Fisheries Research 198 (2018) 1–13

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Indices of abundance in the Gulf of Mexico reef fish complex: A comparative approach using spatial data from vessel monitoring systems

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ARTICLE INFO

Handled by A.E. Punt.

Keywords:
CPUE standardization
Vessel monitoring systems
Reef fish
Abundance index
Simulation
Gulf of Mexico

ABSTRACT

The Gulf of Mexico reef fish complex is socioeconomically important and is exploited by a vertical line fishery capable of high resolution spatial targeting. Indices of abundance derived from fishery dependent catch-per-unit-effort (CPUE) data are an important input to the assessment of these stocks. Traditionally, these indices have been derived from standardized logbook data, aggregated at a coarse spatial scale, and are limited to generating predictions for observed spatiotemporal strata. Understanding how CPUE is spatially distributed, however, can help identify range contractions and avoid hyperstability or hyperdepletion, both of which can mask the true population dynamics. Vessel monitoring systems (VMS) can provide complete, high-resolution distributions of CPUE used to create abundance indices. Here we compare two methods — spatial averaging of VMS-derived catch and effort data and the result of generalized linear models applied to logbook data for generating indices, to evaluate the use of VMS-derived abundance indices in assessments of reef fish stocks. This work suggests that in fisheries where targeting occurs at very fine spatial scales, abundance indices derived from high-resolution, spatiotemporally complete data may more accurately reflect the underlying dynamics of the stock.

1. Introduction

Abundance indices are an important input for stock assessments. Fisheries-dependent data, such as catch-per-unit-effort (CPUE), are a common source of information for estimating trends in abundance, as they typically represent a more spatiotemporally complete and cost effective sample than fisheries-independent data (Ward, 2005).

Despite the availability of fishery dependent data, they may not be reliable as catch rates may not adequately track abundance. Nominal CPUE are widely regarded as disproportionate to abundance (Beverton and Holt, 1957; Harley et al., 2001) due to hyperstability − abundance declining faster than CPUE, or hyperdepletion − CPUE declining faster than abundance (Hilborn and Walters, 1992). These sources of non-linearity between CPUE and abundance can be introduced through gear effects (saturation and handling time; Deriso and Parma, 1987)), changes in fishing power (Bishop et al., 2004; Ye and Dennis, 2009), and interference between vessels (Gillis and Peterman, 1998). In addition, discrepancies between the spatial distributions of species abundance and fishing effort can exacerbate the issue if fishers are not representatively sampling the underlying abundance distributions (Clark and Mangel, 1979; Paloheimo and Dickie, 1964; Rose and Kulka, 1999; Rose and Leggett, 1991; Swain and Sinclair, 1994).

Bias in the relationship between CPUE and inferred abundance due to spatial distributions are typically addressed using one of two approaches: standardization or spatial imputation. Catch rates can be standardized using generalized linear models (GLMs) (Maunder and Punt, 2004; Nelder and Wedderburn, 1972) to separate the abundance trend from other factors. If spatial nominal CPUE data are available, they can be used to infer abundance trends provided they are spatially and/or temporally imputed to account for unfished areas and changes in the distributions of fishing effort (Walters, 2003). Abundance indices generated from spatially imputed nominal CPUE data that randomly sample the entire underlying distribution have been shown to track abundance accurately (Yu et al., 2013). However, for both of these approaches, the level of data aggregation is important to consider. Bias in the inferred abundance can occur if the level of data aggregation is too coarse such that fishing effort is no longer randomly sampling abundance within spatiotemporal strata (Campbell, 2004; Carruthers et al., 2010). Spatially averaging data on a fine spatial scale is more likely to represent the underlying abundance distribution of non-transient species (Carruthers et al., 2011).

Vessel monitoring systems (VMS) have transformed the analysis of fisheries-dependent spatial information. The high-resolution vessel location data provided by VMS have given fisheries scientists and

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http://dx.doi.org/10.1016/j.fishres.2017.10.020
Received 21 June 2017; Received in revised form 24 October 2017; Accepted 25 October 2017
Available online 29 October 2017

managers a better understanding of the spatial distribution of effort (Lee et al., 2010; Mills et al., 2007), fisher behavior (Davie and Lordan, 2011; Vermard et al., 2010), and the abundance distributions of targeted stocks (Bertrand et al., 2008; Vinther and Eero, 2013). Linking self-reported logbook catch records to VMS data has allowed for the creation of species-specific distributions of CPUE in European trawl fisheries for groundfish (Gerritsen and Lordan, 2011; Witt and Godley, 2007) and the vertical line fishery targeting reef fish in the Gulf of Mexico (Ducharme-Barth and Ahrens, 2017).

The vertical line fishery in the Gulf of Mexico is a valuable commercial fishery (NMFS, 2015, 2016) that targets a diverse complex comprised primarily of snappers, e.g. *Lutjanus spp,* and groupers, e.g. *Epinephelus spp* (Scott-Denton et al., 2011). The four most commercially encountered species (red snapper *Lutjanus campechanus*, vermilion snapper *Rhomboplites aurorubens*, red grouper *Epinephelus morio*, and gag grouper *Mycteroperca microlepis*) can be characterized by an association with easily identifiable hard bottom structure (Grimes, 1978; Grimes and Huntsman, 1980; Lindberg et al., 2006; Moran, 1988) and high site fidelity (Coleman et al., 2010, 2011). The vertical line gear (multiple baited lines dropped vertically from a stationary or slowly drifting vessel) fished in multiple short sets (~20 min) allows for high resolution spatial targeting of the hard bottom structure and the targeted fish stocks (Pollack et al., 2013; SAFMC, 2009; Scott-Denton et al,. 2011). This combination of targeting behavior and species characteristics predisposes the fishery to the risk of hyperstability, particularly in the absence of spatial information on where catches occur.

Given the unique set of coinciding circumstances between vertical line fisheries and reef fish behavior, it is worthwhile to evaluate if developing abundance indices from higher resolution catch and effort data from VMS gives a more accurate approximation of the underlying abundance trends. Ideally, one would be able to work with data at a spatial resolution where sampling is representative of the underlying abundance (Walters, 2003). However, the fishing behavior of the vertical line fleet makes it unlikely that data aggregated at all but the finest scales (e.g. reef or artificial structure) meet this criterion. The current practice for generating abundance indices in this fishery is through the standardization of commercial logbook catch records aggregated to a coarse statistical grid, at best a 1 ° spatial grid, using a two-step delta-GLM (Lo et al., 1992; Stefansson, 1996). A delta-GLM is the product of two GLMs: a logistic model that describes the presence-absence of positive catches and an additional model (with normally distributed error structure in this case) that describes the magnitude of log(CPUE) for catches greater than 0. This paper evaluates two methods of creating abundance indices as applied in a vertical line fishery for reef fish, and more generally in fisheries able to achieve a high level of spatial targeting of non-transient species.

We conducted analyses to compare abundance indices derived from the same input catch data using two methods: the delta-GLM standardization (status-quo) and spatial averaging of VMS derived CPUE distributions. The first analysis evaluated the agreement between indices generated from the two methods utilizing as input commercial logbook catch records from a suite of reef fish stocks that make up a large proportion of the catch by the vertical line fleet in the Gulf of Mexico. Agreement was assessed in two ways: (i) by calculating the correlation between the indices from the two methods, and (ii) by calculating the change in abundance inferred by each method. Instances of poor agreement between the two methods provided motivation for determining which method more accurately tracked abundance.

A simulation analysis was used to assess how well each method captured the true population abundance trend under different effort and abundance scenarios. Corresponding catch and VMS records were simulated and passed as input to the two methods to create abundance indices. The deviations of the indices from the true trend were calculated to determine which method was more accurate under the various scenarios. A principal component analysis (PCA) identified characteristics of scenarios where there were large disparities in the accuracy of the two methods. Previous simulation studies investigated the effects of spatial aggregation, changing distribution of effort, and imputing unfished spatiotemporal strata on indices for pelagic fisheries standardized with GLMs (Campbell, 2004, 2015; Carruthers et al., 2010, 2011; Lynch et al., 2012). Other have studies investigated how geostatistical averaging of VMS-informed catch rates compared to a fisheries-independent measure of abundance in a scallop fishery (Walter et al., 2014a,b). This work represents the first direct comparison of abundance indices derived from delta-GLM standardization and spatial averaging of VMS derived CPUE distributions.

2. Material and methods

This study aimed to address the potential fine-scale spatial targeting problem in conventional CPUE standardization by evaluating the use of VMS data for estimating population trends. Multiple analyses, conduct in R 3.3.2 (R Core Team, 2016), were used to compare the delta-GLM and VMS methods. An overview of the fishery and the species included in the study can be found in section 2.1 and a description of the two data sources informing each method can be found in section 2.2. The first step was to use the same fisheries data to estimate abundance indices using the two methods for every study species. Detail on how abundance indices were constructed for each method can be found in section 2.3. The next step was to assess the agreement in species abundance indices estimated using the two methods. This was done using a non-parametric approach described in section 2.4. Calculating the agreement between indices constructed using the same catch data, but with different methodologies allowed us to identify if there were noticeable differences between the abundance indices created.

A simulation study was used to evaluate which method was more accurate in estimating abundance under a suite of scenarios governing how effort and abundance were distributed spatially. The base simulation described in section 2.5.1 was designed to simulate fine scale targeting in a multi-species fishery on a 1/12th degree spatial grid. Section 2.5.2 describes how the base simulation was modified for each scenario. In each scenario, abundance indices for each species were calculated using the two methods along with the deviation from the true simulated population trend (described in section 2.5.3). This allowed us to identify how sensitive the accuracy of each method was with respect to changes in broad patterns of effort and abundance. A multivariate analysis (described in section 2.5.4.) was used to identify the effort and abundance characteristics of species-scenario combinations where the two methods predicted diverging abundance trends.

The base simulation made the simplifying assumption that sampling by the fishery did not affect abundance, as this feedback was not necessary in the direct comparison of the ability of the two methods to handle fine-scale spatial data. However, making this assumption ignored the potential effects of in-year sequential depletion occurring at scales smaller than the spatial grid used in the simulation. Hyperstability could occur in fisheries targeting small aggregations or reefs within a cell if vessels move from reef to reef fishing down each in turn. A modification to the base simulation (described in Section 2.5.5) was used to explore how sequential depletion at the cell level affected the estimated abundance indices' ability to capture the true abundance trend.

2.1. Study frame

The study frame for this project was the vertical line reef fish fishery within the Gulf of Mexico EEZ (Fig. 1) during 2007–2013. Vertical line fishing consists of dropping multiple baited hooks on a single line or multiple lines deployed vertically from a stationary or slowly drifting vessel. These lines are predominantly retrieved using mechanical means such as electric or hydraulic reels though they may also be retrieved by hand. Fishing occurs in distinct spatiotemporal sets defined as the