Fisheries Research 140 (2013) 105–113

Contents lists available at SciVerse ScienceDirect

Fisheries Research

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

Estimators of discards using fishing effort as auxiliary information with an application to Iberian hake (*Merluccius merluccius*) exploited by the Portuguese trawl fleets

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ARTICLE INFO

Article history:
Received 12 March 2012
Received in revised form 5 December 2012
Accepted 6 December 2012

Keywords:
Discards
Discards weight
Estimator
Fishing effort
Jack-knife
Influential observations
Hake
Trawl
Portuguese

ABSTRACT

Estimating discards is an important issue for fisheries management so that total mortality caused by fishing is considered. In 2003, a sampling programme addressing Iberian hake discards by the Portuguese fleets was implemented according to the requirements of the European Commission Data Collection Regulation (Reg. EC No 1543/2000). A preliminary analysis of the data collected showed trip and haul duration to be potential sources of bias, because their relationship to discards per unit effort (DPUE) was not linear. This paper develops estimators for discards by weight using fishing effort as auxiliary information, describes a jack-knife procedure to identify influential observations, applies the methodologies to Iberian hake as a case study and compares the results obtained by each estimator. The estimators tested are based on Cochran's estimator of the total (Cochran, 1977). Four estimators are compared, each one consisting of a combination of (i) weighting or not weighting the observations by fishing effort and (ii) post-stratifying or not post-stratifying the trips by duration in days-at-sea. A jack-knife analysis of observations' influence on the final estimate is performed by year and fleet. The results indicate that the estimator that uses both a weighted DPUE and post-stratification by the trip duration performs best and is the most robust to influential observations. The estimates of hake discards increase with time, while a stable but oscillating pattern is observed in the demersal fleet. Total hake discards show a fluctuating trend until 2009 and a large drop in 2010. The minimum discard estimates after removing influential observations was 795 t in 2006 and the maximum was 1956 t in 2009, with coefficients of variation (CV) between 22% and 74%. Estimates using the full data set were higher but had lower CVs. The observed trend in discards agrees with the recruitment estimates by the Portuguese International Bottom Trawl Survey.

1. Introduction

Returning living or dead organisms to the sea ("discarding") is considered a waste of resources and is thus inconsistent with responsible fisheries (Kelleher, 2005). Recently, the European Union has included discards on the revision of the Common Fisheries Policy (COM/2011/0425) aiming to reduce discarding practices.

Discarded fish represent losses that are not documented in landings statistics. Most discards are killed during capture and sorting (Kaiser and Spencer, 1995), so they represent real removals from the fish stocks (Chen and Gordon, 1997). Several authors argue that including discards in stock assessment improves the estimation of stock dynamics and exploitation status (Chen and Gordon, 1997; Punt et al., 2006; Chen et al., 2007; Dickey-Collas et al., 2007; Fernández et al., 2010; Jardim et al., 2010). Thus, accounting for the fishing mortality that is caused by discarding is an important subject.

Information about discarding practices are typically collected by observers via at-sea sampling programmes. The sampling design is often based on some form of systematic or random sampling to ensure exchangeability between observed and unobserved units (*e.g.* trips). However, whether the data collected in such programs are representative of the whole fishery depends on the proportion of trips with observers and on the assumption that the discard patterns of observed trips are the same as that of unobserved trips (Chen and Gordon, 1997).

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http://dx.doi.org/10.1016/j.fishres.2012.12.006

Table 1
The sampling effort of the Portuguese on-board programme for sampling discards in trawl fleets that target either crustaceans or demersal fish, OTB_CRU and OTB_DEF, respectively between 2004 and 2010.

Year	Fleet activity		Sampling levels					
	Trips		Trips		% Trips		Hauls	
	OTB_CRU	OTB_DEF	OTB_CRU	OTB_DEF	OTB_CRU	OTB_DEF	OTB_CRU	OTB_DEF
2004	2924	8086	17	24	0.6	0.3	111	125
2005	2874	7375	15	39	0.5	0.5	74	159
2006	2595	6098	7	42	0.3	0.7	30	194
2007	2331	6827	12	38	0.5	0.6	73	162
2008	2408	6482	12	34	0.5	0.5	66	128
2009	2820	5467	16	38	0.6	0.7	84	135
2010	2290	4589	16	31	0.7	0.7	103	116

In Europe, because there is no legal obligation to take observers on board, most sampling programmes are voluntary on the part of the fishing industry. In such cases, fully random sampling may be difficult to achieve, especially if the industry perceives that the outcomes of the sampling program may be disadvantageous and a large part of the fleet therefore drops from the sampling frame.

Benoit and Allard (2009) categorise the factors leading to non-random deployment of observers to fishing trips into "accounted" and "unaccounted" sources. Accounted sources, such as duration of haul, are better understood and can be addressed during data analysis by *e.g.* post-stratification. Unaccounted sources are difficult to quantify because of a lack of information, *e.g.* the unwillingness of the crew to collaborate with observers. Both types can affect the quality of the sampling and introduce bias to the estimations of discards.

The case of the hake (*Merluccius merluccius*) fishery in Iberian waters may illustrate such problems. The fishery is composed of Portuguese and Spanish fleets using trawls, gill and trammel nets or longlines along the Iberian coast in ICES sub-Divisions VIIIc and IXa. During the 1990s, a set of regulations that included a minimum landing size of 27 cm and changes in mesh size were introduced. The set of regulations changed the way the fishing industry operated, and discarding is believed to have started in the second half of the decade (Fernández et al., 2010; Borges et al., 2005). Between 2004 and 2010, strong year classes entered the fishery. The capture of these individuals, together with the enforcement of the minimum landing size regulations, were expected to increase the discard of small individuals. In 2003 a sampling programme addressing Iberian hake discards by the Portuguese fleets was implemented following the requirements of the European Commission Data Collection Regulation (Reg. EC No 1543/2000), and in 2010 estimates of the discards were included in stock assessments (Anon., 2010). The implementation of this programme had the same problems as other voluntary programmes in finding vessels that were willing to participate, but funding constraints also limited the sampling effort and deployment of observers. Clearly, there were potential sources of bias due to the non-random deployment of observers, which was a major concern because discard mortality strongly influences the results of stock assessment (Fernández et al., 2010; Jardim et al., 2010) and because discard practices have a negative effect on public opinion. Furthermore, there were concerns that the potential bias could be exacerbated by the low sample size. Ratio estimators rely on scaling the average values to the total of an auxiliary variable in order to compute totals. Therefore, they become very sensitive to unusual observations when the sample size is small.

The work presented here suggests methods to estimate the discards by weight using effort as a scaling variable. Four methods are considered, each consisting of a combination of (i) weighting or not weighting observations by fishing effort and (ii) post-stratifying or not post-stratifying fishing trips by duration in days-at-sea. Additionally, the estimator's robustness to influential observations is assessed using a jack-knife analysis.

2. Materials

To apply the methods developed and compare the resulting estimates, we used data collected by the Portuguese on-board sampling programme of Iberian hake discards in the Portuguese trawl fleets between 2004 and 2010.

During this period, the sampling programme focused on the trawl fleets that were operating off the continental shelf. There are two major fleets, one targeting crustaceans and operating in the Southern area with cod-end mesh sizes of 55–59 mm or >70 mm, and another targeting fish and operating off the continental coastal area with cod-end mesh sizes of 65–69 mm or >70 mm.

The data were collected by the on-board sampling programme of the Portuguese Institute for Biological Resources (INRB/L-IPIMAR). The programme uses a stratified random sampling design with fleet, quarter and region as strata, and fishing trip as the sampling unit. The sampling frame included cooperative commercial vessels with an overall length between 12 and 40 m. Each vessel may be sampled more than once per year. Two observers were deployed per trip to collect information about fishing activity according to the following sampling protocol for each haul:

1. register general information, date, time, location, description of the sea floor, trawl speed and mesh size;
2. collect a sample of the unsorted catch on the deck, three boxes of approximately 12 kg taken from different places;
3. sort the sample according to the crew's criteria about which species are retained;
4. identify, measure and weigh all specimens (both retained and discarded);
5. collect information from the skipper about the weight of the retained species.

For each haul, the discard weight of each species is computed using the ratio of the mass of all retained species to the mass of retained species in the sample. At the trip level, discards by species are computed by summing over hauls. If some hauls were not sampled due to operational constraints, the observed discards are scaled to the trip level using the value of discards by weight per hour (DPUE) and the ratio between the trip's effort and effort of the observed hauls. For more information see Anon. (2011a). Sampling levels for the period 2004–2010 are presented in Table 1 together with the total effort deployed by each fleet.

Auxiliary information about fishing effort was collected from logbooks (haul duration in h) and auction information (number of fishing trips per vessel), both of which were provided by the Portuguese Directorate-General for Fisheries and Aquaculture (DGPA).