Ecosystem Based Fisheries Management; Indicators; Maximum Sustainable Yield; Non-Stationarity; Productivity

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April 20, 2020

Abstract

The Ecosystem Report Card of the Sub-Committee on Ecosystems includes indicators for assessed species based on productivity, i.e. trends of biomass or spawning stock biomass relative and fishing mortality or harvest rate relative to Maximum Sustainable Yield reference points. The objective is to assess whether the main target stocks are in a healthy, cautious or critical state and how this has changed over time. Productivity, however, depends on a variety of physical and biological processes. We therefore use the stock assessments for bigeye and yellowfin tunas from the Atlantic, Indian and Eastern Pacific Oceans, to illustrate the use of diagnostics based on production functions and surplus production trajectories to explore changes in productivity.

Keywords: EBFM, productivity, bigeye, yellowfin

1 Introduction

ICCAT has recently amended its Convention in order to move towards an Ecosystem Approach to Fisheries Management (EAFM). To do this the Commission and its Members shall act to: (a) apply the precautionary approach and an ecosystem approach to fisheries management in accordance with relevant internationally agreed standards and, as appropriate, recommended practices and procedures; (b) use the best scientific evidence available; and (c) protect biodiversity in the marine environment.

Currently the main tool developed by the SCRS to implement an EAFM is the Ecosystem Report Card (ERC) of the Sub-Committee on Ecosystems (SC-ECO). This includes indicators for assessed species and as the Commission moves towards EAFM there is a need to develop models for stock assessment and management that integrate environmental conditions (Travis et al., 2014). Particularly since growth and mortality, and recruitment, may be driven by environmental pressure.

Currently the indicators used for assessed species are based on the ratios of biomass or spawning stock biomass (SSB) relative to B_{MSY}, and fishing mortality or harvest rate relative to F_{MSY}. These indicators are obtained either from age-structured stock assessments that integrate changing vulnerability schedules, mean recruitment relationships, and recruitment anomalies, to estimate stock trends and reference points, or biomass dynamic assessments that fit a production function based on population growth rate (r), carrying capacity (K). In the age-structured models there is an implicit production function and changes in productivity can occur due to process error modelled as variability in recruitment and/or selection pattern. In the biomass dynamic models with an explicit production function process error can be modelled explicitly.

In age-structured models density dependence is mainly accounted for by the stock recruitment relationship. Cury et al. (2014), however, showed that in most cases the stock-recruitment relationship used to estimate productivity and determine reference points, has poor estimation/predictive power and the environmental has a larger effect on productivity, a results confirmed by other studies (e.g. Szuwalski et al., 2015, 2019; Free et al., 2019), and observed 100 years ago by Hjort (1914). Whereas in ICCAT assessments growth, maturation and natural mortality are assumed not to have varied despite the large changes in the environment and stock biomass seen.

Hilborn (2001) therefore recommended looking at patterns of change in surplus production (SP) since these may contain evidence of changes in the growth and mortality components of production, which are typically not represented in models currently used for stock assessment and management. We therefore use the integrated stock assessments conducted with Stock Synthesis 3 (Methot and Wetzel 2013) (Methot, 2005, SS3) for bigeye (in italics: Thunnus obesus) and yellowfin tuna (Thunnus albacares) stocks in the Atlantic, Indian and Eastern Pacific Oceans to estimate surplus production and explore whether the dynamics are determined by a production function or dynamics are recruitment-driven and influenced by the environment.

2 Material and Methods

Walters et al. (2008) argued that plotting of surplus production (SP) against biomass (B) should be one of the basic pieces of information presented in all stock assessments since the plots provide a check on whether there has been non-stationarity in the annual surplus production, i.e. whether similar B levels have exhibited similar SP at different historical times. This is important for management as it checks whether predictions of changes in biomass ($B_{t+1} - B_t$) can be made reliably based on catch and B_t. Plots of SP v B therefore provide a summary of stock performance and include effects not necessarily included in stock assessment models.

The effects not included in the production function used to predict SP can be modelled by an process error term ϵ_t.

$B_{t+1} = B_t - C_t + SP_t + \epsilon_t$

Process error on biomass can account for model structural uncertainty as well as natural variability of stock biomass due to stochasticity in recruitment, natural mortality, growth, and maturation (Francis and Hilborn, 2011; Meyer and Millar, 1999; Thorson et al., 2015; **?**).

We therefore examine the relationships between surplus production and biomass for bigeye and yellowfin tuna stocks in the Atlantic, Indian and Eastern Pacific Oceans using the results from integrated stock assessments. To do this we estimate annual surplus production as the change in stock size plus catch (i.e. $B_t B_{t+1} + C_t$). We then plot the resulting time series of S and B to identify patterns of variation in S.

The process error was then sampled from SS3 stock trajectories as the difference between deterministic expectation of biomass and its stochastic realisation, such that:

$\epsilon_t = SB_t + 1 - (SB_t + SP_t - C_t)$ (I'd prefer this on log-scale)

Long-term changes in process error regimes were evaluated using a sequential t-test algorithm for regime shifts (Rodionov, 2004).

In the case of ICCAT and IOTC stocks, quarterly assessment models were used surplus production was calculated on an annual basis by aggregating catch and biomass across seasons and areas using r4ss[1].

3 Results

Time series of SSB, biomass and catch relative to MSY reference points are shown in **Figure** 1. For both ICCAT and IOTC stock has declined as a result of an increase in fishing pressure. In the case of ICCAT yellowfin a large increase in biomass and SSB was seen which appears to have been independent of fishing pressure. The picture in the Eastern Pacific Ocean appears less clear as changes in biomass and SSB appear to occur independently of fishing pressure.

Surplus production is plotted against biomass in **Figure** 2, dark to light colour of the trajectory indicates early to late periods. Clockwise cycling is seen in SP for IAATC bigeye, ICCAT yellowfin and IOTC yellowfin. This is caused by positive production anomalies, i.e. productivity over and above that predicted by the production function.

The production functions, with trajectories of catch and biomass; red indicates region of overfishing and overfished, are shown in **Figure** 3.

[1]https://github.com/r4ss/r4ss

Time series of process error are shown in **Figure** 4 and scaled relative to mean biomass, with regimes in **Figure** 5.

4 Discussion

ICCAT and IOTC stocks have shown long term declines, while both IATTC stocks have shown variability over time with no long term trend. This may be due to the model specification rather than the actual dynamics since IATTC uses a steepness value for the stock recruitment relationship (SSR) of h=0.99 which assumes that a means that dynamics are driven by recruitment, whereas ICCAT and IOTC use values in realms of 0.7-0.9.

Independent and positive lognormal recruitment anomalies resulted in pronounced clockwise loop of successive values when SP_t is plotted against stock size SB_t for IATTC bigeye, ICCAT yellowfin and IOTC yellowfin implying that dynamics are recruitment driven. For IOTC bigeye and yellowfin, larger values of SP_t were seen at low stock biomass.

The observed dynamics may be an indication of model misspecification. Diagnostic tools to check for model mis-specification and validation currently includes deterministic Age-Structured Production Model (ASPM), likelihood profiling (Lee et al., 2014) and Runs Tests (Maunder, 2015; Carvalho et al., 2017), but need to be developed further, specifically with regards to implication for assessment model prediction skill under non-stationary process error (Kell et al., 2016; Chang et al., 2019).

5 Conclusions

The presence of clockwise cycling due to recruitment anomalies, implies that future catches are driven by incoming year classes possibly due to environmental drivers rather than a production function. This has consequences for management based on target and limit reference points, since it follows that future biomass trends can not be predicted from current biomass based on setting total allowable catches.

There is also the possibility of model mis-specification, as some of the tRFMOs omit the possibility of a stock recruitment relationship by setting as the default that fact that recruitment driven stock (i.e. h=0.99 in IATTC), which may or may not be the case. It is important therefore as part of stock assessment to adopt quality control procedures to diagnose and facilitat the interpretation of model mis-specification (Maunder and Piner, 2017).

Additional work is required to validate models and in particular to identify model mis-specifucation evaluate whether there have been changes in growth, mortality and habitat that might have impacted in productivity. In this regards tagging studies are extremely valuable and historic tagging data should be analysed to identify hypotheses that can be tested in the future if the Commission is to move towards an EAFM in a cost effective way.

Operating Models for use in Management Strategy Evaluation should be conditioned on hypotheses related to ecological processes, particularly as this study showed that either the models used for stock assessment are mis-specified or do not account for important ecological processes.

6 Acknowledgement

References

Carvalho, F., Punt, A. E., Chang, Y. J., Maunder, M. N., and Piner, K. R. (2017). Can diagnostic tests help identify model misspecification in integrated stock assessments? *Fisheries Research*, 192:28–40.

Chang, Y. J., Winker, H., Sculley, M., and Hsu, J. (2019). Evaluation of the status and risk of overexploitation of the Pacific billfish stocks considering non-stationary population processes. *Deep-Sea Research Part II: Topical Studies in Oceanography*, page in press.

Cury, P. M., Fromentin, J.-M., Figuet, S., and Bonhommeau, S. (2014). Resolving hjort's dilemma how is recruitment related to spawning stock biomass in marine fish? *Oceanography*, 27(4):42–47.

Francis, R. C. and Hilborn, R. (2011). Data weighting in statistical fisheries stock assessment models. *Can. J. Fish. Aquat. Sci.*, 68(6):1124–1138.

Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., and Jensen, O. P. (2019). Impacts of historical warming on marine fisheries production. *Science*, 363(6430):979 LP – 983.

Hilborn, R. (2001). Calculation of biomass trend, exploitation rate, and surplus production from survey and catch data. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(3):579–584.

Hjort, J. (1914). Fluctuations in the great fisheries of northern europe viewed in the light of biological research. ICES.

Kell, L. T., Kimoto, A., and Kitakado, T. (2016). Evaluation of the prediction skill of stock assessment using hindcasting. *Fisheries Research*, 183:119–127.

Lee, H.-H., Piner, K. R., Methot Jr, R. D., and Maunder, M. N. (2014). Use of likelihood profiling over a global scaling parameter to structure the population dynamics model: an example using blue marlin in the pacific ocean. *Fisheries Research*, 158:138–146.

Maunder, M. (2015). Reference points, decision rules, and management strategy evaluation for tunas and associated species in the eastern pacific ocean. *IATTC Stock Assessment Report*, (13):107:114.

Maunder, M. N. and Piner, K. R. (2017). Dealing with data conflicts in statistical inference of population assessment models that integrate information from multiple diverse data sets. *Fisheries Research*, 192:16–27.

Methot, R. D. (2005). Technical description of the stock synthesis II assessment program version 1.17-March 2005. *Unpublished draft report provided on the CD-ROM of background materials for the STAR. NOAA Fisheries, Seattle, Washington, USA*.

Meyer, R. and Millar, R. B. (1999). BUGS in Bayesian stock assessments. *Canadian Journal of Fisheries and Aquatic Sciences*, 56(6):1078–1086.

Rodionov, S. N. (2004). A sequential algorithm for testing climate regime shifts. *Geophysical Research Letters*, 31(9).

Szuwalski, C. S., Britten, G. L., Licandeo, R., Amoroso, R. O., Hilborn, R., and Walters, C. (2019). Global forage fish recruitment dynamics: A comparison of methods, time-variation, and reverse causality. *Fisheries Research*, 214:56–64.

Szuwalski, C. S., Vert-Pre, K. A., Punt, A. E., Branch, T. A., and Hilborn, R. (2015). Examining common assumptions about recruitment: A meta-analysis of recruitment dynamics for worldwide marine fisheries. *Fish and Fisheries*, 16(4):633–648.

Thorson, J. T., Jensen, O. P., and Hilborn, R. (2015). Probability of stochastic depletion: an easily interpreted diagnostic for assessment modelling and fisheries management. *ICES Journal of Marine Science*, 72:428–435.

Travis, J., Coleman, F. C., Auster, P. J., Cury, P. M., Estes, J. A., Orensanz, J., Peterson, C. H., Power, M. E., Steneck, R. S., and Wootton, J. T. (2014). Integrating the invisible fabric of nature into fisheries management. *Proceedings of the National Academy of Sciences*, 111(2):581–584.

Walters, C. J., Hilborn, R., and Christensen, V. (2008). Surplus production dynamics in declining and recovering fish populations. *Canadian Journal of Fisheries and Aquatic Sciences*, 65(11):2536–2551.

7 Figures

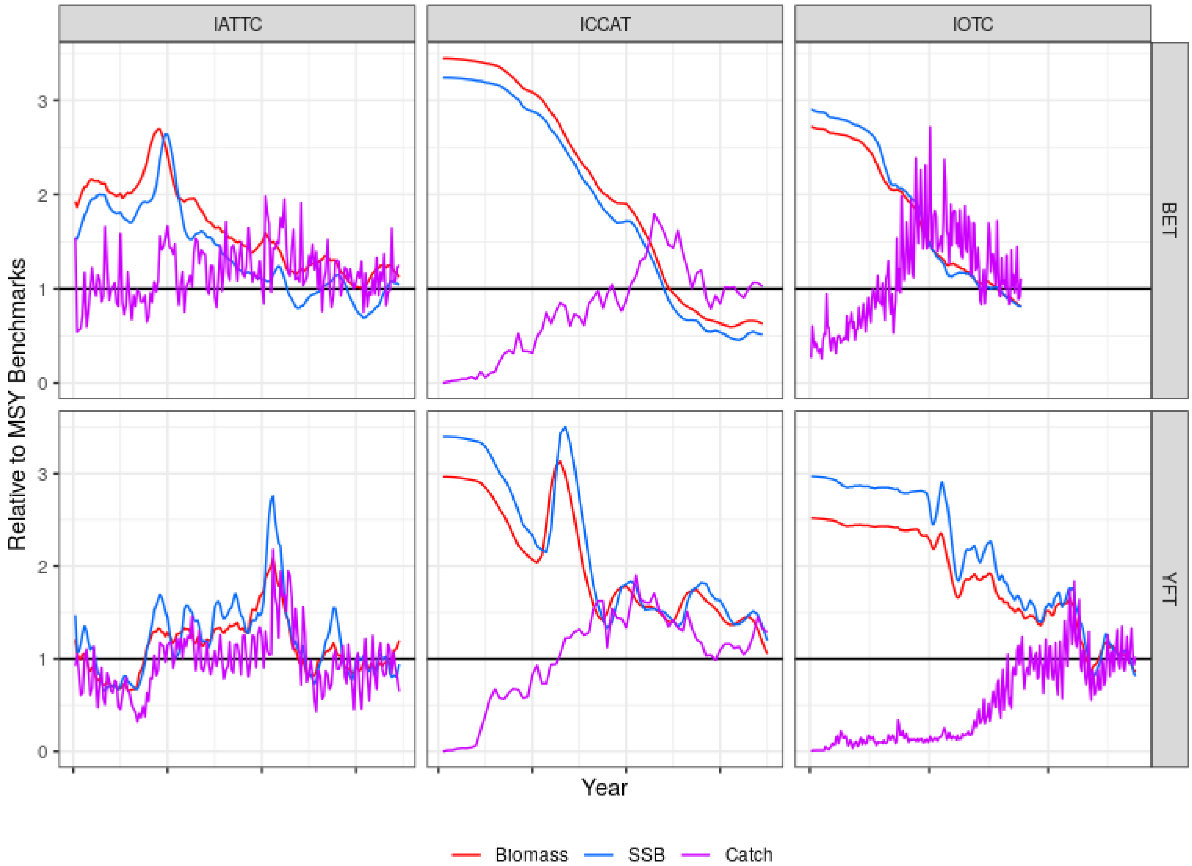

Figure 1: Time series of SSB (blue), biomass (red?) and fishing mortality (purple) relative to MSY based reference points.

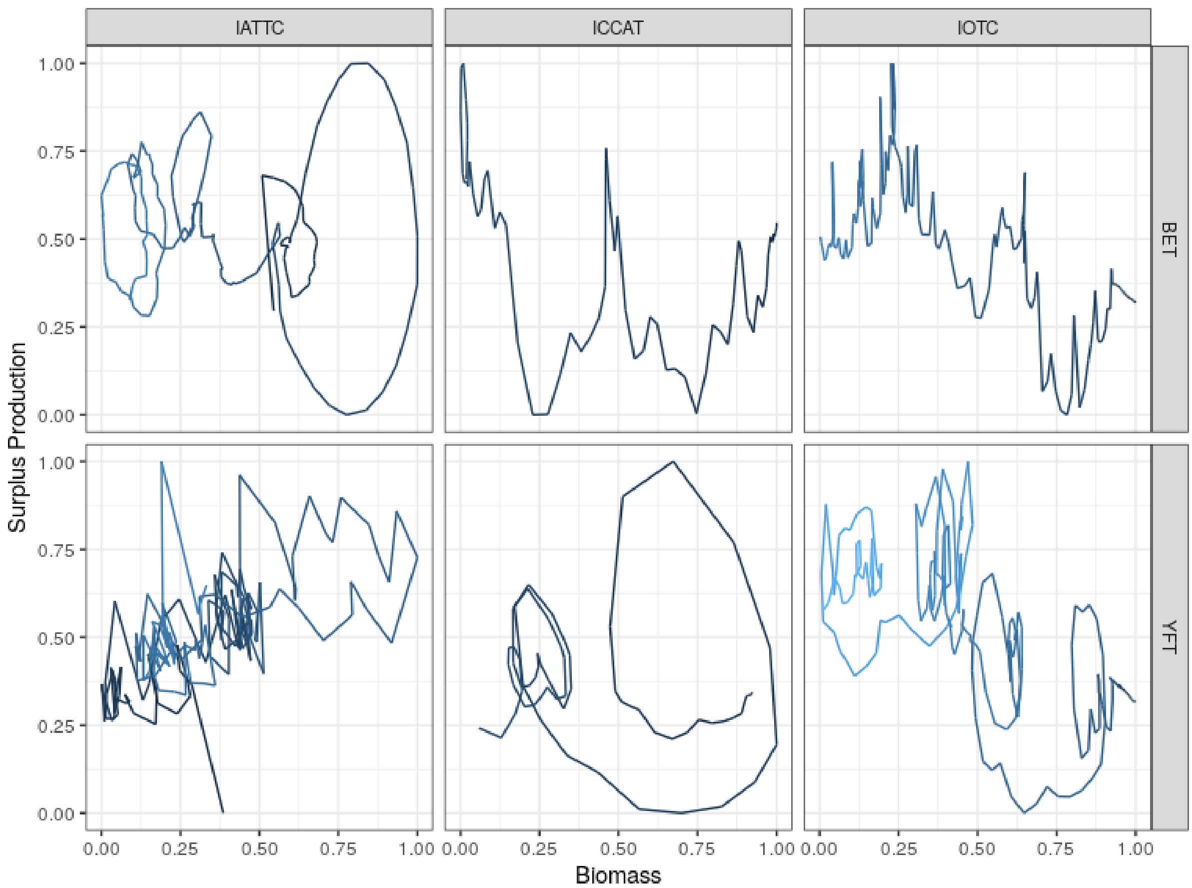

Figure 2: Surplus production plotted against biomass, dark to light trajectory colours indicates early to late period; clockwise loops in surplus production indicate positive production anomalies.

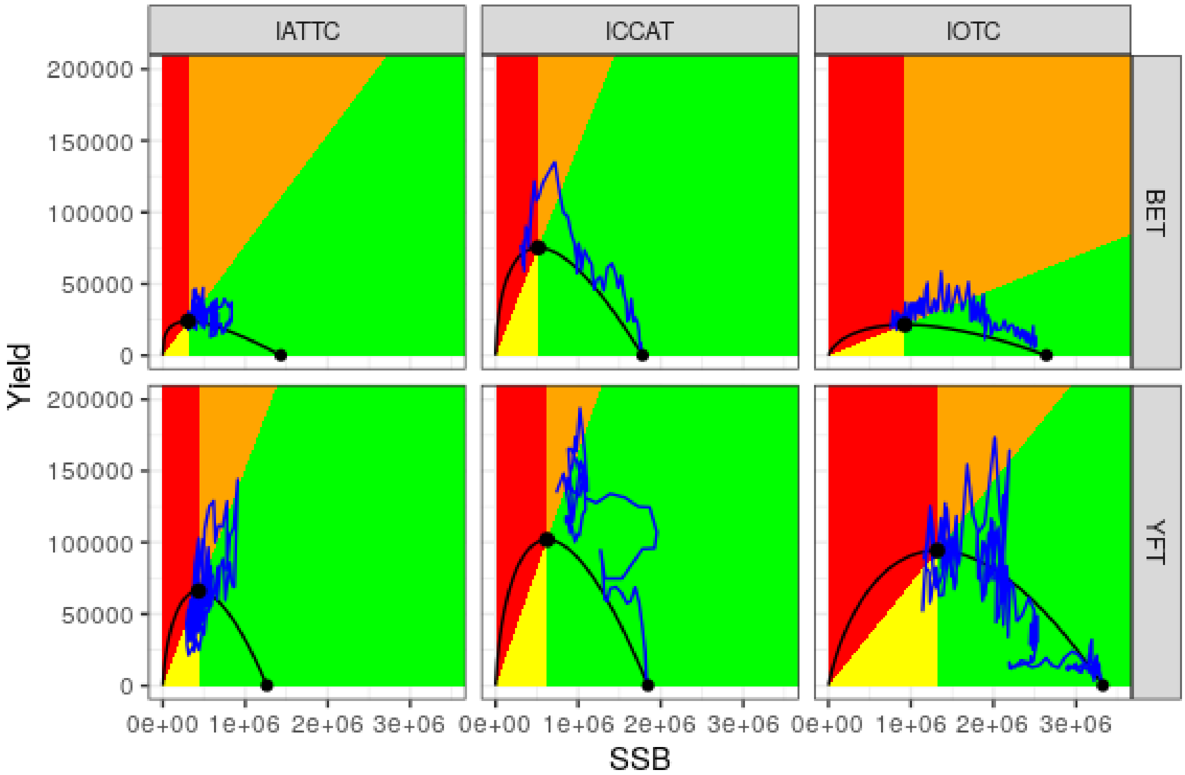

Figure 3: Surplus Production phase plots, with trajectories of catch and biomass; coloured regions correspond to Kobe quadrants, i.e. red indicates overfishing and overfished corresponding to the Kobe phase plot classification.

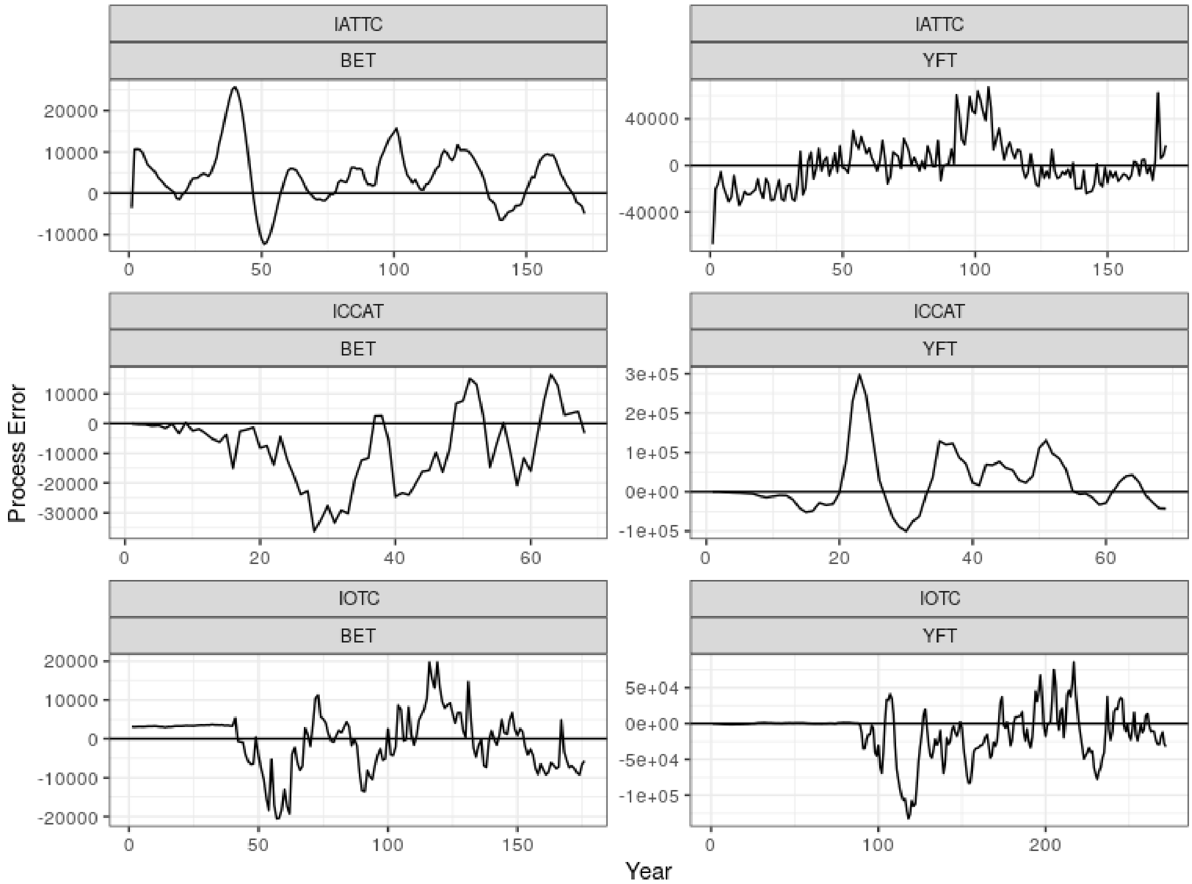

Figure 4: Time series of process error expressed deviation of stochastic biomass and its deterministic expectation for time step

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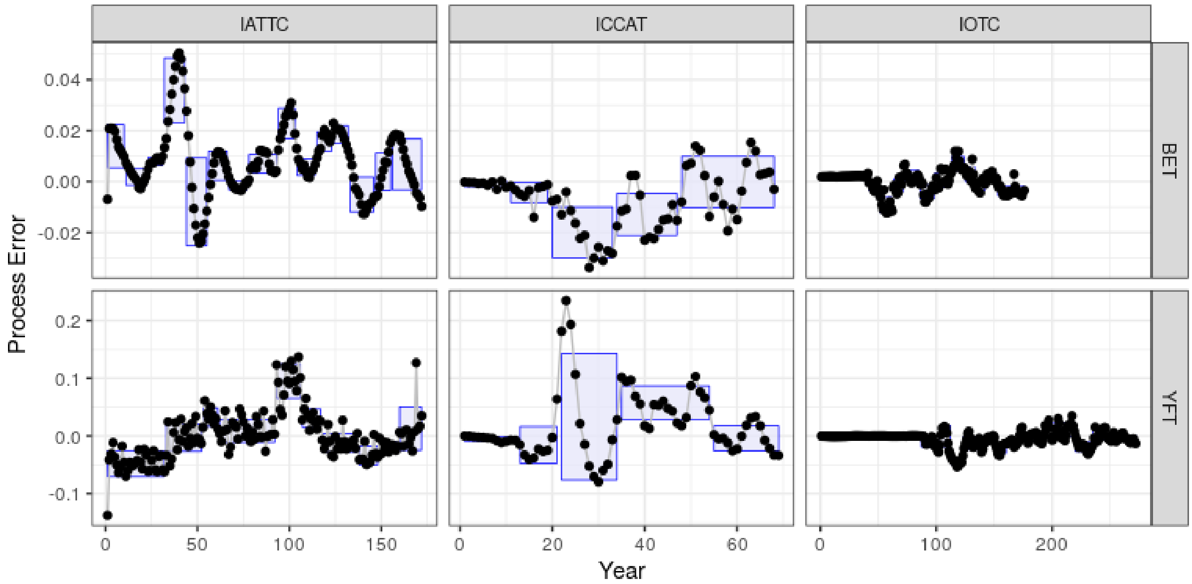

Figure 5: Process error, scaled relative to mean biomass, with regimes.