Fisheries Research Short Communication

Title: Towards triple separability: a proof-of-concept that simultaneously estimates correlations for age, year, and cohort effects in stock assessment processes

Abstract: Many demographic processes vary by age and over time, and accounting for this variation within fisheries management remains a key challenge for many contemporary stock assessments. Although there is evidence for time, age, and cohort specific effects on various components within stock assessment (e.g., selectivity, growth), methods are lacking to simultaneously estimate autocorrelation over time, among ages, and by cohort while also quantifying residual variation. Drawing from previous research on separable cohort models, we reintroduce the idea of “triple-separability”, which simultaneously estimates autocorrelation for time, age, and cohort effects, and reduces to two-dimensional autocorrelation when one of the processes is fixed at zero. Utilizing XXX as a case-study, we illustrate differences in predicted weight-at-age values from models with and without a triple-separable assumption and show that traditional model selection tools can be used to identify the relative evidence and magnitude of age, time, and cohort effects. We recommend that the method be integrated as a routine option within next-generation stock assessments, and note that it generalizes widely-used options in existing assessment frameworks (i.e., WHAM and SAM).

Introduction:

Fisheries often experience dynamic shifts in demographic (e.g., growth, natural mortality, movement) and removal processes (e.g., fleet structure, selectivity), which can be facilitated by environmental forcing and management regulations [(Eigaard *et al.*, 2014; King *et al.*, 2015)](https://www.zotero.org/google-docs/?U3GJX4). Although it is well recognized that these processes are correlated and vary across, space, time, ages, and cohorts [(Sampson and Scott, 2012; Taylor and Methot, 2013; Thorson and Minte-Vera, 2016)](https://www.zotero.org/google-docs/?i5MiUJ), these processes are commonly represented as invariant within stock assessments. We first briefly discuss how these processes can arise within fisheries, and then provide examples for the consequences of assuming invariant age, time, and cohort-dependent effects. Correlated age processes can arise when individuals of the same age-classes experience habitat conditions that result in consistent ontogenetic variation in demographic processes. Likewise, year processes can arise when individuals in a given year experience similar environmental conditions (e.g., marine heatwaves; [Barbeaux *et al.*, 2020)](https://www.zotero.org/google-docs/?UN74xd), or when the fishery experiences changes in fishing practices [(Martell and Stewart, 2014)](https://www.zotero.org/google-docs/?3W3sbR). Finally, cohort-specific effects can result from large recruitment events that alter targeting strategies from fishers and/or density dependence in growth [(Rose *et al.*, 2001; Goethel *et al.*, 2021)](https://www.zotero.org/google-docs/?b7ZJms). However, as noted previously, these processes are often assumed to be invariant within stock assessments, despite evidence suggesting otherwise. Nonetheless, failing to appropriately account for these processes can result in biased estimates of model results and resulting harvest recommendations. For example, [Taylor and Methot, (2013)](https://www.zotero.org/google-docs/?1Wo37p) found that disregarding individuals exhibiting differential growth trends resulted in biased estimates of spawning biomass and depletion. Similarly, failing to account for time-varying selectivity, and age-and-time varying natural mortality has been illustrated to result in biased estimates of quantities [reference points, spawning biomass, recruitment (Deroba and Schueller, 2013; Martell and Stewart, 2014)](https://www.zotero.org/google-docs/?jlEIGP). Consequently, it is imperative for stock assessment models to be parameterized by realistic model structures that adequately represent the underlying stock and fishery dynamics.

Parameterizing model structures that are both rationally and biologically motivated is often a key challenge within stock assessment modeling. However, recent advances in computational tools have aided in such model parameterizations [(Kristensen *et al.*, 2016)](https://www.zotero.org/google-docs/?pN934r), allowing for the efficient computation of latent variables, which are well-suited to represent correlations in biological and fishery processes [(Nielsen and Berg, 2014; Xu *et al.*, 2019; Stock and Miller, 2021)](https://www.zotero.org/google-docs/?fwiF5Q). However, methods are currently lacking that allow for the simultaneous estimation of correlated processes among ages, years, and cohorts. Thus, drawing from research on separable cohort models, we reintroduce the idea of “triple-separability”, which was initially applied to estimate age, time, and cohort-dependent processes in selectivity, to account for the increased vulnerability of more abundant cohorts (*sensu* [Vasilyev, 2000)](https://www.zotero.org/google-docs/?UhaNTi). In the present study, we extend this work by estimating correlations among ages, years, and cohorts for weight-at-age represented as a Gaussian Markov Random Field (GMRF) using XXX as a case-study. Our method described is widely applicable, and can be extended to represent other biological and fishery parameters that are commonly estimated within integrated stock assessments.

Methods:

Results:

* Highlight key differences between predicted WAA matrix with and without triple separability and AIC results

Discussion:

* Discussion on: 1) general results, and 2) how Wald tests and AIC can be used for model selection
* Discuss about the benefits of implementing triple-separability, and potential consequences of failing to account for such processes
  + Describe to the audience that this can be practical within contemporary stock assessments and can be implemented in growth, natural mortality, selectivity processes, survival, maturity (e.g., tell folks what the main use of this new method is).
* Potential limitations and caveats of this method?
* Link to current literature (e.g., state-space models, GMRFs, 2DAR1 processes that are currently being implemented)
* Finally, discuss future research (e.g., simulation testing, real-world examples, and implement on other components of stock assessment)

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