LETTER

Production is a poor metric for identifying regime-like behavior in marine stocks

Vert-pre et al. (1) identified regimes in productivity for marine fish stocks, with the goal of urging management to develop strategies that are robust to regime-like behavior. Identification of drivers of productivity [i.e., is the stock driven by spawning biomass (the abundance hypothesis in Vert-pre et al.'s analysis in ref. 1) or environment (the regimes, random, and mixed hypotheses)?] is key to selecting management strategies. Management strategies that are robust to regime-like behavior (e.g., constant F or shifting target biomasses) can be more risky for spawning biomass-driven stocks. Therefore, to be useful to management, the presented methods must identify the drivers of productivity for individual stocks and answer the question: Are production dynamics driven by spawning biomass or the environment for this stock? In table 2 of ref. 1, "Abundance" denotes spawning biomass-driven production, yet these methods only identify spawning biomass-driven production as well as flipping a coin would (54%). Making some adjustment for bias and declaring some percentage of stocks show shifts in production regime attributable to changes in spawning biomass are not useful to management because, with no way of identifying drivers of production for an individual stock, the precautionary principle behooves management to assume spawning biomass drives production: the consequences of the contrary assumption are too great (2). Hilborn (3) used this same argument to rebut Gilbert's (4) claims of environmentally driven recruitment.

The application of production models to stocks which are structured by age or size compounds the problem of misidentification of spawning biomass-driven stocks. Vert-pre's (1) methods were unable to identify a simulated stock deterministically driven by spawning biomass as driven by biomass (see Fig. 1 for description). Surplus production following a Mixed model is expected for a spawning biomass-driven stock which includes age structure when the common fish down/stabilize pattern of fishing mortality is applied (5). Furthermore, the abundance model was only selected 24% of the time when the methods were applied to 1,000 simulations of the above stock with stochasticity in recruitment ($\sigma_R = 0.6$). This level of misclassification is considerably higher than that reported, and this simulated stock has near-ideal contrast in the data. Stocks with poorer contrast may be more poorly identified.

The thought process behind Vert pre et al. (1) is a step in the right direction, and it is difficult to simulate the size of the changes in regimes that are seen in some of the stocks in Vert-pre et al.'s analysis without changes in parameters determining productivity. The environment is likely important to the productivity of exploited marine stocks but, until methods are formulated that can identify a stock with spawning biomass-driven production, the precautionary approach must prevail.

Cody Szuwalski[1]
School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195

1 Vert-pre KA, Amoroso RO, Jensen OP, Hilborn R (2013) Frequency and intensity of productivity regime shifts in marine fish stocks. *Proc Natl Acad Sci USA* 110(5):1779–1784.
2 Myers R-A, Hutchings J-A, Barrowman N-J (1996) The decline of cod in the north Atlantic. *Mar Ecol Prog Ser* 138: 293–308.
3 Hilborn R (1997) Comment: Recruitment paradigms for fish stocks. *Can J Fish Aquat Sci* 54(4):984–985.
4 Gilbert D-J (1997) Towards a new recruitment paradigm for fish stocks. *Can J Fish Aquat Sci* 54(4):969–977.
5 Punt A-E, Szuwalski C-S (2012) How well can FMSY and BMSY be estimated using empirical measure of surplus production? *Fish Res* 134-136:113–124.

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[1]E-mail: szuwalsk@uw.edu.

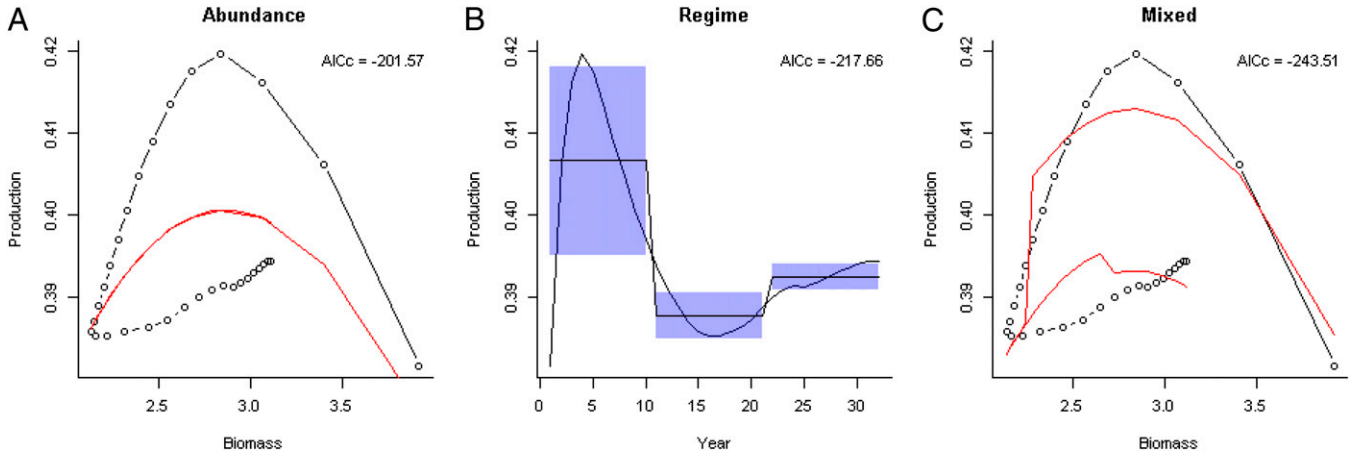

Fig. 1. Application of Vert-pre et al.'s (1) methods to a surplus production from the deterministic simulation of an age-structured stock with dynamics driven by spawning biomass, and fishing mortality following a fish down/stabilize pattern. Purple boxes (*B*) denote regime shifts identified by STARS (see *Methods* in ref. 1). Red lines are the fits of the respective models in *A* and *C*.

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