An application of hazard function models to estimate mortality rates affecting fish populations

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Fisheries stock assessment: what is it ? why we do it ?

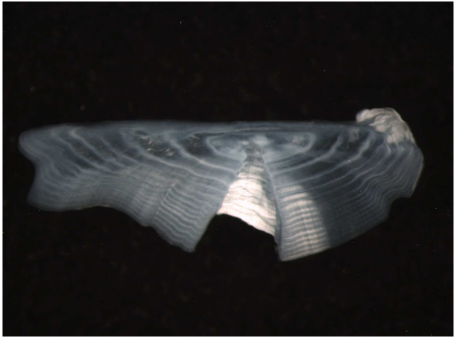
- governments are interested in sustainable exploitation of their natural resources
- fishermen and research organizations collect data to assess the status of fish species
- a mathematical model is calibrated to available data and later used to determine sustainable levels of fishing
- Essentially, a stock assessment model estimates mortality rates (and recruitment)

Motivations for doing this work

- provide estimates of fish mortality rates using age data from a sample of catch
- work within the likelihood framework in order to compare different models

Age data available to fisheries scientists

- otoliths, rings



- continuous time variable segmented into discrete interval (often yearly)
- data from a random sample of the catch

Deterministic theory of fishing for a single cohort

Exponential decline a cohort through time from Quinn and Deriso [1999]

$$\frac{dN}{dt} = -FN - MN \tag{1}$$

$$N(t) = N_0 e^{-(F+M)t} \tag{2}$$

Baranov catch equation (1910)

$$\frac{dC}{dt} = FN \tag{3}$$

$$C_{0\rightarrow\tau} = \frac{F}{M+F} N_0 (1 - e^{-(M+F)\tau}) \tag{4}$$

Deterministic parameters estimations (N_0, M, F) by least square or likelihood using catches at age

PROBLEMS: high number of parameters, convergence failure, require accurate starting values, fixing some parameters as a solution, etc...

Survival analysis approach to a single cohort

Survival analysis [Cox and Oakes, 1984, Ferrandis and Hernández, 2007] using a constant hazard function

$$h(t;\theta) = M + F \tag{5}$$

The probability density function (pdf)

$$f(t;\theta) = (M + F)\ e^{-(M+F)t} \tag{6}$$

The likelihood [Edwards, 1992] of a sample of fish caught in the fishery (S_i) using the probability of dying in the interval $[a_i; a_{i+1}]$.

$$\mathcal{L} = \prod_{i=1}^{n} \Big(\int_{t=a_i}^{t=a_{i+1}} f(t;\theta)\ dt \Big)^{S_i} \tag{7}$$

The logarithm of the likelihood was

$$\log(\mathcal{L}) = \sum_{i=1}^{n} S_i \log\big(e^{-(M+F)\times a_i} - e^{-(M+F)\times a_{i+1}} \big) \tag{8}$$

Can we deal with particular cases within this framework

- restricted range of ages $\rightarrow$ truncated pdf
- +group $\rightarrow$ integrate over a larger interval $[a_+; \infty[$

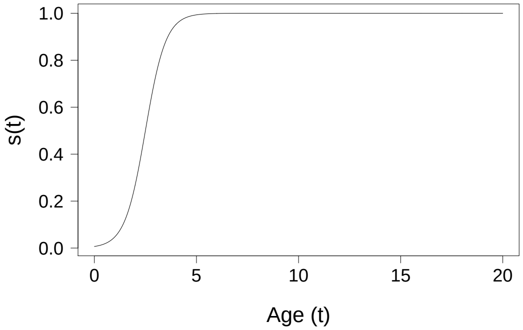
Hazard models for more complicate situations

Fishing mortality is a function of effort (E)

$F(t) = q\ E(t) \rightarrow h(t;\theta) = M + q\ E(t)$

Gear selectivity (s) varies with age

$F(t) = q\ s(t)\ E(t) \rightarrow h(t;\theta) = M + q\ s(t)\ E(t)$



Applying hazard model to data from multiple cohort

		age − groups				
		1	$\ldots$	j	$\ldots$	n
years	1	$\ldots$		$\ldots$		$\ldots$
	$\vdots$	$\ldots$		$\ldots$		$\ldots$
	i	$\ldots$		$S_{i,j}$		$\ldots$
	$\vdots$	$\ldots$		$\ldots$		$\ldots$
	p	$\ldots$		$\ldots$		$\ldots$

- $n + p - 1$ cohorts, separability $F_{i,j} = q\ E_i \otimes s_j$

The likelihood

$$\mathcal{L} = \prod_{k=1}^{n+p-1} \prod_{l=1}^{r_k} \Big(\int_{t=a_{k,l}}^{t=a_{k,l+1}} g_k(t;\theta)\ dt \Big)^{S_{k,l}} \tag{9}$$

Computer implementation of these methods

Methods implemented in R [R Core Team, 2013] in a package called Survival Analysis for Fisheries Research (SAFR)

Available at: `https://github.com/mkienzle/SurvivalAnalysisForFisheries`

Manuscript: `http://arxiv.org/abs/1501.03131`

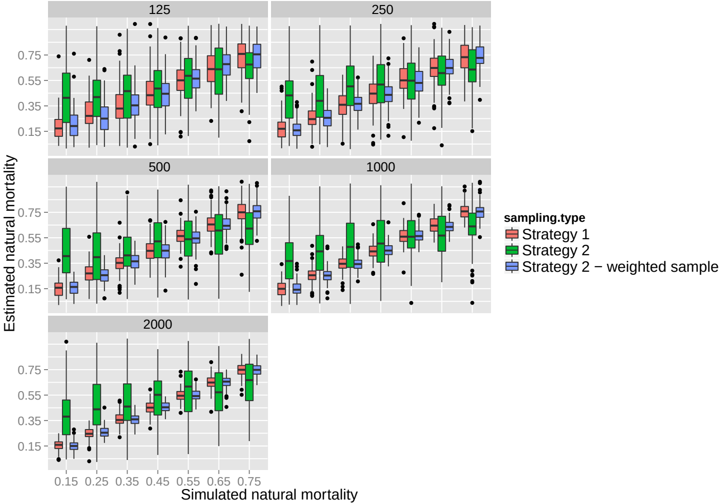
Testing hazard functions with Monte Carlo simulations

Simulate a fishery using random population characteristics (recruitment, natural mortality) and random catch (catchability, effort and gear selectivity)

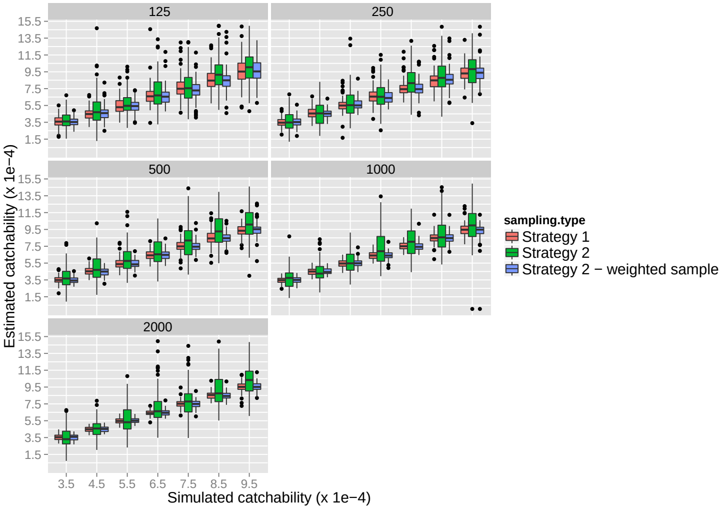
2 types of sampling to generate artificial catch data

- random sampling (benchmark) [strategy 1]
- systematic [strategy 2] (weighted by catch or un-weighted)

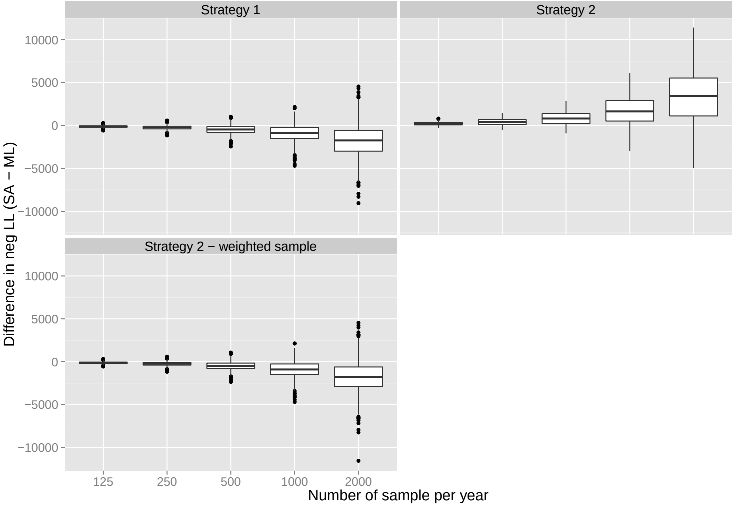
Hazard function models can estimate natural mortality when age-sample are weighted by total catch



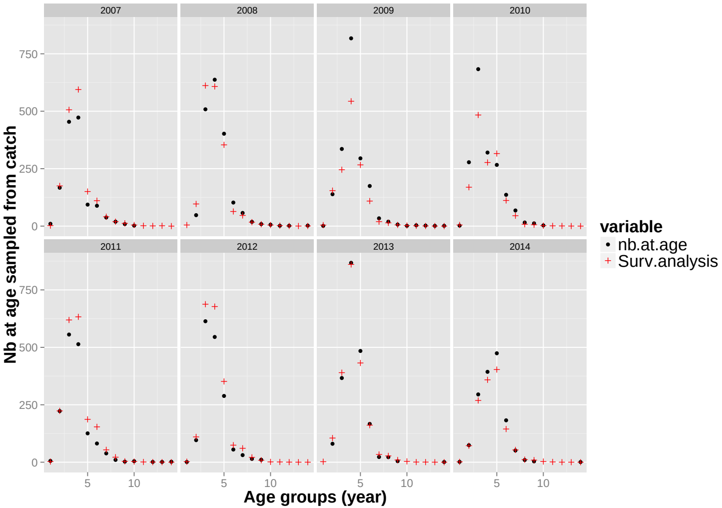
Sampling strategy 2 using weighted samples can estimate catchability (q)



Hazard function fit better than the traditional multinomial approach



Example of fit to real data (Qld mullet fishery)



Conclusions

- hazard functions seems perfectly suited to estimate mortality rates for fisheries research
- likelihood ratios suggest survival analysis provides a better model of mortality rates than the traditional one
- for the moment, survival analysis seems fairly unknown in fisheries research circles

Characteristics	Traditional methods	Survival analysis
likelihood based	not always	yes
use all data	not always	yes
estimate nat. mort.	no	yes
tested with MC	not always	yes

Thank you for your attention

- Any comments about applying survival analysis to estimate fish mortality rates ?
- Do you know of any R package readily available to process fish-age data ?
- Would you like to contribute your expertise to articles on this topic ?