A statistical time series approach for the monitoring of cephalopod fisheries

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Summary
The life-history characteristics and data limitations of many cephalopod stocks cause difficulties to their assessment and management. When formal advice based on sophisticated multivariate assessment models cannot be provided, available time series of commercial fisheries data may still be routinely monitored and categorized as being "in-control" or "out-of-control" so that minimal advice can be given to industry and management and used to set research priorities. In this study we used forecasts obtained from seasonal autoregressive integrated moving average (SARIMA) models to monitor the behavior of >10 time series of monthly landings obtained from two Portuguese cephalopod fisheries: the common octopus and the European squid. We show that through a careful and ordered application of time series methods, SARIMA models can be quickly and appropriately fit to time series of monthly cephalopod landings with model parametrization being related to known life-cycle events and fishing strategies. Furthermore, we show that SARIMA models produce reasonable forecasts of future landings and are able to readily detect major events occurring in the cephalopod fisheries (e.g., a recruitment failure in the squid fishery), with their prediction intervals being useful as baseline advice for fishers and managers dealing with data-limited situations.

Introduction
Research on fisheries assessment has primarily focused on fisheries with long multivariate data sets and plentiful information on the life-cycle of exploited species. Less research exists on methods applicable to data-poor stocks and fisheries which assessments are limited by the quality and/or quantity of available data. These fisheries include the vast majority of fisheries worldwide and many cephalopod fisheries in Europe for which advise has not been routinely given. In many countries, the most readily available fisheries data are commercial landings. Commercial landings result from complex interactions between the environment, the fishing fleet, and the stocks, and therefore do not directly reflect the status of the underlying exploited populations. However, landing records and other univariate fisheries-dependent data do contain valuable information that can be used to advise managers in data-limited situations where other methods do not apply. For such advice to be produced a) routine monitoring, rather than stock assessment, should be incorporated in management objectives, b) appropriate time series methodologies should be used to analyze the data (Box et al., 2008) and c) a quality control perspective should be considered in the evaluation of monitoring results. In fact, even if landings provide suboptimal indications on the status of the stocks, statistical analyses of landings can lead to the timely detection of phenomena such as sudden increases in fishing effort or marked population declines that could otherwise remain undetected. These results can that help to prioritize research and advise the industry and managers when comprehensive population and fisheries data are not available. In the present study we report on an application of a statistical time series quality control framework (Prista et al., 2011) to the analysis of landings of two Portuguese cephalopod fisheries for which no routine ICES advice is presently given (common octopus and European squid) and show how it can be used to quickly draw forecasts of future landings and detect changes in the underlying fisheries process improving advice to fishers and managers and helping to set priorities in data-limited contexts.

Materials and Methods
We obtained small and moderately-sized time series of monthly landings of common octopus and European squid in different regions of the Portuguese coast and made by different fleet segments from

the Directorate-General for Natural Resources, Safety and Maritime Services (DGRM) and modeled them using Seasonal Autoregressive Integrated Moving-Average models (SARIMA). SARIMA models are simple time series models that assume monthly data are the output of a stochastic process, generated by unknown causes, from which future values can be predicted as a linear combination of past observations and estimates of current and past random shocks to the system (Box et al., 2008). SARIMA models are applicable to many already-available univariate data sets and have been found to provide forecasts of both annual and monthly landings that are comparable to or even better than forecasts obtained from many multivariate models (see review in Prista et al., 2011). In addition to good forecasting, these models also possess significant capabilities for monitoring landings that become apparent when the forecasts of SARIMA models are approached from a statistical process-control perspective (Box et al., 2008; Prista et al., 2011). Briefly, appropriately fit models will only provide good landing forecasts as long as significant changes do not take place in the fishery during the course of the forecasting period. Consequently, large forecast errors indicate that changes in the underlying data-generating process (i.e., in the unknown relationship between biological, oceanographic and anthropogenic factors that ultimately drives fishery landings) took place that require further research and/or deserve attention of fishers and managers. Under such setup the prediction intervals of SARIMA forecasts are statistically valid guidelines that can be used to assess the significance of future changes in landings (Prista el al., 2011). In the present study, SARIMA models, forecasts and prediction intervals were derived using an improved version of the semi-automated AIC_C-based approach developed by Prista et al. (2011) that now allows careful modeling and monitoring of each time series to be carried out in about 30 minutes.

Results and Discussion

All models adequately fitted the landings data. Trends were only identified in 1 out of 7 octopus data sets (2003-2013) but an improvement in fit was obtained after considering trend in the modeling of 4 out of 7 European squid time series (1995-2013). Strong seasonality was detected in the landings of European squid but not in octopus landings, with the exception of the trawl fisheries taking place in the northwestern and southern coasts. Strong correlations were found between present landings and landings registered in previous months and previous years. Model parameterization closely reflected presently known facts from the life cycle and fisheries of common octopus and European squid, namely their short life-span, recruitment seasons and typical fisheries practices, thus sustaining the application of the models. SARIMA model forecasts outperformed an array of simpler alternatives indicating an overall usefulness of SARIMA modeling and forecasting in these data-limited scenarios. Most importantly, the prediction intervals of SARIMA models allowed the detection of a recruitment failure in the 2nd semester of 2006 that came to affect the production of European squid by trawl fishery in the following years. In 2013 all time series were found to be "in-control" from a statistical quality control perspective indicating no evidence for significant changes in the underlying data generating process, i.e., in the presently unknown combination of biological, oceanographic and anthropogenic factors that drives the landings. However, European squid landings were somewhat lower than expected in the 2nd semester of 2013 signaling a lowering of fisheries production that deserves attention and further investigation. Altogether these results highlight that SARIMA forecasts and prediction intervals are useful tools for the regular monitoring of cephalopod landings when more sophisticated data-intensive alternatives are not available (or cannot be routinely implemented), thus contributing to the identification and setting of research priorities and advice to fishers and managers dealing with data-limited resources.

References

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