Estimation of Atlantic Cod Exploitation Rates From a Capture-Recapture Study

SFU

Beliveau, Audrey and Sun, Zheng, Simon Fraser University
abelivea@sfu.ca, zhengs@sfu.ca

Statistics and Actuarial Science
Simon Fraser University
British Columbia, Canada

Introduction

Objective: Estimate the yearly exploitation rates of cod (Gadus Morhua) in coastal Newfoundland

Study: Fisheries and Ocean Canada conducted a capture-recapture study from 1997-2011.

- Approximately 124,000 fish were catched, tagged and re-leased in different regions.
- Fishers were offered rewards for returning the tags (≈ 21,000 fish reported).
- Fish were tagged either with a single low-reward (10$) front tag (78 %), a single high-reward (100$) front tag (13 %) or two low-reward front and back tags (9 %).

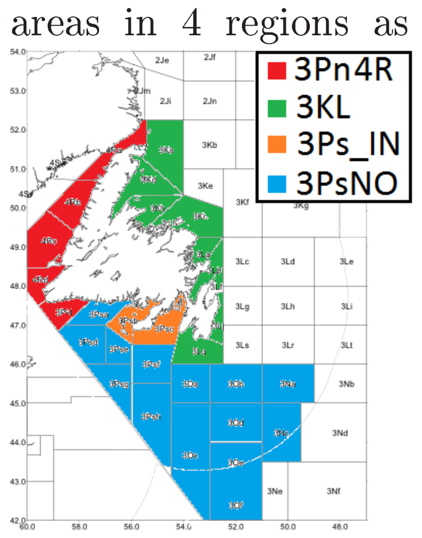
Data: The following information was recorded for both release and recapture (provided the tag was returned): length, NAFO area, date (week near) and tag condition, that is:

- S: Front tag on single low-reward tagged fish
- DF: Front tag only on double tagged fish
- DB: Back tag only on double tagged fish
- DD: Front and back tags on double tagged fish
- H: Front tag on single high-reward tagged fish.

Descriptive Statistics

Time unit and region:

We use yearly data and merge areas in 4 regions as follows:



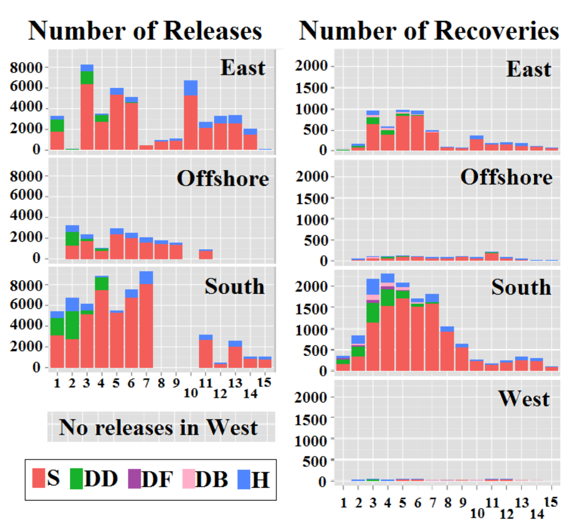
Migration:

Migration between region from release (left) to catch (top).

	E	O	S	W
E	85.1	1.0	13.8	0.1
O	2.8	53.3	25.4	18.6
S	3.4	2.4	94.0	0.2
W	-	-	-	-

Releases and reports:

blablab lablablabl ablabl ablablablabla blablabla



Tag Retention: Double tag releases were recovered 72% as DD, 19% as DB and 9% as DF.

Notation

Data: Let i denote the release year, j the capture year, s the release region, t the capture region and g the tag condition. The data can be summarized into the following quantities:

- N_{ig} : Vector whose sth element is the number of type g =S, DD or H fish released during year i in region s
- R_{ijg}: Random matrix whose element (s,t) is the number of type g =S, D1, D2, DD or H fish released during year i in region s, catched with at least one tag during year j in region t, and returned .

Notation (cont'd)

Parameters:

- ϕ_l: vector whose uth element is the probability that a fish in region u at the beginning of year l survives during the year.
- p_l: vector whose uth element is the probability that a fish in region u at the beginning of year l is captured during the year
- Q_l: matrix whose (u,v) element is the probability that a fish in region u at the beginning of year l migrates to region v by the end of the year.
- Λ_{ilg}: probability that a fish is in tag condition g at the end of year l
- Φ_{ilF} and Φ_{ilG}: cumulative probabilities that a fish in region u at the end of year l retained its Front/Back tag all the way from its release in year i
- λ_{lg}: vector whose uth element is the probability that a fish caught in region u in year l in condition g is reported

Operator: The operator "$\tilde{}$" transforms a d-elements vector into a $d\times d$ diagonal matrix by placing its elements in order along the diagonal

Assumptions

Catch and Release : All releases happened at the beginning of a year and all catches at the end of a year.

Survival, Capture and Migration : Every fish in region u at the beginning of year i have the same survival, migration and capture probabilities over year i.

Reporting Rate: Fish caught at time j with high-reward tag are all reported, that is

$$\lambda_{jH} = 1. \tag{1}$$

Moreover, fish caught with one low-reward tag are all reported with the same probability, that is

$$\lambda_{jS} = \lambda_{jDF} = \lambda_{jDB}. \tag{2}$$

Tag Retention: Double tagged fish retain their front and back tag independently:

$$\Lambda_{ijS} = \Lambda_{ijH} = \Phi_{ijF} \tag{3}$$

$$\Lambda_{ijDD} = \Phi_{ijF}\Phi_{ijB} \tag{4}$$

$$\Lambda_{ijDF} = \Phi_{ijF}(1-\Phi_{ijB}) \tag{5}$$

$$\Lambda_{ijDB} = \Phi_{ijB}(1-\Phi_{ijF}) \tag{6}$$

Brattey and Cadigan (2006) [1] show that...

Closed Population: Fish do not travel outside the study area

Methods

Model: Following Cowen et al. (), we model the R_{ijg}'s as independent Poisson r.v. with parameter $E(R_{ijg})$.

If $g =$ S or H,

$$E(R_{ijg}) = \tilde{N}_{isg}\left[\prod_{l=i}^{j-1}\tilde{\phi}_l Q_l(1-\tilde{p}_l)\right]\phi_j Q_j \tilde{p}_j \Lambda_{ijg}\tilde{\lambda}_{jg} \tag{7}$$

and if $g =$ DF, DB or DD,

$$E(R_{ijg}) = \tilde{N}_{isDD}\left[\prod_{l=i}^{j-1}\tilde{\phi}_l Q_l(1-\tilde{p}_l)\right]\phi_j Q_j \tilde{p}_j \Lambda_{ijg}\tilde{\lambda}_{jg} \tag{8}$$

Methods (cont'd)

Interpretation: Element (s,t) of the matrix $E(R_{ijDF})$ is the expected number of double tagged fish released in year i in region s $(\tilde{N}_{isDD})$ that survived $(\tilde{\phi}_i)$ and migrated (Q_i) and were not captured $(1-\tilde{p}_i)$ during year i. Further, they survived, migrated and were not captured up to the end of year $j-1$. Then, during year j, they survived, migrated to region t and finally were captured (p_j) with only a front tag (Λ_{ijDF}) and were reported (λ_{jDF}).

Tag Loss Model: Following Brattey and Cadigan (2006) [1], we model Λ_{ilF} and Λ_{ilG} using Kirkwood's parametric model. That is, for $h = F$ or B,

$$\Phi_{ilh} = \left[\frac{\beta_{1h}}{\beta_{1h}+\beta_{2h}(l-i)}\right]^{\beta_{2h}}, \beta_{1h}>0, \beta_{2h}>0. \tag{9}$$

Constraining parameters: Parameters that represent probabilities are constrained between 0 and 1 using a logit transformation. Kirkwood's parameters in () are constrained > 0 using an exponential transformation.

Point & Variance Estimation: Maximum likelihood and Delta method

Model Selection: Due to the complexity of the model and the sparse, we have been able to fit only very few models with success. Therefore, we will only present the most sophisticated model we have been able to fit. We would suggest using QAIC to compare different models.

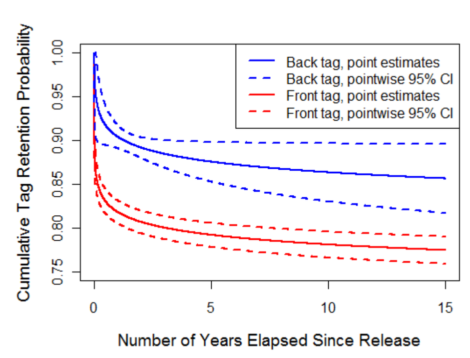
Computing: We use R version ... Our code is general for any time period length or number of regions. We use design matrices allowing to constraint some parameters to be equal. (Newton-Raphson algorithm)

Results

Exploitation rates: Table showing estimate(SE) in % per region and year. (*) : Unable to recover SE numerically

	East	Off	South	West
1997	0.6(0.2)	0.9(0.8)	5.5(*)	8.1(12.5)
1998	5.5(0.9)	2.3(0.5)	5.9(*)	2.3(0.7)
1999	11.3(1.6)	3.3(0.6)	13.4(*)	2.7(0.7)
2000	5.8(0.5)	4.2(*)	12.5(0.6)	0.9(0.2)
2001	7.8(0.6)	3.2(*)	11.2(0.6)	1.7(0.3)
2002	7.6(0.6)	2.6(*)	8.9(0.5)	0.9(0.2)
2003	14.8(1.7)	2.7(0.5)	8.2(0.1)	0.3(0.1)
2004	3.8(0.6)	3.2(0.6)	7.4(0.2)	0.4(0.2)
2005	3.1(0.5)	6.4(1.2)	7.4(0.2)	0.5(0.2)
2006	5.9(0.5)	5.4(0.7)	8.1(0.8)	0.3(0.2)
2007	3.1(0.3)	21.4(1.4)	4.1(0.5)	1.1(0.4)
2008	3.2(0.3)	10.3(1.2)	7.1(0.8)	1.1(0.4)
2009	2.6(0.3)	7.8(*)	5.0(0.4)	1.0(0.4)
2010	1.7(0.2)	6.9(*)	5.6(0.7)	0.7(0.3)
2011	1.0(0.2)	2.8(0.6)	2.6(0.4)	0.4(0.3)

Tag Retention:
Estimated Cumulative Tag Retention Probabilities (Kirkwood's Model)



Migration:

	E	O	S	W
E	94.5	0.6	4.7	0.1
O	0.6	47.6	5.2	46.7
S	3.0	3.3	93.2	0.6
W	0.3	1.9	0.2	97.5

Reporting rates: For fish recovered as S, DF or DB, it varies from 18 % to 99 % with SE's ranging from 3 % to 18 %. For fish recovered as DD, it varies from 7 % to 100 % but many SE's are large and probably indicate identifiability problem. See "further work".

Results (cont'd)

Annual Survival Rate : 74.6 %, SE=0.4. We investigated the effect of doubling the natural death rate on exploitation rates by fixing the survival probability to 49.3 % in our modelé Following table shows estimate(SE) in % per region and year. (*) : Unable to recover SE numerically

	East	Off	South	West
1997	0.6(0.2)	0.9(0.8)	5.5(*)	8.1(12.5)
1998	5.5(0.9)	2.3(0.5)	5.9(*)	2.3(0.7)
1999	11.3(1.6)	3.3(0.6)	13.4(*)	2.7(0.7)
2000	5.8(0.5)	4.2(*)	12.5(0.6)	0.9(0.2)
2001	7.8(0.6)	3.2(*)	11.2(0.6)	1.7(0.3)
2002	7.6(0.6)	2.6(*)	8.9(0.5)	0.9(0.2)
2003	14.8(1.7)	2.7(0.5)	8.2(0.1)	0.3(0.1)
2004	3.8(0.6)	3.2(0.6)	7.4(0.2)	0.4(0.2)
2005	3.1(0.5)	6.4(1.2)	7.4(0.2)	0.5(0.2)
2006	5.9(0.5)	5.4(0.7)	8.1(0.8)	0.3(0.2)
2007	3.1(0.3)	21.4(1.4)	4.1(0.5)	1.1(0.4)
2008	3.2(0.3)	10.3(1.2)	7.1(0.8)	1.1(0.4)
2009	2.6(0.3)	7.8(*)	5.0(0.4)	1.0(0.4)
2010	1.7(0.2)	6.9(*)	5.6(0.7)	0.7(0.3)
2011	1.0(0.2)	2.8(0.6)	2.6(0.4)	0.4(0.3)

Further Work

Length: To be incorporated in the analysis because exploitation rate is known to vary by length. This involves growth curve estimation, see method in Cadigan and Brattey (2001) [2] which was applied to a subset of the 1997-2000 data.

Population structure: Use a latent-state model (eg. bayesian approach) to distinguish between resident inshore and migrant offshore cods.

Reporting rates: As in [2], estimate the odds ratio of reporting double vs single low-reward tags, rather than estimating λ_{DD} (results in improved precision in estimating double tag reporting rates and reduced number of parameters).

Model Sophistication: Fit models successfully using smaller time scale (season, month) and areas.

2-step MLE: Preliminary developements suggest that likelihood can be broken in 2 pieces that can be maximized successively. This allows to estimate tag retention and reporting rates separately, reducing the complexity of the problem.

References

[1] Brattey, J. and Cadigan N.G. (2006). Reporting and Shedding Rate Estimates From Tag-Recovery Experiments on Atlantic Cod (Gadus Morhua) in Coastal Newfoundland. *Can. J. Fish. Aquatic Sc.*, 63(9), 1944-1944.

[2] Cadigan N.G. and Brattey, J. (2001). A Nonparametric Von Bertalanffy Model for Estimating Growth Curves of Atlantic Cod. ICES CM 2001/O:18. Available from: http://www.ices.dk/products/CMdocs/2001/O/O1801.pdf. Accessed May 2012.

[3] Cowen, L. et al. (2009). Estimating Exploitation Rates of a Migrating Population of Yellowtail Flounders Using Multi-State Mark-Recapture Methods Incorporating Tag-Loss and Variable Reporting Rates. *Can. J. Fish. Aquatic Sc.*, 66, 1245-1273.

Acknowledgements

We are indebted and very grateful to Laura Cowen for sharing her code from [3]. Special thanks to our mentor, Carl Schwarz. The authors acknowledge the support from NSERC.