with that of the full likelihood.

The population dynamics model used here differs from Seber's (1970) model and its derivatives (Brownie et al., 1978) in that it assumes a value for the natural mortality which allows a relation to be made between the survival rate and the tag recovery rate (Equation 1). It is not possible to estimate the natural mortality with such a model however because that parameter is strongly correlated with the tag reporting rate. The interest of using the tag recovery data in this way is that it provides independent estimates of absolute exploitation rates which can be compared with those obtained from catch and abundance indices using similar assumptions.

The precision of exploitation rate estimates depends on the size of the tagged population and on the tag reporting rate. To maintain a proper tagged fish population during years of intense exploitation, the frequency of tagging sessions should be increased accordingly. To improve tag reporting rates, fishers participation to tagging programmes should be promoted using the most effective incentives. One of which being the opportunity to take part in a very tangible way to the resource assessment process.

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