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Evaluation of alternative stratifications for a stratified random fishery-independent survey

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A R T I C L E I N F O

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A B S T R A C T

Stratified random sampling (StRS) can lead to improved precision and accuracy in estimating key fisheries population parameters, particularly when the spatial distributions of target fish populations have high heterogeneity among different strata and homogeneities within a stratum in the survey area. As the spatial distributions of many fish populations might shift in response to environmental changes and fishing activities, survey designs developed based on previous fish distribution patterns may need to be re-examined. A simulation study was conducted to evaluate the performances and consistency of 12 stratification designs for achieving multiple survey objectives, including the abundance indices of fish species and species diversity indices, for a fishery-independent survey in the coastal waters. Relative estimation error (REE), relative bias (RB) and coefficient of variation (CV) were used to measure the precision and accuracy of mean estimates values for the 12 stratification schemes. The performances of different stratification designs were likely to differ for various survey objectives. As for a multispecies survey, though the current stratification design (design 10) did not always have the lowest REE and absolute RB values, it had the most stable performances for all indices over 3 years. It indicated that the current survey design was still the optimal design according to these measurements. Thus, even though the distribution of fish populations and community composition changed over seasons and years, the current stratification design was robust and could still capture key characteristics of target fish populations and community composition.

1. Introduction

Fisheries management requires information about abundance and distribution for target fish populations, which is commonly collected through a well-designed fishery-independent survey (Doubleday, 1981; Pennington and Stromme, 1998; Liu et al., 2009). Spatial distribution patterns of target fish species may change over years/seasons due to environmental variability and human perturbation, which makes collection of a large quantity and high quality data difficult. Fishery-independent surveys can provide high precision inputs to fisheries stock assessment and management (Arbia and Lafratta, 2002; Peel et al., 2013; Li et al., 2016; Yu et al., 2017). Compared with fishery-dependent surveys, fishery-independent surveys tend to be more expensive. Thus, it is necessary to design a cost-effective fishery-independent survey, which can yield high quality data with limited sampling effort (Scheirer et al., 2004; Zhao et al., 2014).

Traditionally, stratified random sampling (StRS) is often adopted in fisheries-independent surveys for providing estimates of abundance index. Such a design can improve precision and accuracy of estimates when heterogeneities between strata are much higher than those within a stratum (Manly et al., 2002; Smith and Tremblay, 2003; Lohr, 2009; Xu et al., 2015a). Spatial distribution and abundance of fish species can be influenced by many environmental variables such as depth, temperature, and substrate type, which are usually considered in defining strata for a fishery-independent survey (Vanderwal et al., 2013; Last et al., 2015; Zhang et al., 2015; Pecl et al., 2017).

Distributions of many fish populations may shift in response to environmental change and fishing practices (Blanchard et al., 2008; Tang et al., 2011; Vanderwal et al., 2013; Xu et al., 2017), resulting in changes in food web structure and biodiversity distribution (Zhang et al., 2015; Pecl et al., 2017). So it is difficult to find an appropriate strata division for each species over years/seasons. When the species distribution in each stratum was heterogeneous, stratified random sampling design might perform even worse than simple random sampling design (Koyuncu and Kadilar, 2010). It is often unclear if a stratified random survey design based on previous fish spatial distributions

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performs well when environmental conditions change. It is thus important to periodically evaluate the performance of a survey design. Few survey designs can satisfy all objectives for a survey (Bijleveld et al., 2012). This is especially true for surveys targeting multiple species as different species tend to have different spatio-temporal dynamics. Sampling designs are likely to differ for different survey objectives. Thus, objectives of a survey program need to be clearly identified and carefully evaluated. For multispecies survey, when survey objectives are changed or added, the performance of previous survey designs should be re-evaluated. Species distribution in each stratum is not homogeneous and the distribution pattern varies among years and seasons, which will cause an adverse impact on the efficiency of stratified random sampling design. To address this issue, we examined the performances of the current stratified sampling design and other stratified sampling designs over different seasons and years using computer simulation in this study. The objective was to evaluate the consistency of different stratification schemes and find out the most efficient sampling design over time to improve the precision and accuracy of estimates in fishery-independent surveys. Such an evaluation study is important to make sure the good performance of the survey design used in current time and in the future for long-term fishery stock assessment and management. And it also could provide knowledge and experience to design or evaluate the multispecies fishery-independent surveys.

2. Materials and methods

2.1. Study area

Haizhou Bay, a typical open bay, is located in the western Yellow Sea (Fig. 1). The oceanographic conditions in the bay are mainly influenced by the Yellow Sea Warm Current, Yellow Sea Coastal Current and Yellow Sea Cold Water Mass (Wang et al., 1993). As an important spawning, feeding and nursery ground for many fish species, it was also one of the most important fishing ground in China due to its high productivity (Jiang, 1964; Chen, 1991; Wan and Jiang, 1998). The fishery resources in the bay have declined dramatically or even been depleted due to intensive fishing activities and environment degradation in the Yellow Sea ecosystem, and many traditionally important fish species with high commercial values cannot support fisheries in the waters (Jin and Tang, 1996; Xu and Jin, 2005). It is imperative to obtain sufficient and effective data to support fisheries stock assessment, management the sustainable utilization of the fish resources in the Haizhou Bay. The species were mostly small-sized individuals (either small-sized species or juveniles). It is difficult to find fish more than 2 years old. Large changes occurred in species compositions and biomass as well as the species distribution in the bay (Tang et al., 2011), which made Haizhou Bay to be a typical study area to evaluate the consistency of fishery-independent survey design.

2.2. Fishery-independent surveys in the Haizhou Bay

The multispecies bottom trawl survey designed for collecting information on the overall species composition and abundance indices of fish species was conducted in the spring (May) and autumn (October) from 2013 to 2015 in the Haizhou Bay (Fig. 1). The bottom trawl survey was conducted using a 220 kW otter trawl vessel in the daytime, with the towing speed of 2–3 knots and the hauling duration of 1 h on average. The open width of the sampling net was 25 m and the mesh size for the codend net was 17 mm.

The survey followed a stratified random survey design, which divided the survey area into five strata based on depth and bottom types identified as key environmental variables influencing fish spatial dynamics (Xu et al., 2015a,b). As identified in a previous study, sampling efforts in the stratified random survey could be 18 while still achieving relatively high precision and accuracy for most indices, with the number of sampling sites in stratum from A to E being 2, 4, 2, 7 and 3, respectively (Xu et al., 2015b) (Table 1). Spatial distribution patterns of fish species varied in different seasons and years. The parameters including mean, standard deviation (SD) and coefficient of variation (CV) for abundance index of fish species and community diversity indices in each stratum were calculated based on the original survey data from 2013 to 2015, respectively. Here, we selected the abundance index of

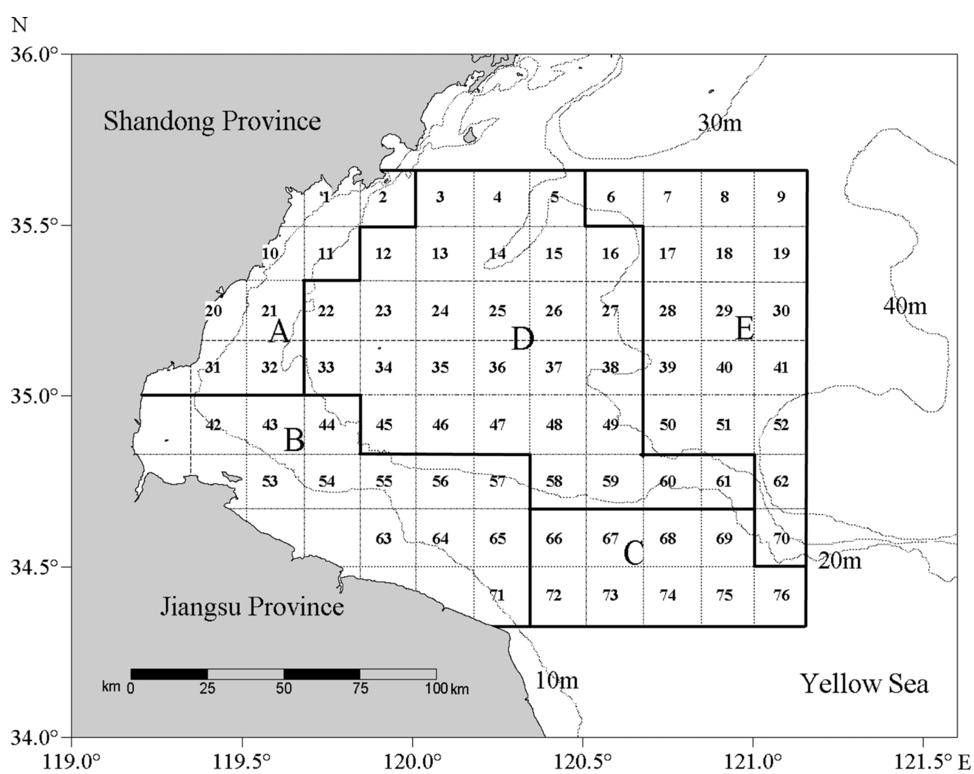

Fig. 1. Strata division of the current fishery-independent survey design in the Haizhou Bay, China.