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Probability-based survey to monitor catch and effort in coastal small-scale fisheries

Jon Helge Vølstad[a,1], Paula Santana Afonso[b], Ana Paula Baloi[b], Narci de Premegi[b], Jørgen Meisfjord[c,d], Massimiliano Cardinale[e,*]

[a] Institute of Marine Research, PO Box 1870 Nordnes, N-5817 Bergen, Norway
[b] IIP-Instituto Nacional de Investigação Pesqueira, Av. Mao Tsé Tung 389, Maputo, Mozambique
[c] Institute of Biology, University of Bergen, Norway
[d] Norwegian Institute of Public Health, PO Box 4404 Nydalen, N-0403 Oslo, Norway
[e] Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Marine Research, Turistgatan 5, Lysekil, Sweden

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ABSTRACT

Catch and effort data form an important, and often the only, source of data for stock assessment and management of marine resources in developing countries. Population parameters and management quantities important for stock assessment are often estimated by fitting production models to standardized series of catch-per-unit-effort (CPUE). Such basic information is notoriously hard to obtain for small-scale fisheries because of the large spatial and temporal variability in effort, numerous landing sites, and limited access for biological data collections. In this paper, we present a probability-based survey sampling method for the monitoring of the small-scale fisheries in Mozambique. The survey is an on-site intercept design, which supports the estimation of annual catch and effort and other key statistics for the coastal fisheries in a sampled geographic area. Estimates of catch and effort, with associated relative standard errors, for beach seine fisheries in the district of Angoche and for Inhambane Bay are used to illustrate the applicability of the methodology. The flexible survey design is nowadays used to monitor small-scale fisheries in all provinces of Mozambique. We also present a method for obtaining approximate estimates of total catches for a study area when the coverage of fishing centers is incomplete. Survey estimates of the average proportion of beach seines that are actively used in fishing by month are used to adjust fishing effort derived from census data on the total number of beach seines for fishing centers not covered in the survey. The adjusted effort is then combined with estimates of CPUE to estimate the total catches for fishing centers that are not covered in the survey. Results suggest that the common method (often referred to as a frame survey) for studying artisanal fisheries that relies on effort estimates from a census of landing sites at some intervals in time, combined with CPUE from regular sampling from a small subset of fishing centers selected ad-hoc would introduce substantial bias of variable magnitude. The reason is that effort in small-scale fisheries strongly depends on weather conditions and socio-economic factors.

1. Introduction

Coastal areas of tropical countries are mostly exploited by artisanal fisheries (Salas et al., 2007), but quantitative knowledge of the status of the exploited stocks is often very limited (e.g. Salas et al., 2007; Vincent et al., 2007). Hence, assessment of the status of exploited stocks to be used for a sustainable management of coastal marine resources and ecosystems is urgent. The basic information which is needed in stock assessment and management of marine resources are usually information on catches and effort exerted by the fleet (Xiao, 1998).

Mozambique is a developing country in southeast Africa, with one of the world's lowest GDPs (Gross Domestic Product) and per capita income (The World Factbook, 2009; https://www.cia.gov/library/publications/the-world-factbook/; accessed 20/11/2012). Yet, Mozambique has potentially extensive fisheries resources, which could contribute not only to an improvement in GDP but also to enhance the socio-economic status of its population (~18 million). For many years, the offshore industrial prawn fisheries have been a key component of export for foreign exchange earnings and national income. However, the small-scale coastal fishery, largely driven by an artisanal sector,

* Corresponding author. Tel.: +46 730 342209; fax: +46 52313977.
E-mail addresses: jon.helge.voelstad@imr.no (J.H. Vølstad), massimiliano.cardinale@slu.se (M. Cardinale).
[1] Tel.: +47 55 23 84 11; fax: +47 23 85 31.

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contributes significantly to the informal economy, especially at the local level, and it is a major source of protein for coastal residents. Small-scale fisheries in Mozambique's marine waters take place throughout the extensive coastline (2780 km) at different levels of fishing effort, with yearly landings that account for the largest part of the domestic fish consumption (Charlier, 1995). In a 2002 census conducted by the institute for development of small-scale fisheries (IDPPE), it was estimated that approximately 70,000 fishermen were involved in the artisanal fisheries in Mozambique, with a majority of the effort associated with 658 fishing centers (IDPPE, 2007). Despite the importance of the coastal marine resources to a large sector of Mozambique's population, little information was available for assessing the sustainability of the small-scale fisheries, or the characteristics of their landings, before the implementation of the current monitoring survey.

Rational decisions concerning future management and development of the small-scale fisheries in a province or district require reliable data on catch and effort (In the Mozambican artisanal fisheries discarding is negligible, and we have used catch and landings interchangeably in this paper.) Population parameters and management quantities important for stock assessment can be estimated by fitting production models to standardized series of catch-per-unit-effort (CPUE) (Xiao, 1998). However, such basic information is notoriously hard to obtain for small-scale fisheries (Pauly and Mines, 1982; Munro, 1983). Many studies of artisanal fisheries rely on a census of landing sites at some intervals in time, combined with regular sampling of effort and landings from a small subset of fishing centers (e.g., Stamatopoulos, 2002). In the census of landing sites, often referred to as a frame survey (Caddy and Bazigos, 1985), the number of vessels (by type), fishing gears, and fishermen are typically recorded. The total effort (boat days) for a time period is estimated by adjusting the potential number of boat days for the expected activity level. Total catch over a time period is then estimated by extrapolating mean CPUE from the intercept samples to the estimated effort. However, such estimates of total catch may be subject to bias when fishing effort, CPUE, and the composition of the landings exhibit substantial variation between fishing centers, and through time. In general, estimates based on sampling in a few centers chosen ad-hoc will not be representative for all centers.

Probability-based sampling provides an alternative approach for assessment and monitoring of artisanal fisheries (e.g., Solana-Sansores and Arreguín-Sánchez, 1990). In this paper we present a probability-based survey that is used to monitor the small-scale fisheries in Mozambique, where the sampling frame is a matrix of landing sites and days. The fishery concerned operates from beaches, or in near coastal waters (generally within 5 km), and it is dominated by beach seines, hand-lines, and gillnets deployed by a mixed fleet of vessels less than 10 m in size. Vessels usually conduct daily fishing trips using one type of gear, but in some cases multiple gears are employed simultaneously. The vast majority of fishing trips can be accessed for sampling at a finite list of landings sites along the coast.

The overall goal of this paper is to present on-shore monitoring methods developed to support precise and unbiased estimates of total catch and effort and catch composition by species and size of the coastal small-scale fisheries in a given geographical area over time. The access-point survey presented here is an on-site, intercept design (Hayne, 1991; Pollock et al., 1994) similar to designs used for estimating catch and effort in recreational fisheries in many developed countries. To illustrate the utility of the monitoring methods, yearly estimates of catch and effort for beach seine fisheries from 1997 to 2003 are presented for Inhambane Bay, where the sampling frame covers nearly all the landing sites, and for one district in the Nampula Province (Angoche) with incomplete sampling coverage of landing sites.

2. Methods

2.1. The sampling frame

Management of the small-scale fisheries in Mozambique is done on a provincial or district level. The on-shore catch sampling program in Mozambique closely follows best practices as recommended in ICES (2012, 2013). A spatio-temporal sampling frame was developed for each stratum h based on a list of fishing centers (access-sites) F_h crossed with days (D). The primary sampling units (PSUs) are a combination of days and fishing centers (site-days) (ICES, 2013). The access-sites were derived from a map of coastal fishing centers (landing sites), using comprehensive information from the 1996 atlas of the artisanal fishery and the 2002 national census conducted by the institute of small scale fisheries (IDPPE, 2007). Fishing centers are stratified based on geography, and in some cases by their size, for example large medium and small based on the number of registered fishing units. In addition, temporal strata of one month were used to improve the estimates of yearly catch and effort.

2.2. Multi-stage sampling

The objective of the monitoring survey is to collect data on catch, effort, and biological characteristics of the catches that are representative for the total catch over a time period (e.g., monthly or yearly). This was achieved through spatial and temporal stratification and multiple stages of selection.

In the first stage, we used the sampling frame as a mechanism for selecting a stratified random sample of fishing centers over time (site-days). To ensure good temporal coverage in each stratum, we used restricted random sampling (Jessen, 1978), with sampling of fishing centers scheduled on random days during each calendar week from each stratum. This design ensures that the probability of visiting any particular fishing center at any particular day is equal within each stratum. For each week, sampling is typically conducted on three randomly selected days within each stratum.

In the second stage, a census of the number of active and passive fishing units by type is conducted for each PSU. The active fishing units in a PSU are then stratified by type. The field staff conducts the second stage sampling by selecting a random subsample of at least two active fishing units from each type of gear. For these secondary sampling units, data are collected on catch in weight and numbers by species, and the size composition for selected species. Some socio-economic and meteorological data are also collected for each PSU.

When implementing a survey in a new district, it is recommended that the number of samples per stratum be allocated proportionally to strata sizes (A_h), approximated by the number of fishing units recorded in the most recent census. When estimates of catches and their spatiotemporal variances (s_h^2) becomes available from the survey, the survey efficiency may be optimized by allocating samples proportionally as $n_h \propto A_h s_h^2$ (Cochran, 1977). In reality other factors, such as travel time, may be important to consider for achieving minimum variance in estimated total catch for a fixed cost.

Within a PSU it is generally advantageous to sample dominant gears more frequently than gears with less fishing effort and catch. Nevertheless, the sampling effort within each PSU is determined in practice by logistics. When only one crew is available, the sample sizes within a day will largely be fixed. The allocation of sampling effort among gears within a PSU, however, might be based on their relative importance, with more samples allocated to the gear that catches most fish. At a minimum, two subsamples are collected from each gear to allow the estimation of variance components. For each selected PSU, the boats were stratified on-site by