A simulation framework for exploring spatio-temporal dynamics in mixed fisheries

Paul J. Dolder[a,b,*], Cóilín Minto[a], Jean-Marc Guarini[c], Jan-Jaap Poos[d]

[a] *Galway-Mayo Institute of Technology (GMIT), Dublin Road, Galway, Ireland*
[b] *Centre for Environment, Fisheries and Aquaculture Science (Cefas), Pakefield Road, Lowestoft, UK*
[c] *Université Pierre et Marie Curie, 4 Place Jussieu, 75005 Paris, France*
[d] *Wageningen Marine Research, Haringkade 1 1976 CP IJmuiden, Netherlands*

Abstract

[A concise and factual abstract is required. The abstract should state briefly the purpose of the research, the principal results and major conclusions. An abstract is often pnresented separately from the article, so it must be able to stand alone. For this reason, References should be avoided, but if essential, then cite the author(s) and year(s). Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself. Graphical abstract: Although a graphical abstract is optional, its use is encouraged as it draws more attention to the online article. The graphical abstract should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of 531 X 1328 pixels (h X w) or proportionally more. The image should be readable at a size of 5 x 13 cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files.]

Keywords: Some, keywords, here. Max 6, American ”spelling”

2010 MSC: 00-01, 99-00

*Corresponding author
Email address: paul.dolder@gmit.ie (Paul J. Dolder)

1. Introduction

Fishers exploit fish populations that are heterogenously distributed in space and time without prior knowledge of species distributions and non-selective fishing gear. Fisheries managed by single-species quotas still catch an assemblage of species, known as mixed fisheries, leading to discarding of overquota catch. Reducing discarding is crucial to ensure biological and economic sustainability of fisheries and as such there is increasing interest in technical solutions such as gear, spatial closures as a way of avoiding discarding unwanted catch.

Use of spatial management as a tool is hampered by lack of knowledge of fish and fishery spatiotemporal dyanmics and understanding of the scale at which processes are important for management, crucial in order to implement measures at the right resolution to ensure effective management[1] which promote species avoidance for vulnerable or low quota species while allowing continance of sustainable fisheries for available quota species.

Ensuring measures are implemented at an appropriate scale has been a challenge in the a past that has led to ineffectual measures with unitended consequences such as limited impact towards the management objective wirth increased benthic impact on previously unexploited areas (e.g. the cod closure in the North Sea[2, 3]). Since then more refined spatial information has become available through the combination of logbook and Vessel Monitoring System (VMS) data[4, 5, 6, 7], though such information is patchy and derived from a biased sampling programme (i.e. targeted fishing). Further, generally fishers only recorded landings (not catch) on a daily basis. This leads to questions about the validity of inferences that can be drawn from landings data assigned to VMS activity pings.

In order to test the assumption that VMS associated landings data can be used to draw inference on the underlying population structures we develop a simulation model where population dynamics are known rather than inferred from sampling or commercial catches, population movement driven by a random (diffusive) and directed (advective) process and characterisation of a number of different fisheries exploiting four fish populations with different spatial and population demographics.

Using our model we simulation 20 years of exploitation of the fish populations and use the results to draw inference on the underlying population structures. We compare this inference to i) a simulated stratified fixed-site sampling design commonly used for fisheries monitoring purposes, ii) the underlying population structures input to the simulation.

[Could fit a geostatistical model (e.g. VAST) to the fisheries-dependent and fisheries-independent data, though may be overkill...]

We simulate a fishery closure to protect one species based on the fishery-dependent inferred distributions at a spatial and temporal scale typical in fisheries management, and assess a theoretical "benefit" to the population, and effect on the other three populations. Further, we extend our analysis to a range of spatial and temporal scales to assess the impact of these processes on the success of the management measure.

[Guidance:: State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.]

2. Materials and Methods

[Provide sufficient details to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized, and indicated by a reference. If quoting directly from a previously published method, use quotation marks and also cite the source. Any modifications to existing methods should also be described.]

We developed a simulation model with a modular discrete-event approach to each of the processes so that they can occur on different time-scales. The fishing model operated on a tow-by-tow basis, while population dynamics (fishing and natural mortality, growth) operate on a daily time-step. Population movement occurs on a two-weekly time-step, while recruitment occurs periodcally each year for a set time period (e.g. 3 weeks) at at specified point individual to a species. The model structure is summerised in Figure 1.

2.1. Population dynamics

The basic population level processes are simulated using a modified two-stage Deriso-Schnute delay difference model [8, 9] occurring at the weekly time-step [10]. Here, population biomass growth and depletion for pre-recruits and fish recruited to the fishery are modelled separately as a function of previous recruited biomass, intrinsic population growth and recruitment:

$$
\begin{aligned}
B_{y,w+1} = & \\
& (1+\rho)B_{y,w} \cdot e^{-Z_{y,w}} - \rho \cdot e^{-Z_{y,w}} \qquad \times \\
& (B_{y,w-1} \cdot e^{-Z_{y,w-1}} + Wt_{R-1} \cdot \alpha_{w-1} \cdot R_{\tilde{y}(y,w-1)}) \quad + \\
& Wt_R \cdot \alpha_w \cdot R_{\tilde{y}(y,w)}
\end{aligned}
$$

ρ is Brody's coefficient, shown to be approximately equal to $exp(-K)$, where K is the growth rate from a von bertalanffy logistic growth model [9]. Wt_{R-1} is the weight of fish prior to recruitment, while Wt_R is the recruited weight. α_w represents the proportion of fish recruited during the week, while $R_{\tilde{y}}$ is the annual recruits.

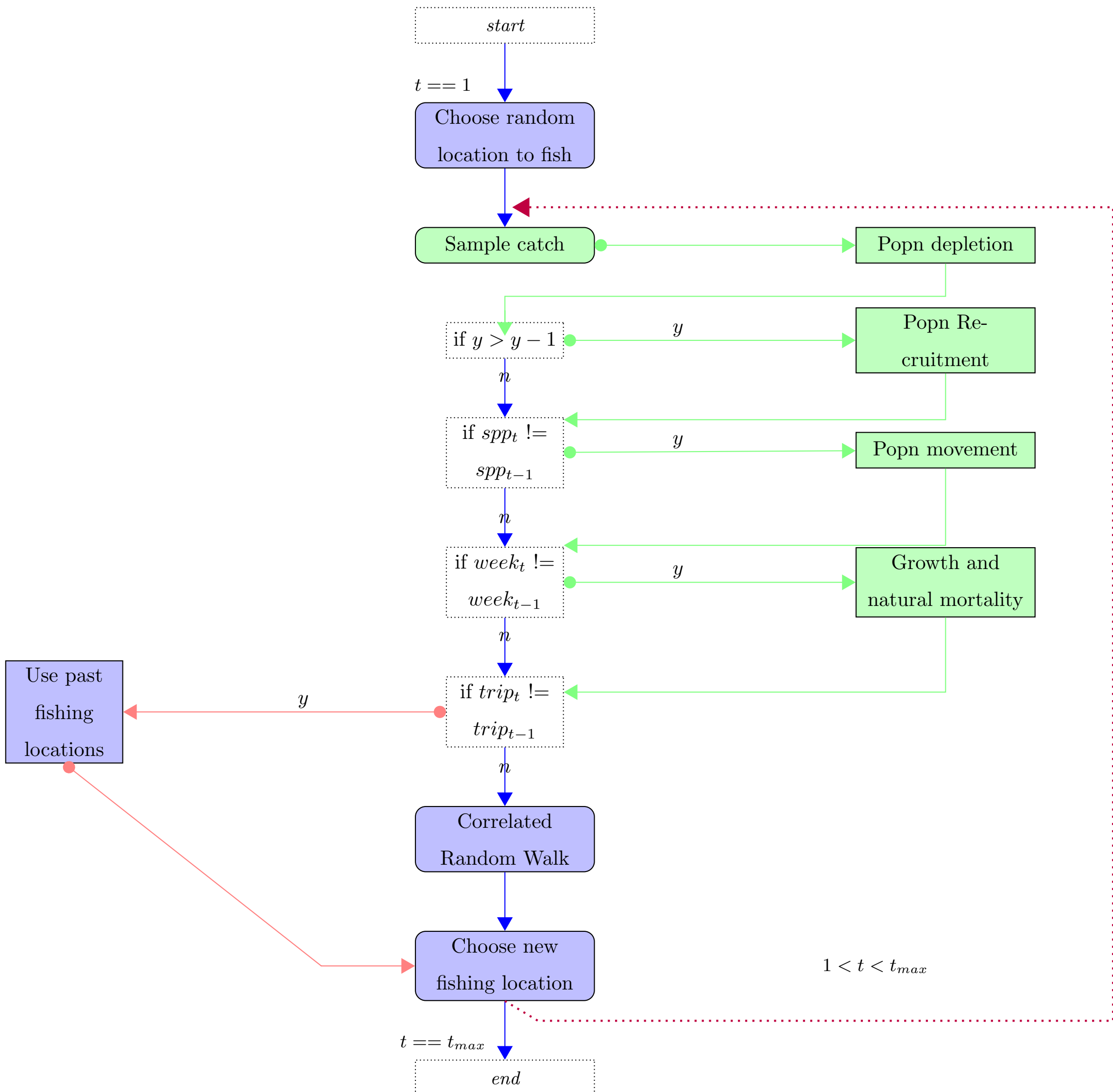

Figure 1: Overview Schematic of simulation model

Mortality Z can be decomposed to natural mortality, M, and fishing mortality, F, where both M and F are instantaneous rates with M fixed and F calculated by solving the Baranov catch equation [11] for F:

$$C_w = \frac{F_w}{F_w + M_w} * (1 - e^{-(F_w+M_w)}) * B$$

where C is the summed catch from the fishing model across all fleets and vessels for the species, year and week respectively, and B the weekly biomass for the species.

2.2. Recruitment dynamics

Recruitment is modelled through a function relating the biomass at time of recruitment to recruits, either as a stochastic Beverton-Holt stock-recruit form ([12]):

$$\bar{R} = \frac{(\alpha * B)}{(\beta + B)}$$
$$R \sim N[(\bar{R}, \sigma^2)]$$

Where α is the maximum recruitment rate, β the spawning stock biomass (SSB) required to produce half the maximum, and B current SSB;

or a stochastic Ricker form [13]

$$\bar{R} = B * e^{(\alpha - \beta * B)}$$
$$R \sim N[(\bar{R}, \sigma^2)]$$

where α is the maximum productivity per spawner and β the density dependent reduction in productivity as the SSB increases.

2.3. Population movement

2.4. Fleet dynamics

3. Theory/calculation

[A Theory section should extend, not repeat, the background to the article already dealt with in the Introduction and lay the foundation for further work.

In contrast, a Calculation section represents a practical development from a theoretical basis.]

HERE DESCRIBE THE PARAMETERISATION, AND ANY COMPARISON AGAINST 'REAL' DATA

4. Results

Present simulated closures in terms of % change in population biomass and fishery.

[Results should be clear and concise.]

5. Discussion

This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

6. Conclusions

The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

Appendices

If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Abbreviations

Detail any unusual ones used.

Acknowledgements

those providing help during the research..

Funding

This work was supported by the MARES doctoral training program; and the Centre for Environment, Fisheries and Aquaculture Science seedcorn program.

References

[1] D. C. Dunn, S. M. Maxwell, A. M. Boustany, P. N. Halpin, Dynamic ocean management increases the efficiency and efficacy of fisheries management, Proceedings of the National Academy of Sciences (2016) 201513626`doi:10.1073/pnas.1513626113`.
URL `http://www.pnas.org/content/early/2016/01/02/1513626113.abstract`

[2] A. D. Rijnsdorp, G. J. Piet, J. J. Poos, Effort allocation of the Dutch beam trawl fleet in response to a temporarily closed area in the North Sea, Ices Cm 2001/N: 01 (2001) 1–17.

[3] T. A. Dinmore, D. E. Duplisea, B. D. Rackham, D. L. Maxwell, S. Jennings, Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities, ICES Journal of Marine Science 60 (2) (2003) 371–380. `doi:10.1016/S1054-3139(03)00010-9`.

[4] J. Lee, A. B. South, S. Jennings, Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data, ICES Journal of Marine Science 67 (6) (2010) 1260–1271. `doi:10.1093/icesjms/fsq010`.

[5] F. Bastardie, J. R. Nielsen, C. Ulrich, J. Egekvist, H. Degel, Detailed mapping of fishing effort and landings by coupling fishing logbooks with

satellite-recorded vessel geo-location, Fisheries Research 106 (1) (2010) 41–53. doi:10.1016/j.fishres.2010.06.016.
URL http://dx.doi.org/10.1016/j.fishres.2010.06.016

[6] H. D. Gerritsen, C. Lordan, C. Minto, S. B. M. Kraak, Spatial patterns in the retained catch composition of Irish demersal otter trawlers: High-resolution fisheries data as a management tool, Fisheries Research 129-130 (2012) 127–136. doi:10.1016/j.fishres.2012.06.019.
URL http://dx.doi.org/10.1016/j.fishres.2012.06.019

[7] M. Mateo, L. Pawlowski, M. Robert, Highly mixed fisheries: fine-scale spatial patterns in retained catches of French fisheries in the Celtic Sea, ICES Journal of Marine Science: Journal du Conseil (2016) fsw129doi:10.1093/icesjms/fsw129.
URL http://icesjms.oxfordjournals.org/lookup/doi/10.1093/icesjms/fsw129

[8] R. B. Deriso, Harvesting Strategies and Parameter Estimation for an Age-Structured Model, Canadian Journal of Fisheries and Aquatic Sciences 37 (2) (1980) 268–282. arXiv:arXiv:1410.7455v3, doi:10.1139/f80-034.

[9] J. Schnute, A genera theory for analysis of catch and effort data, Canadian Journal of Fisheries and Aquatic Sciences 42 (1970) (1985) 414–429. doi:10.1139/f85-057.

[10] C. M. Dichmont, A. E. Punt, A. Deng, Q. Dell, W. Venables, Application of a weekly delay-difference model to commercial catch and effort data for tiger prawns in Australia ' s Northern Prawn Fishery, Fisheries Research 65 (2003) 335–350. doi:10.1016/j.fishres.2003.09.024.

[11] R. Hilborn, C. Walters, Quantitative fisheries stock assessment: Choice, dynamics and uncertainty, Vol. 2, 1992. arXiv:arXiv:1011.1669v3, doi:10.1007/BF00042883.

[12] R. J. Beverton, S. J. Holt, On the Dynamics of Exploited Fish Populations (1957) 533doi:10.1007/978-94-011-2106-4.

[13] W. E. Ricker, Stock and recruitment, Journal of the Fisheries Research Board of Canada 11 (5) (1954) 559 – 623.