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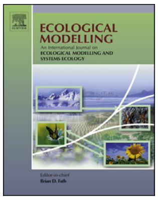

Evaluating long-term monitoring of temperate reef fishes: A simulation testing framework to compare methods

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ABSTRACT

A simulation testing framework was developed to evaluate the efficacy of detecting population trends of two sampling methods used to monitor inshore fish populations: angling and baited remote underwater stereo-video systems (stereo-BRUVs). The study is based on data collected as part of a long-term monitoring program in the Tsitsikamma National Park marine protected area, South Africa. As a test scenario, declining population trajectories of the most abundant species, *Chrysoblephus laticeps*, were simulated by introducing consecutive years of reduced recruitment over periods of 10 and 20 years applying an age-structured operating model. The operating model was designed to generate method-specific relative abundance indices and length–frequency data, using parameters derived from existing data collected in the long-term monitoring program. These were then fitted with an age-structured estimation model. Estimated spawner-biomass depletion was compared to the 'true' simulated population to quantify method-specific accuracy and bias using root-mean-squared error. Due to higher data variability and inherent size selectivity of angling, stereo-BRUVs provided more accurate spawner-biomass trends when describing a distinct population decline over 10 and 20 years. Additionally, spawner-biomass was found to be a more accurate population estimate than relative abundance indices due to the inclusion of population size structure information. The study demonstrates the potential of using simulation testing to evaluate sampling methods, given that the process generates the 'true' population with a known abundance and size structure.

1. Introduction

In order to effectively monitor fish populations, and design management strategies that respond to observed changes, efficient and standardized methods for quantifying fish populations must be readily available. Recent technological advances have promoted the use of underwater video sampling techniques in fisheries ecology (Bernard et al., 2014; Mallet and Pelletier, 2014). Specifically, the development of baited remote underwater stereo-video systems (stereo-BRUVs) has enabled the remote measurement of fish length with a high degree of accuracy (Harvey et al., 2012; Langlois et al., 2014, 2012) whereas preceding single camera BRUVs (mono-BRUVs) techniques were limited to providing abundance data (Bernard and Götz, 2012; de Vos et al., 2014). The inclusion of size frequency data can substantially increase robustness when modelling population trends (Ono et al., 2014) whereas abundance indices alone have proven less reliable in identifying differences in fish populations (Cappo et al., 2003; Watson et al., 2007). As a result, stereo-BRUVs have gained popularity over mono-BRUVs, despite higher operating costs (Bernard, 2012). Furthermore, stereo-BRUVs are able to sample a wider range of species with minimal length-selectivity bias than more invasive traditional fisheries-independent sampling methods which collect size frequency data, such as angling (Langlois et al., 2012; Parker et al., 2016) and fish traps (Harvey et al., 2012; Langlois et al., 2014).

Information pertaining to method performance and suitability gained from traditional method comparisons is inherently limited,

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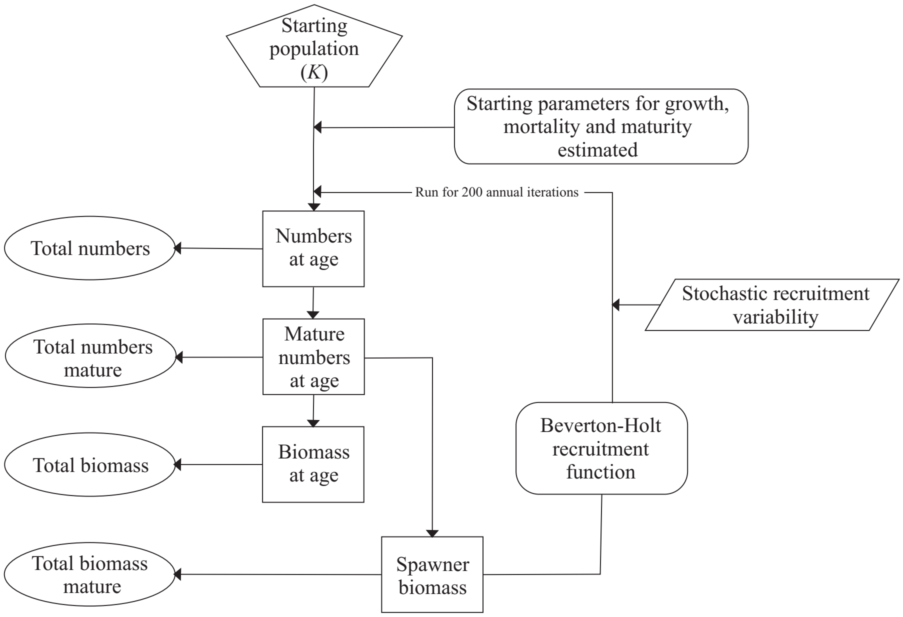

Fig. 1. Conceptual diagram of the operating model used to generate the simulated 'true' population. An arrow from *a* to *b* indicates that *b* is derived from *a*.

as ecologists are forced to compare one method against another in a 'trade-off' manner. The benefits of method comparisons are obvious, as they provide insight into method-specific biases, which can then be accounted for (Langlois et al., 2012; Willis et al., 2000). However, a distinction must be drawn between method comparison and method evaluation. Fundamentally, the word 'comparison' is defined as 'an estimate of similarities or differences' and describes an appraisal of one or more characteristics against each other. In contrast, a method evaluation aims to present a tangible appraisal of the sampling-induced error specific to a method, providing an evaluation of accuracy, precision and overall method performance.

The recent incorporation of simulation testing in marine ecology (Dorner et al., 2013; Oken and Essington, 2015; Spencer et al., 2012) has provided a means to evaluate sampling methods despite the actual population being unknown. Simulation overcomes the uncertainty of an unknown population by generating data through an 'operating model' (Fig. 1) and evaluating candidate estimation procedures and/or methods in terms of their ability to recover operating model properties (Anderson et al., 2014; Cooke, 1999; Thorson et al., 2012). The specific intricacies of operating models differ vastly depending on the type of data required, but in most cases these models aim to replicate natural ecosystems under prescribed conditions. The power of the procedure is that the prescribed conditions, whether environmental or managerial, can be easily modified to produce an endless number of possible permutations, known as 'scenarios'. The entire process is well suited for evaluating sampling methods as a population is generated, and therefore the 'true' abundance known (Lynch et al., 2012). To date, simulation testing has been applied to evaluate monitoring methods and survey designs (Cao et al., 2014; Li et al., 2015), performance of standardization models for relative abundance indices (Carruthers et al., 2010; Lynch et al., 2012; Ono et al., 2015; Thorson et al., 2012; Winker et al., 2014), performance of stock assessment models (Chang et al., 2015; Ono et al., 2014; Thorson and Berkson, 2010), robustness of alternative management strategies (Butterworth and Punt, 1999; Punt et al., 2013; Smith et al., 1999) and implications of model misspecification (Deroba et al., 2014; Piner et al., 2011; Wang et al., 2014).

If we are to promote the use of stereo-BRUVs for monitoring (Bernard et al., 2014; Harvey et al., 2012; Langlois et al., 2010) it is imperative that there is reliable evidence indicating the method will consistently outperform other sampling methods for various scenarios and over long-term periods. The simulation framework development here is based on existing count and size-frequency data derived from angling and stereo-BRUVs sampling conducted as part of a long-term monitoring (LTM) programme in the Tsitsikamma National Park (TNP) marine protected area (MPA), South Africa. The TNP is South Africa's largest and oldest 'no take' MPA, and is therefore considered an important sentinel site to monitor long-term environmental effects on resident marine life in the absence of fishing. Using method-specific sampling parameters derived from the LTM data, the ability of each method to accurately describe a long-term trend of a simulated population of roman (*Chrysoblephus laticeps*), the most common endemic seabream, is evaluated.

The importance of collecting length–frequency data in ecological monitoring programmes has frequently been advocated (James et al., 2012; Langlois et al., 2012; Shin et al., 2005), but its application has been largely limited to descriptive size-based indicators. In this study, we aim to extract the full potential of length–frequency data by integrating size information with relative abundance indices in an estimation framework. To achieve this, a stochastic age-structured model was developed and used as an operating model to simulate a 'true' population trend for roman. This 'true' population initially fluctuated around carrying capacity, resembling a situation that may be found in the TNP MPA after 50 years of 'not take' protection. In the absence of fishing, environmental stochasticity causing variation in recruitment is commonly considered to be the most important driver of population fluctuations (Quinn and Deriso, 1999). Here, we hypothesised that any potential environmental change is most likely to impact the most vulnerable early life-history stages, which could lead to reduced recruitment success. To simulate this, a population decline driven by consecutive years of poor recruitment was induced in order to test the capacity of each sampling method to correctly describe the decreasing population. Once the declining roman population had been generated, it was then sampled by simulating relative abundance indices and size frequencies derived from each sampling method, (angling and stereo-BRUVs) which were fitted to an age-structured estimation model. Evaluating method accuracy was done by comparing the estimated abundance and spawner-biomass indices against those of the 'true' population.