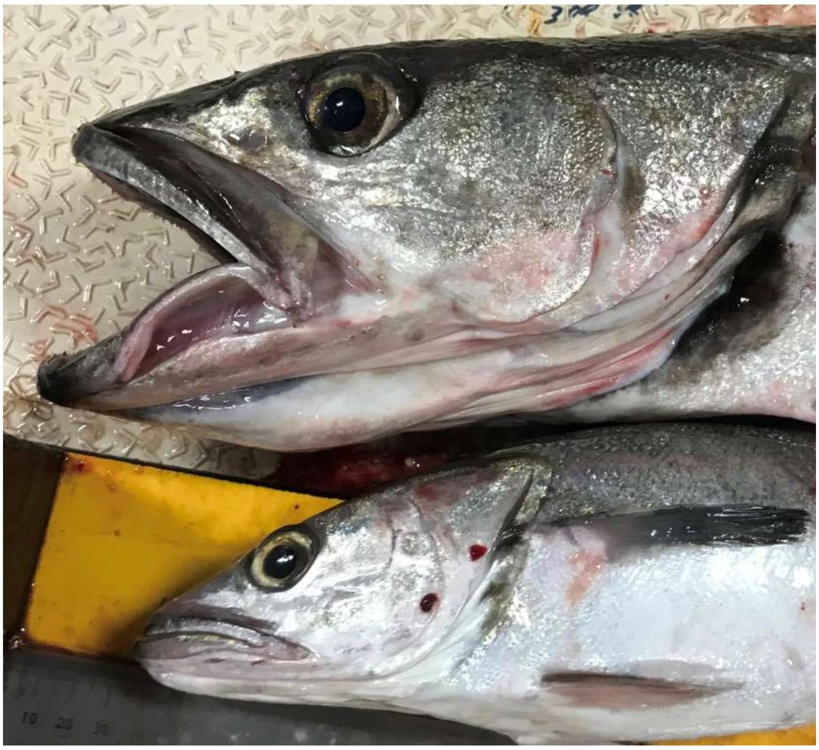
Age structure of the common hake *Merluccius hubbsi* from Falkland Islands water: January – December 2018



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1. Introduction

The age structure in a fish population provides the basic information for mortality rates, recruitment and growth (Hussy et al., 2016). These parameters are essential inputs in age-structured stock assessment models that provide the basis for management advice in many world fisheries (de Pontual et al., 2006; Morales-Nin et al., 1998; Pineiro and Sainza, 2003; Vaz-dos-Santos and Rossi-Wongtschowski, 2007). Due to the key role of age in stock assessment models, bias in age estimates can therefore fundamentally influence the perception of the stock and fishing mortality, resulting in erroneous predictions of stock size and related management advice.

The common hake *Merluccius hubbsi* is a demersal species distributed in the south western Atlantic from 21° to 55° S (Vaz-dos-Santos and Rossi-Wongtschowski, 2007). It is one of the species of primary importance in the Falkland Islands finfish fishery due to its relatively high commercial value and seasonal abundance with catches of around 27000 t in 2018. This annual report, presents a reliable ageing methodology for the construction of age length keys and estimation of growth and mortality parameters from hake samples obtained in the Falkland Islands during 2018. It also aims to provide estimates of inter- and intra-reader bias and precision in the age estimation in order to establish the reliability of the age estimation protocol and their potential use in future stock assessment and subsequent management advice.

2. Methods

2.1. Data *Collection*

Hake were sampled by scientific observers and other scientific staff of the Falkland Islands Government Fisheries Department. Data were collected on board commercial fishing vessels operating bottom trawls under various license types. In addition data were collected on board RV 'Monteferro' operating bottom trawls during research cruises.

Randomly sampled hake were measured to the nearest cm (TL), sexed and the stage of reproductive maturity assigned according to an eight-stage scale (I and II –

immature, III and IV – maturing, V – mature, VI – running, VII – post spawning and VIII – spent). Each annual collection of otoliths are stored in paper envelopes in four quarterly time periods (A: Jan – Mar, B: Apr – Jun, C: Jul – Sep and D: Oct – Dec).

Otoliths for ageing are selected to cover the length distribution of sampled fish from each quarterly otolith collection. This ensures that sufficient otoliths are aged for all lengths on a temporal basis.

2.2. Preparation of otoliths

Otoliths were embedded in rows of five in blocks of amber coloured polyester resin and left to set for 24 hours. Fully dried blocks are ground in order to provide smooth linear surfaces and the nucleus marked using a pencil. This is undertaken in order to guide the cutting angle and ensure that sections are cut precisely at right angles. Resin blocks were subsequently sectioned using a Buehler Isomet Low Speed Saw. Between two and six sections of 0.35mm were taken per resin block and mounted on microscope slides under coverslips with clear polyester resin.

2.3. Reading methodology

Sections were viewed under reflected light at 10 to 25 times magnification. All sections of each row of otoliths were inspected and the section closest to the primordium was used for subsequent ageing. Images were taken for the best section for each otolith and enhanced to provide assistance in ageing.

Following previous work on age estimation of this species, the sector from the primordium to the proximal edge of the section, on the ventral side of the sulcus was chosen as the area in which to count increments. However, for some preparations, increments formed on the dorsal side were at least as clear as those on the ventral side. Each otolith was aged at least twice by the primary reader. For otoliths where the first two readings did not agree, a third reading was undertaken. All counts of annuli were made without prior knowledge of fish size, date of capture or previous age estimates. Two independent age readers (Ind. 1 [in house] and Ind. 2 [external]) provided age estimates for a sub-sample of otoliths covering the length distribution of the total sample.

2.4. Precision of the age estimates

Repeated readings of the same otoliths provide a measure of intra-reader or inter-reader variability. They do not validate the assigned ages but provide an indication of size of the error to be expected with a set of age estimates, due to variation in interpretation of an otolith. Beamish and Fournier (1981) have developed an index of average percent error (IAPE), which has become a common method for quantifying this variation. The IAPE is calculated as:

$$APE = 100\left[\frac{1}{N}\sum_{j=1}^{N}\left(\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij} - X_j|}{X_j}\right)\right]$$

Where N is the number of fish aged, R is the number of times fish are aged, Xij is the ith determination for the jth fish, and Xj is the average estimated age of the jth fish.

An IAPE was calculated for all repeated readings undertaken (1) by the primary reader; (2) between the primary reader and the two independent age readers; and (3) between the two independent age readers.

2.5. Estimation of von Bertalanffy parameters

A von Bertalanffy growth function was fitted to the observed length-at-age data:

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where L_t is length (TL in cm) at time *t* (years), L_∞ the asymptotic length, *K* is the rate (year^{-1}) by which L_∞ is approached, and t_0 is the theoretical age at length zero. Growth curves were fitted for males and females by non-linear least-square regression in R (R Core Team, 2017). Likelihood ratio tests were used to estimate whether a combined sex growth model or sex-separated models better described the length-at-age data. A parametric bootstrapping procedure with 1,000 iterations was employed to estimate 95% confidence intervals for final parameter estimates (Baty et al., 2015).

2.6. Mortality estimates

Catch-at-age frequency plots for each sex were obtained from representative length frequency data, by applying age-length keys derived from the aged otoliths (Ogle et al., 2018). The annual survival rate (S) and instantaneous rate of total mortality (Z) were estimated from catch-at- age data on the descending limb of the catch-curve using the Chapman- Robson approach (Chapman and Robson, 1960) with the variance estimate corrected for overdispersion as recommended by Smith et al. (2012). Initial ascending points representing fish that were not fully recruited to the fishery were excluded from the analysis.

3. Results and discussion

3.1. Distribution of Samples

Hake captured in the trawl fishery occurred primarily within the ‘hake box’ (north of 52°S, west of 60°W) to the north-west over the Falkland Islands shelf at depths between 80 and 412 m depth (Mean = 169.3 m; Figure 1). Samples were also sporadically obtained to the east, south and west of the Falkland Islands along the 200m depth contour.

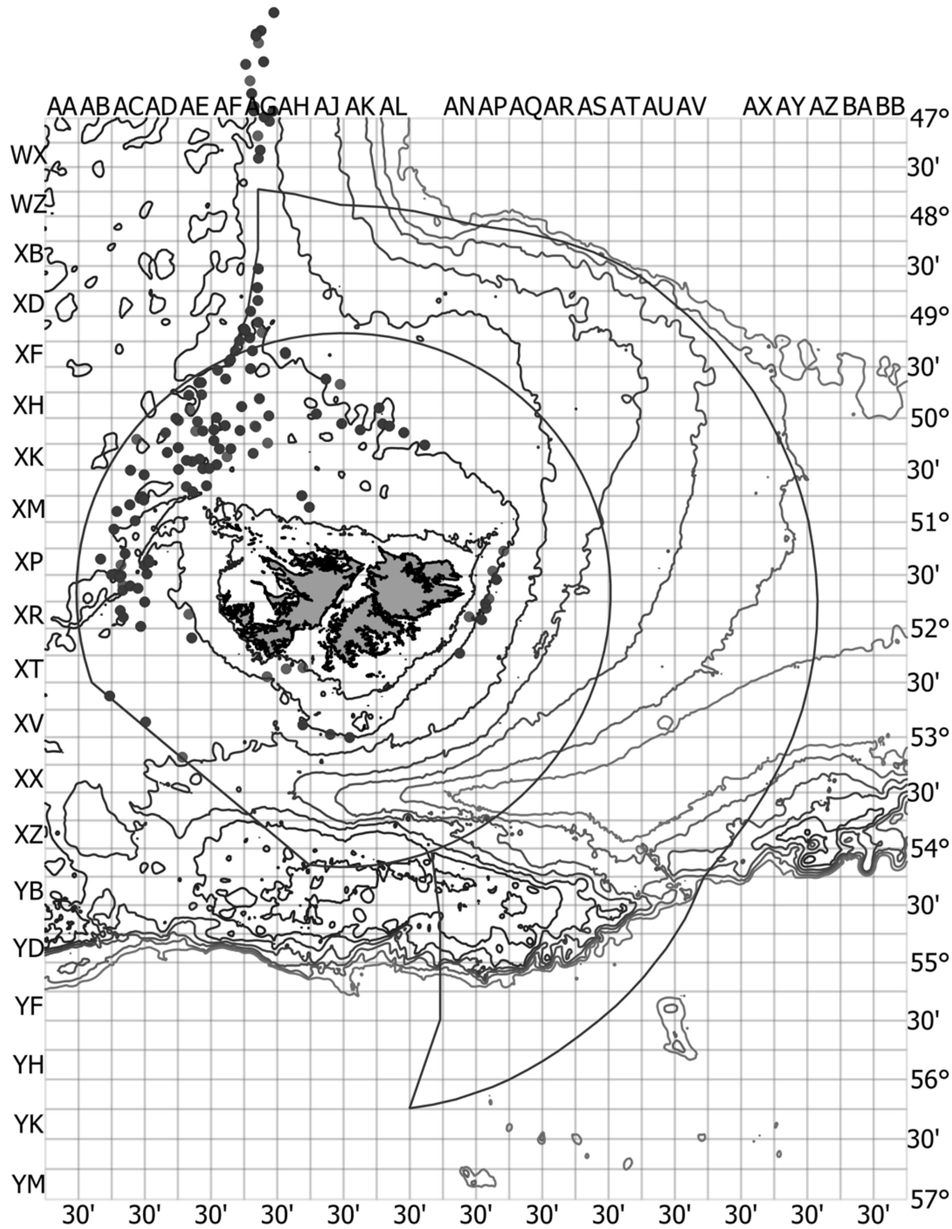

Figure 1: Positions from which common hake samples were obtained over the Falkland Islands shelf for 2018.

3.2. Length and Age composition

Biological information were collected from a total of 25 638 hake samples of which 7165 were male, 18444 were female and 39 were not assessed for sex. Lengths ranged between 17 and 89 cm TL for females and 19-70 cm TL for males. Differences were evident in the length frequency distributions between male and female fish. Male fish displayed a smaller modal length (40 cm TL), and mean (36 cm TL) compared to females (mode: 43 cm TL, mean: 43.1 cm TL, Figure 2A). Female fish were more abundant in the larger (>30 cm TL) length classes with very few males >52 cm TL.

As age estimates were only obtained from 660 individuals, the age frequency distribution was derived from the age length keys. Unsexed fish were excluded from these analyses. The modal age of the catch was 4 years for females (1-17 years) and 3 years for males (1-14 years; Figure 2B). The majority of hake being caught within the Falkland Islands were older than 2 years old. Females were in greater abundance in all age classes greater than three years old, with few females greater than 8, and males greater than 6 years old.

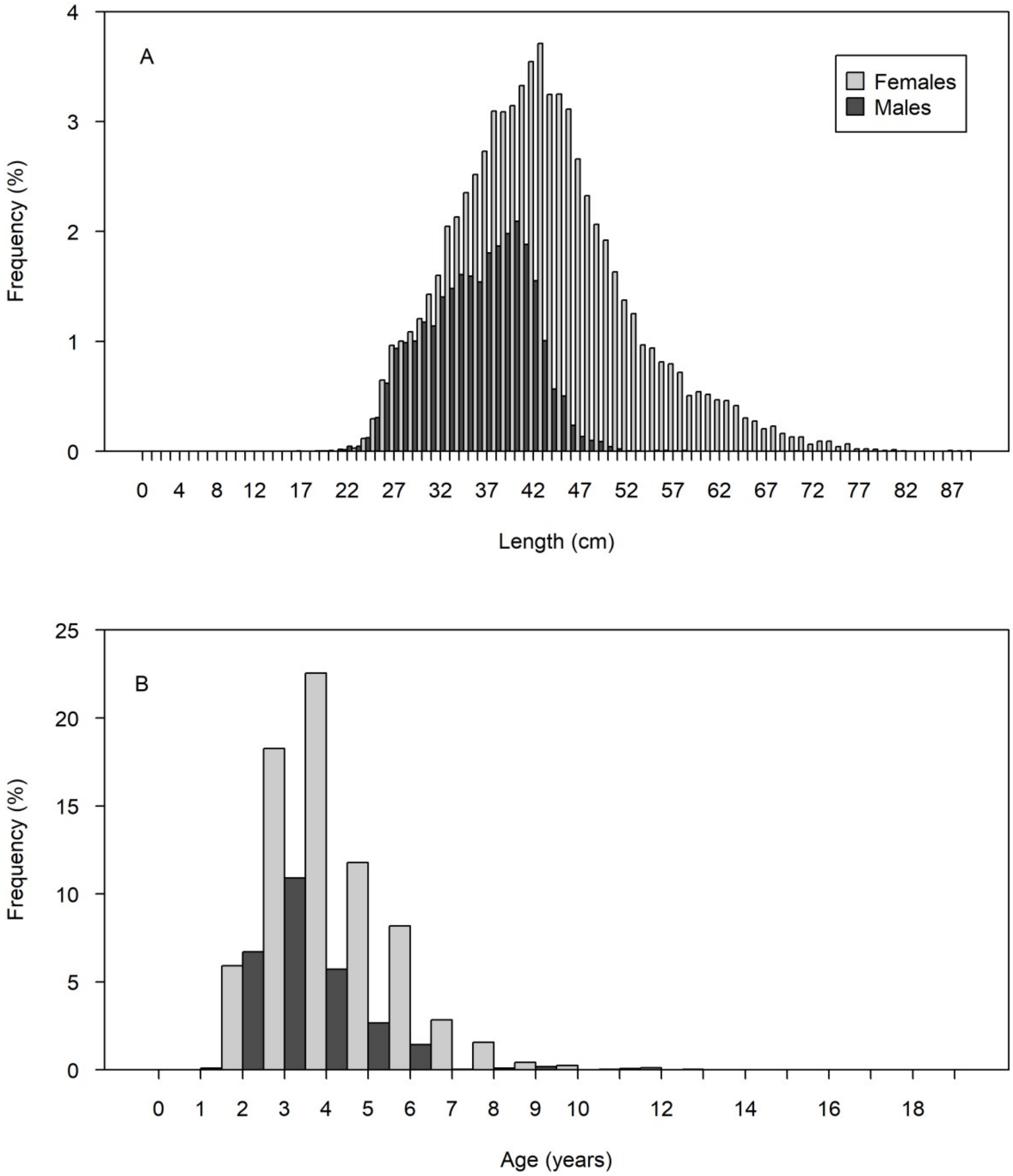

Figure 2: Length (A) and age frequencies (B) estimated from the total (aged and unaged) sampled catch of hake captured in the trawl-based fishery as estimated from the age-length key (n = 25609). 39 fish were unsexed and excluded from the age-length key analyses.

3.3. Otolith interpretation

Otoliths were extracted from a total of 1181 fish of which 660 were processed for age determination. Otolith interpretation in hake was complex because of the presence of many macrostructures visible as thin translucent zones that probably correspond to short environmental and/or physiological events (Courbin et al., 2007), with fish appearing to undergoing a series of growth interruptions particularly during the early life-history period (Brown et al., 2004). The first 0-3 years of hake otolith growth was characterised by wide diffuse annuli, containing numerous false rings or ‘checks’ (Figure 3). Three characteristic ‘checks’ have been described occurring in *Merluccius* spp, prior to the first annual growth ring (Pineiro and Sainza, 2003; Vaz-dos-Santos and Rossi-Wongtschowski, 2007), and have been associated with the larval phase, pelagic phase and the onset of the demersal phase. The varying position of the first annuli relative to the nucleus (1-1.5 mm from the primordium) is related to the extended spawning season of this species. A check commonly forming between the 1st and 2nd annuli is thought to be due to a change in diet from invertebrates to fish (Pineiro and Sainza, 2003). The second annulus consistently forms at 2 mm from the primordium, frequently followed by another check prior to the formation of the 3rd annulus. Subsequent annuli (>3-4 years), which seem to occur after the onset of maturity, became increasingly narrow and distinct.

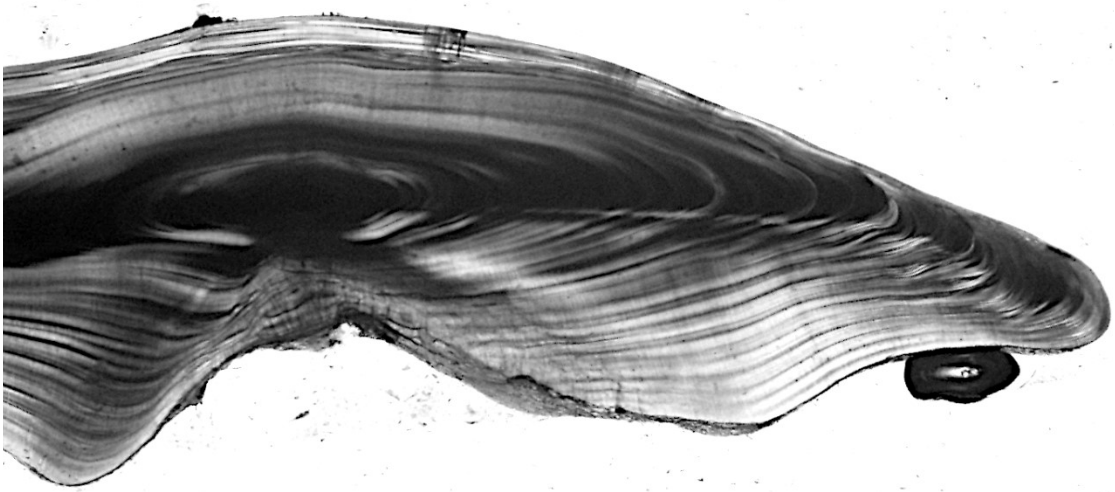

Figure 3: Sectioned otolith from a 75 cm female hake with an estimated age of 13 years, viewed at 16x magnification.

3.4. Age and growth

Likelihood ratio tests indicated significant differences in growth between male and female common hake (χ^2=184.87; *P*<0.01). Likelihood ratio tests indicated significant differences in the $L\infty$ (χ^2=30.07; *P*<0.01) and *K* (χ^2=19.52; *P*<0.01), but not for the t_0 (χ^2=2.61; *P*=0.106) parameter estimates for male and female fish. Calculated von Bertalanffy growth parameters and their 95% confidence intervals for male and female fish are presented in Table 1 and Figure 4. Female fish grew to a larger size and age compared to males. Male fish, however reached their asymptotic size at a faster rate compared to females.

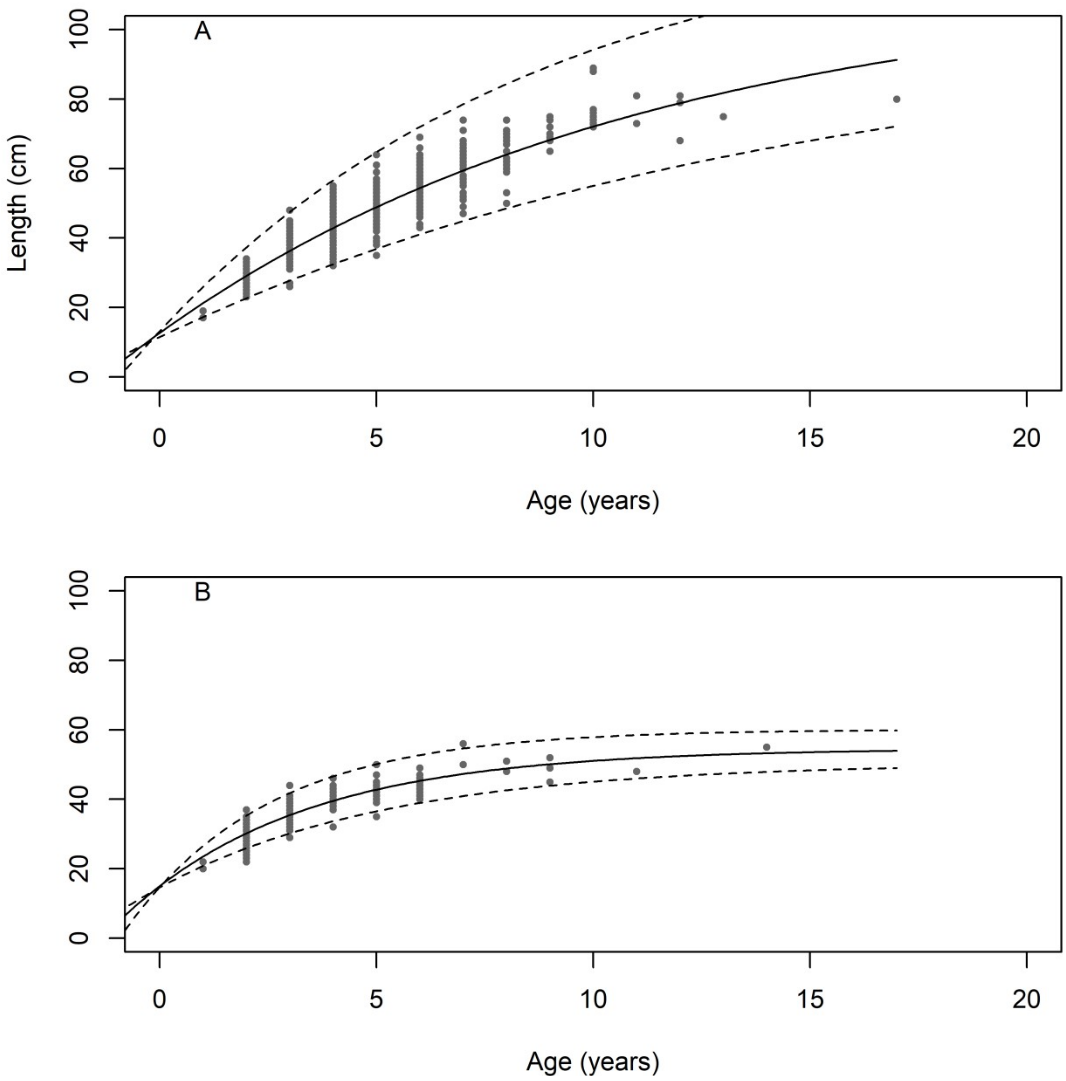

Figure 4: Length versus age with superimposed best-fit von Bertalanffy growth model and 95% confidence bands (dashed lines) for (A) female and (B) male common hake sampled during 2018.

Table 1: Von Bertalanffy parameters (with 95% confidence intervals) for common hake sampled during 2018.

Parameters	Estimate	Std Error	LCI	UCI
Females				
$L\infty$	113.53	8.19	100.73	133.48
K	0.089	0.012	0.067	0.11
t_0	-1.32	0.23	-1.80	-0.92
n	495			
Males				
$L\infty$	54.57	2.46	50.38	60.07
K	0.24	0.029	0.19	0.30
t_0	-1.32	0.23	-1.80	-0.92
n	165			

3.5. Mortality estimates

The threshold ages for the mortality estimates for hake were 4 years for females and 3 years for males, respectively (Figure 5). The mortality estimates obtained from the catch curves differed between the sexes. The total annual survival and mortality rate for females was 48.76% (Z=0.72 year−1) compared to 42.75% (Z=0.85 year−1) for males (Table 2, Figure 5). The natural mortality (M) and fishing mortality (F) components, however requires further investigation.

Table 2: Estimates of survival rate and total mortality for hake using the Chapman-Robson catch-curve estimator.

	Estimate	Std. Error	95% LCI	95% UCI
Females				
S	48.760	0.325	48.123	49.397
Z	0.718	0.038	0.643	0.794
Males				
S	42.751	0.513	41.745	43.757
Z	0.850	0.066	0.720	0.979

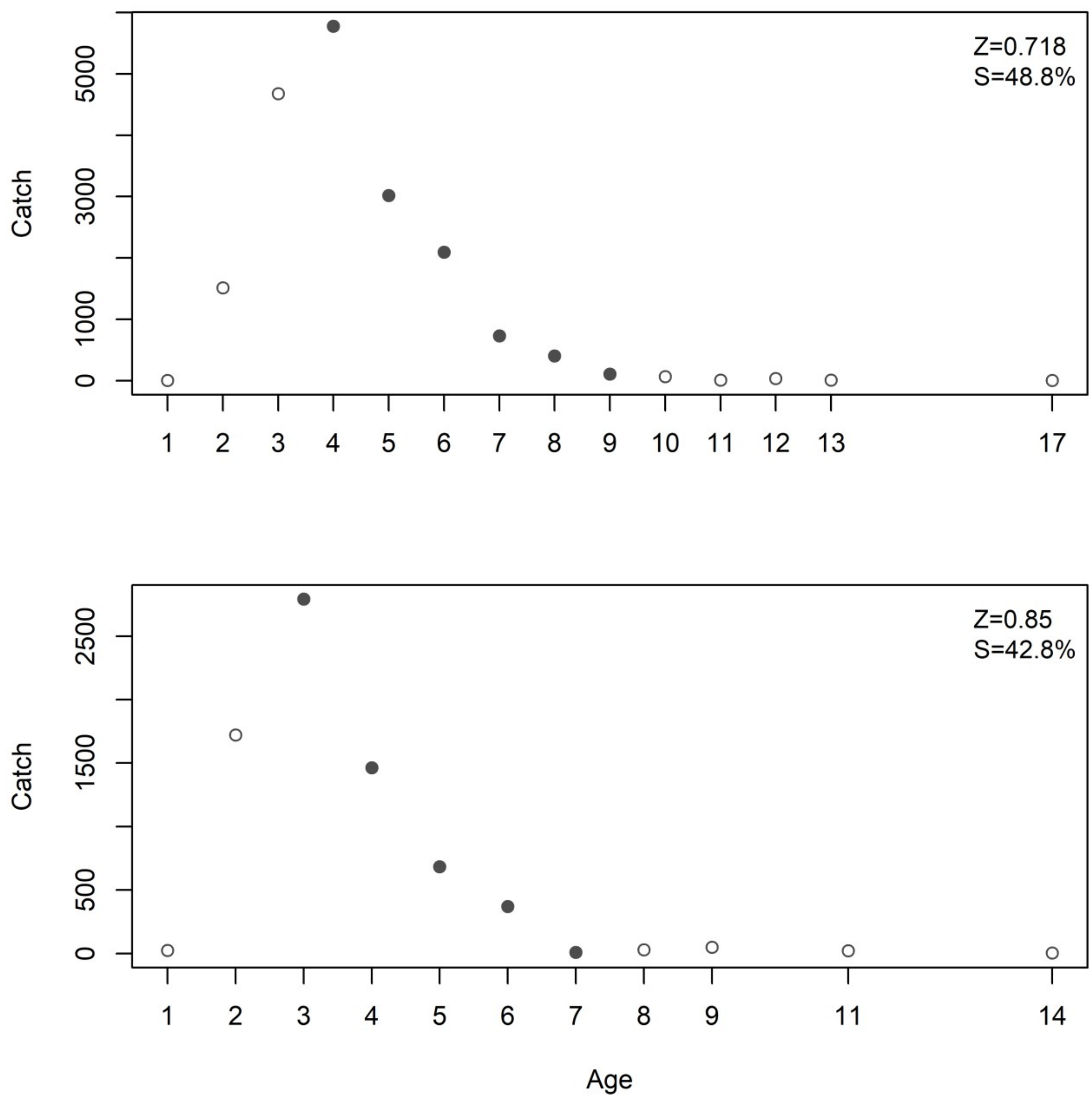

Figure 5: Catches at estimated ages for hake. The solid points were used to compute the Chapman-Robson estimates of *S* and *Z*.

3.6. Precision of the age estimates

The percentage agreement table indicates that multiple estimates of ages by the primary reader agreed for 73.48 to 76.98% of the fish otoliths, while 20.61 and 23.79% differed by one year (Table 3). Age estimates between the primary and independent readers agreed between 56.81 and 58% of the fish, while 51.35% of the age estimates were the same between the two independent age readers (Table 3).

Age bias between the age readings was normally distributed across the age range. The APE was between 3.26 and 4.04% for the primary reader and the ACV was 4.60

to 5.71% (Table 3). These indicate that ageing precision was relatively high in common hake.

Table 3: Percentage table of raw differences between multiple readings of hake otoliths and the associated APE and ACV for 2018.

	Age difference (%)									
	0	1	2	3	4	5	6	N	APE	ACV
Age v. Age 1	76.97	20.61	2.27	0.15				660	3.26	4.60
Age v. Age 2	73.48	23.79	2.58	0.15				660	4.04	5.71
Age v. Ind. 1	58.00	36.00	6.00					150	5.68	8.03
Age v. Ind. 2	56.81	40.58	2.03		0.29		0.29	345	6.54	9.24
Ind 1 v. Ind. 2	51.35	44.59	2.70	1.35				74	8.23	11.63

4. Conclusion

Results of the current study provide biological parameters for hake in the Falkland Islands for 2018. Our findings indicate that the prescribed ageing protocol provides a moderately reliable method for age estimation for the successful application of empirical age-length keys for the assessment of the hake stock. Nonetheless, difficulties remain in interpreting patterns of annuli formation, particularly within the first 5 years (de Pontual et al., 2006). Further attention should be given to the development and refinement of a robust age estimation and interpretation protocol for hake in the Falkland Islands and greater Patagonian Shelf within which the stock is shared. In particular, annual age structure work on hake in the region needs to be complemented by research into daily age estimation in order to quantify the observed variability in the formation of the first annuli.

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