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Using the gonadosomatic index to estimate the maturity ogive: application to Chilean hake (*Merluccius gayi gayi*)

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The proportion of mature fish at age or length is one of the most important population attributes in assessing reproductive potential. This proportion is usually named the maturity ogive. The most crucial step in estimating this proportion deals with maturity staging assessed by macroscopic or histology analysis. Macroscopic analysis is relatively inexpensive but usually introduces large amount of error. Histology is the most accurate method for maturity staging but is expensive and time consuming. Here, we propose using the gonadosomatic index (*GSI*) as an alternative way to estimate the maturity ogives. A logistic multinomial model was implemented to separate immature, mature-active, and mature-inactive fish, based only on their value of *GSI*. We evaluated the performance of the *GSI*-based method by comparing the results with ogives estimated from macroscopic and histological staging using the extensive database available for Chilean hake (*Merluccius gayi gayi*). Maturity ogives from *GSI* analysis were evaluated at the start and end of the reproductive season. Results showed that, in all cases analysed, maturity ogives from *GSI* were closer to the ogives based on histology than those from macroscopic staging. Comparing across periods, those maturity ogives computed at the start of the reproductive season give estimates very similar to those from histological staging. To have unbiased estimates of maturity ogives from *GSI* analysis, we recommend using data from the start of the reproductive season to minimise the frequency of spent fish. In addition, the assumption of the isometry between gonad and gutted weight across maturity stages needs to be tested before the use of this *GSI* method. The analyses presented here provide a promising method to estimate maturity ogives when histological staging data are lacking or when macroscopic analysis is suspected to have large amounts of errors.

Keywords: gonadosomatic index, logistic multinomial model, maturity ogive, maturity staging, reproduction.

Introduction

The proportion of mature individuals at age or length, usually called the maturity ogive, is an important population attribute because it directly relates to the reproductive potential of the population. Knowledge of the maturity ogive is especially important in exploited fish populations because it determines the spawning biomass upon which conservation measurements are usually based. The estimation of the maturity ogive commonly consists of three steps. First, the spawning season must be identified. Second, representative samples of individuals collected during the spawning season are assessed to establish their maturity stage. Finally, observed proportions of maturity at length or age are computed which are then conventionally modelled using a logistic function. The maturity staging process is the most crucial step in estimating the maturity ogive because small errors in stage assignment can lead to profound variations in estimated parameters for the fitted model (Vitale *et al.*, 2006). Macroscopic and histology analyses are the most common methodologies to assess maturity in fish. Macroscopic analysis is the quickest method to assign maturity stages and it is based on the appearance of the gonad when assessed by naked eye. This method is relatively inexpensive, as a large number of samples can be processed by a single trained observer. However, macroscopic

analysis may involve high levels of error due to the difficulties in distinguishing between immature and spent fish from a visual inspection of the gonad. Histology is the most accurate method used to determine maturity stage in fish (West, 1990). Histological staging involves studying the structures within the ovary or testes and therefore gives an unambiguous interpretation of maturity status (West, 1990). However, histological analysis is relatively expensive and time consuming, thus limiting its routine application. These limitations in macroscopic and histological analyses call for alternative approaches to be explored for the purposes of maturity staging.

Previous studies have successfully applied various methods based on the gonadosomatic index (*GSI*) to improve accuracy in determining maturity stage (McQuinn, 1989; Vitale *et al.*, 2006; McPherson *et al.*, 2011). These studies allowed immature fish to be separated from spent or recovering fish and identified the degree of maturity for females when neither histology nor macroscopic analyses were available. *GSI* is a metric that represents the relative weight of the gonad to the fish weight. *GSI* has been widely used to evaluate reproduction timing (Lowerre-Barbieri *et al.*, 2011) because it is inexpensive and easy to compute. Changes in *GSI* are mostly determined by variations in yolk concentration during different oocyte stages and thus it provides information about maturation and seasonal patterns in gonad development (Wallace and Selman, 1981; West, 1990). McPherson *et al.* (2011) proposed a logistic multinomial model to evaluate maturity staging based only on *GSI* that was successfully applied to *Clupea harengus* to correct estimates from macroscopic staging, thus providing an alternative use of the *GSI* on the context of maturity staging.

In this study, we extend the application of the method proposed in McPherson *et al.* (2011) to actually separate mature and immature fish in the same manner macroscopic or histological analysis is used to estimate proportion of mature individuals. Thus, we propose an alternative way to compute maturity ogives based on *GSI*. We also improve estimates of maturity at length from *GSI* by evaluating two different reproductive periods according to the relative frequency of spent and recovering fish. By separating different reproductive periods, we aim to correct the bias reported in McPherson *et al.* (2011) where immature and recovering fish can have the same value of *GSI* and thus, increasing the chance of misclassification when computing the proportion of mature fish.

Using the extensive data for macroscopic and histology analyses in Chilean hake (*Merluccius gayi gayi*), we assess the reliability of using *GSI* for estimating maturity ogives. The Chilean hake is one of the most important species fished in Chile in terms of total catch and economic importance (Aguayo, 1995). According to compiled logbooks, the Chilean hake fishery in Chile is conducted on the continental shelf between Coquimbo (29°00′S) and Chiloé Island (42°00′S) in depths ranging from 50 to 400 m (Lillo *et al.*, 2006). This species is currently exploited by an industrial multispecies trawl fishery, which operates predominantly between San Antonio (33°30′S) and Talcahuano (36°41′S). It is also fished by artisanal longline and gillnet vessels over its entire distribution (Lillo *et al.*, 2007). Chilean hake has asynchronous ovary development with indeterminate fecundity, characterised by the simultaneous presence of oocytes of different stages and reproductive activity throughout the annual cycle with a peak between July and November (Balbontín and Fischer, 1981). Information regarding maturity was available from the intensive sampling programme carried out by the Instituto de Fomento Pesquero (IFOP-Chile). Data were collected from both the routine sampling programme of the commercial operations and the scientific acoustic sampling programme.

Precision of maturity ogive estimates depend mostly on the maturity staging method but also to some extent on how well represented the size structures are. In Chilean hake, maturity ogives are estimated using histology from samples collected mainly on the acoustic surveys. These surveys of short duration are performed during the spawning season and as a result the size structure usually lacks medium to small individuals. This may be due to latitudinal variations of catchability and durations of reproductive activity (Balbontín and Fischer, 1981; Alarcón *et al.*, 2004). In contrast, samples collected during commercial fishing provide a representative size structure, with an extensive spatio-temporal coverage. However, during commercial fishing sampling, mainly macroscopic analyses are conducted. Thus, here we validate the use of *GSI* for estimating maturity ogives by comparing them with those estimated from histology and macroscopic analyses and also assessing the consistency between maturity ogives estimated for two seasonal periods: at the beginning (southern winter) and at the end of the reproductive season (southern spring).

Material and methods

Data

The study area corresponds to the main fishing ground of Chilean hake between 29°10′S and 42°00′S. Data were collected from the commercial fishery targeting Chilean hake between 1997 and 2010, the details of this commercial sampling programme can be found in Gálvez *et al.* (2012).

On-board scientific observers selected a random sample of fish and recorded total length (cm), gutted weight (g), gonad weight (g), and maturity stage. Although both sexes were collected in these random samples, we only considered females in this study because the macroscopic staging of testes is difficult to assess. A total of 65 217 gonads were assigned to a macroscopic maturity stage according to the maturity scale of Balbontín and Fischer (1981). This scale defined six stages for Chilean hake: virgin (Stage 1), immature (Stage 2), maturation (Stage 3), maturation with recent spawning (Stage 4), spawning (Stage 5), and spent (Stage 6).

A total of 1214 gonads collected during 2001 were analysed by the means of histology. Gonads were preserved in 10% buffered formalin. The sampling protocol included the dehydration of 3 mm thick subsamples of preserved gonad tissue embedded in paraffin. Sections, 5 μm wide, were stained with Harris's haematoxylin and eosin was used to analyse and characterise the gonad development and thus determine the different maturity stages according to the modified scale of Herrera *et al.* (1988): virgin (Stage 1), immature (Stage 2), early maturing (Stage 3), late maturing (Stage 4), mature (Stage 5), ripe (Stage 6), spawning (Stage 7), partial post-spawning (Stage 8), and spent (Stage 9).

Statistical analysis

GSI was computed as the ratio between gonad weight (G) and gutted weight (W) in each individual sampled as follows:

$$GSI = \frac{G}{W}. \quad (1)$$

Using only the data from histology, we modelled relationship between gonad weight and gutted weight using a power function as $G(W) = a_i W^{b_i}$, where a_i and b_i are parameters estimated for each histological stage i. Model selection was conducted by residual

analysis. To validate the independence between *GSI* and individual size, we used a log–log scale to linearise the power function then assessed the value of the slope. When this slope is not significantly different from 1, then the relationship is approximately isometric (Somarakis *et al.*, 2004). We also evaluated how similar these slopes are among different maturity stages, a condition known as homogeneity (DeVlaming *et al.*, 1982; Erickson *et al.*, 1985). Isometry and homogeneity were evaluated using *t*-test and covariance analyses, respectively.

To study the duration and intensity of the reproductive season, the *GSI* and the proportion of active mature females (P_{MA}) were modelled using generalised additive models (GAM) following Wood (2006). The data used to implement this GAM corresponded to that collected between 1997 and 2010. The following model was implemented:

$$E[x] = \alpha + te(\text{Month, Length}), \tag{2}$$

where $E[x]$ is the expected value of the modelled *GSI* or P_{MA}, α is intercept, and *te* is a two-dimensional tensor product smooth of the month and size strata covariates. Specifically for these analyses, fish that achieved Stages 3–5 in the macroscopic scale were classified as active mature (P_{MA}). Model selection for *GSI* was performed using the generalised cross-validation value (GCV) and the model for P_{MA}, was selected using the unbiased risk estimator because of the binomial nature of maturity data (Wood, 2006).

Fish collected during 2001 that had reached at least Stage 3 in the macroscopic and histological scales were classified as mature. In addition, for same data, the method in McPherson *et al.* (2011) was also applied to determine maturity. This method was based on a logistic multinomial model which was used to compute the conditional probability of an individual *Y* of being in the maturity stages y_j given the *GSI* $P(Y = y_j|GSI)$ such as

$$P(Y = y_j|GSI) = \frac{\exp(\alpha_j + \beta_j \times GSI)}{\sum_{h=1}^{J} \exp(\alpha_h + \beta_h \times GSI)}, \tag{3}$$

where α_j is the intercept and β_j is the slope of the corresponding *GSI*. Here $j = \{1, 2, \ldots, J\}$ are the histology stages grouped in three categories: immature (Stages 1 and 2), mature-inactive (Stage 9), and mature-active (grouping Stages 3–8). Mature-active fish were designated as the reference category and each of the other categories (immature and mature-inactive) was compared with this baseline. Hereafter, this method for maturity assignation is named as $GSI_{\text{cut-off}}$ analysis.

A cut-off *GSI* score can be defined as the test score at which an individual is as likely to be in category j as in category $j + 1$. Parameters α_j and β_j were estimated using maximum likelihood method and the goodness of fit was evaluated using likelihood ratio (G^2 (M)) and the McFadden pseudo-R^2 (R^2_{MF}) as suggested by McFadden (1974).

As recommended by Gerritsen and McGrath (2006), the Cohen's kappa coefficient (Cohen, 1960) was used to evaluate the agreement in the proportion of individuals assigned to each maturity group using the histology and macroscopic approaches and also between histology and $GSI_{\text{cut-off}}$. The kappa coefficient (κ) is computed as follows:

$$\kappa = \frac{P_o - P_e}{1 - P_e}. \tag{4}$$

Here, P_o is the relative observed agreement between maturity staging analyses, and P_e is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each analysis randomly falling each category. If the analyses are in complete agreement then $\kappa = 1$. If there is no agreement between analyses other would be expected by chance (as defined by P_e), $\kappa = 0$. The value of P_e is calculated as

$$P_e = \sum_{i=1}^{n} P_{a,i} \times P_{b,i}, \tag{5}$$

where $P_{a,i}$ is the proportion of individuals assigned to maturity category i by the macroscopic or $GSI_{\text{cut-off}}$ analysis and $P_{b,i}$ is the proportion of individuals assigned to maturity category i by the histology analysis. According to Landis and Koch (1977), the values of κ describing the level of agreement can be interpreted as: 0.0–0.20 poor, 0.21–0.40 low, 0.41–0.60 moderate, 0.61–0.80 considerable, and 0.81–0.99 optimum. As recommended by Gerritsen and McGrath (2006), we used a non-parametric bootstrap to compute the 95% confidence interval of κ using the percentile method (Efron and Tibshirani, 1993).

For each analysis described, the proportion of maturity at length (P_L) was modelled using a logistic function as follows:

$$P_L = \frac{1}{1 + \exp(\beta_1 + \beta_2 \times L)}, \tag{6}$$

where β_1 and β_2 are the parameters estimated using maximum likelihood and assuming a binomial error distribution. Uncertainty was incorporated into the model using a parametric bootstrap (Roa *et al.*, 1999). The goodness of fit was assessed using the Hosmer–Lemeshow test (*HL*) as suggested by Hosmer and Lemeshow (1989). The comparison among maturity ogives by maturity staging methods was performed using the Wald test. All statistical analyses were conducted using R statistical software (www.r-project.org).

Results

The linear log–log relationship between gonad and gutted weight showed a positive allometry (slope > 1) in immature (Stage 2), early maturing (Stage 3), and spent (Stage 9) fish. For the rest of maturity stages, the slope was not significantly different from 1, indicating that *GSI* is independent of size once females reached an advanced active maturity stage (Table 1).

A GAM of *GSI* with a Gamma error distribution (inverse link) was selected based on the lowest value of the generalised GCV. The explained deviance of the *GSI* model was 26%. In addition, the GAM fitted to the proportion of active females (P_{MA}) was implemented using a Binomial error distribution (logit link) which yielded an explained deviance of 16%. Despite the relatively low percentage of explained deviance, both models described relative high values of *GSI* and P_{MA} during winter and spring where size strata >34 cm had high frequency of reproductively active fish (Figure 1). In addition, females that were ~37 cm in length or larger had similar *GSI* during spawning season, agreeing with the homogeneity assumption of *GSI*.

The estimated parameters of the logistic multinomial model (Equation 3) were statistically significant ($p < 0.05$) and the conditional probability of an individual of being in each one of the three maturity stages based on the *GSI* is showed in Figure 2.

Table 1. Summary of log–log relationship between gonad (g) and gutted weight (g) in samples grouped by maturity stages *i* collected during 2001.

Stage	a_i (s.e.)	b_i (s.e.)	d.f.	r^2	$\|t\|$
2	−4.89 (0.11)	1.98 (0.04)	637	0.80	50.3***
3	−3.58 (0.50)	1.62 (0.18)	52	0.62	9.2***
4	−2.47 (0.60)	1.37 (0.21)	128	0.25	6.5
5	−1.31 (0.42)	1.02 (0.15)	148	0.24	6.9
6	−2.51 (0.71)	1.48 (0.25)	34	0.51	6.0
8	−1.60 (0.96)	1.06 (0.33)	14	0.42	3.2
9	−3.23 (0.49)	1.46 (0.17)	45	0.62	8.5**

a_i, intercept; b_i, slope; s.e., standard error; d.f., degrees of freedom; r^2, coefficient of determination; $|t|$, Student's *t*-test for the hypothesis of isometry ($b = 1$).
Significance levels: $^{**}p < 0.01$; $^{***}p < 0.001$.

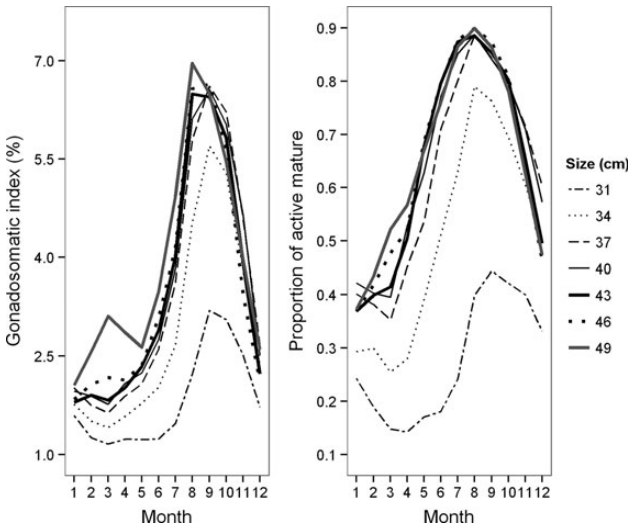

Figure 1. Response variable modelled across months and size strata using generalised additive models for *GSI* (left) and proportion of mature-active females (right). The data correspond to samples collected between 1997 and 2010.

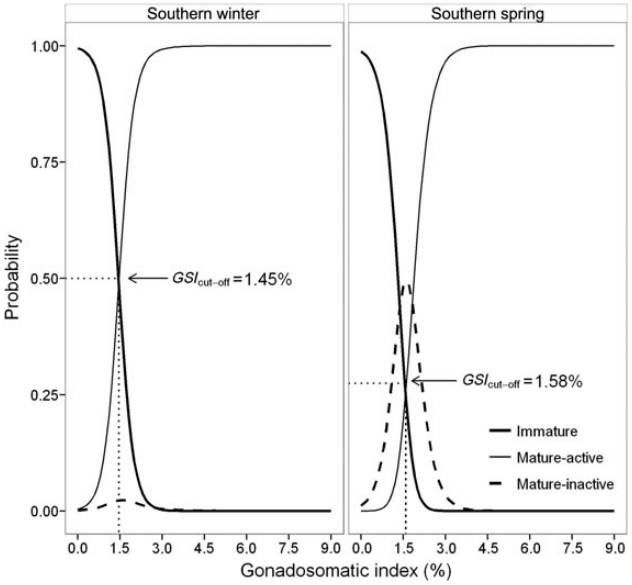

Figure 2. Probability of being immature, mature-active, and mature-inactive given the *GSI* value. Dotted vertical line indicated the estimated values of *GSI* cut-off. $GSI_{cut\text{-}off}$ is defined as the cut-off value that corresponds to the intersection between the immature curve and mature-active curve. The data correspond to samples collected during 2001.

Table 2. Agreement level of kappa (κ) between methods and seasons for samples collected during 2001.

		Histology vs. macroscopy		Histology vs. $GSI_{cut\text{-}off}$	
Season	Females (*n*)	κ (95% *CI*)	% Error	κ (95% *CI*)	% Error
Winter	446	0.60 (0.53–0.67)	28.4	0.87 (0.81–0.91)	13.7
Spring	314	0.58 (0.51–0.66)	28.1	0.72 (0.65–0.79)	23.2
Global	760	0.60 (0.54–0.64)	28.3	0.81 (0.76–0.85)	18.5

The 95% *CI* of κ is in brackets. % Error represents the percentage of individuals that were incorrectly assigned to each stages categories (immature, mature-active, and mature-inactive).

According to the likelihood ratio test (G^2), the goodness of fit of the model was significant ($p < 0.05$) for both periods, with values of R^2_{MF} of 71 and 66% for winter and spring, respectively. The values of $GSI_{cut\text{-}off}$ to separate immature from mature-active fish were 1.45 and 1.58% corresponding to winter and spring, respectively (Figure 2).

Computed values of the kappa coefficient (κ) for the inter-agreement between maturity staging techniques are shown in Table 2. $GSI_{cut\text{-}off}$ showed larger κ values than macroscopic analysis when compared with histological staging for both seasons. Thus, $GSI_{cut\text{-}off}$ has higher agreement with histological staging compared with macroscopic analysis. Using Landis and Koch (1977) interpretation for κ ranges, $GSI_{cut\text{-}off}$ showed considerable and optimum agreement with histological staging (Table 2). The macroscopic staging agreed well with histology for fish of lengths <35 cm, but for larger sizes showed bigger differences with histological staging because of the confounding effect between immature and spent fish, mainly during spring (Figure 3). $GSI_{cut\text{-}off}$ has lower agreement with histological during southern spring compared with winter, because inactive mature (spent) and immature females show similar *GSI* values increasing the chances of misclassification in a wide range of fish sizes (Figure 4).

The estimated parameters of the maturity ogive were significant ($p < 0.05$) for the three methods assessed (Table 3). The maturity ogive computed using macroscopic analysis was significantly different ($p < 0.05$) from that computed using histology staging in both seasons. The maturity ogive from macroscopic analysis overestimates the probability of maturity in most length strata (Figure 5, Table 3). In contrast, the maturity ogive from the $GSI_{cut\text{-}off}$ analysis and that computed using histology for winter season were not significantly different ($p > 0.05$). However, the ogives from these two approaches were significantly different ($p < 0.05$) during spring when the frequency of spent females was high (Figure 5, Table 3).

Discussion

The use of the *GSI* as reliable reproductive measure relies on two main assumptions. First, the slope of the linear log–log relationship

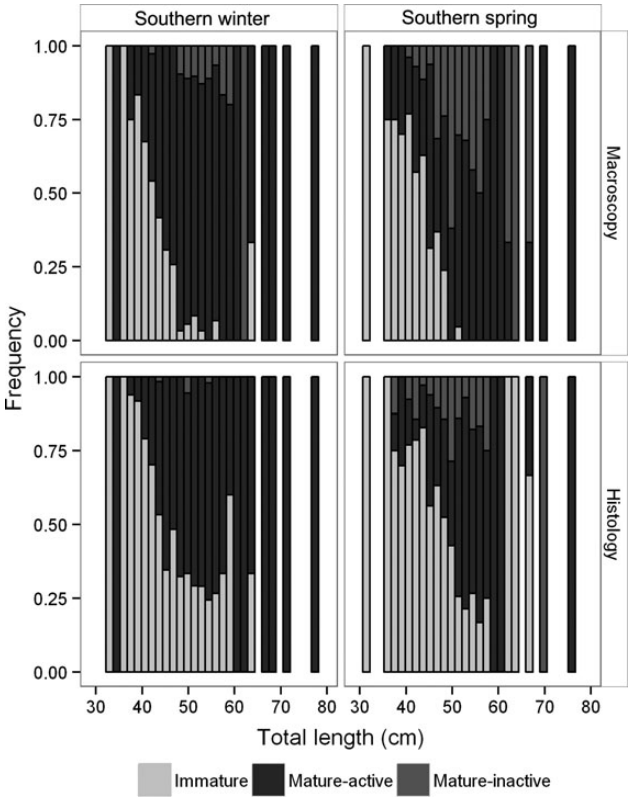

Figure 3. Relative frequency of immature, mature-active, and mature-inactive across lengths and seasons for macroscopic and histological analyses, for the samples collected during 2001.

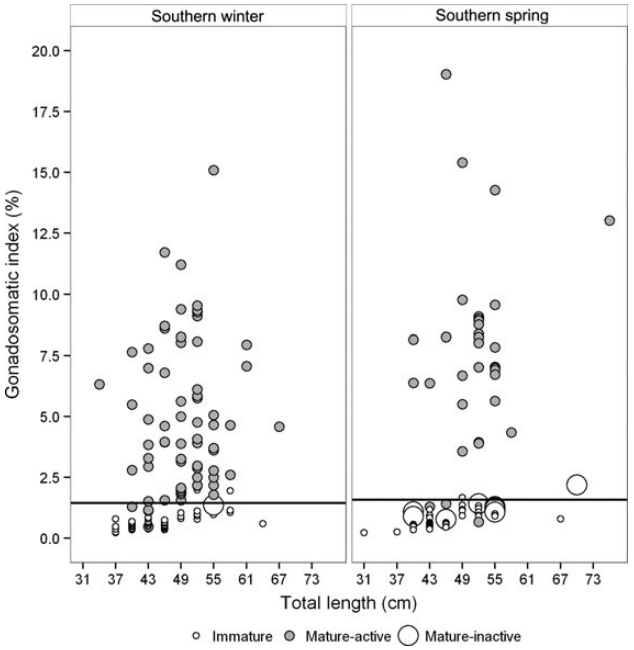

Figure 4. Values of *GSI* grouped by categories of mature stage across length strata and seasons for the samples collected during 2001. The horizontal line correspond to the *GSI* cut-off values.

between the gonad weight and the gutted weight in samples grouped by maturity stages should not be significantly different than 1, a condition named as isometry (Somarakis *et al.*, 2004). Second, these slopes should not be significantly different among maturity stages, a condition named as homogeneity (DeVlaming *et al.*, 1982; Erickson *et al.*, 1985). For Chilean hake, we showed that these assumptions are valid from stages of late maturing (Stage 4) to partial post-spawning (Stage 8), indicating that *GSI* is independent of size once the females reached advanced active maturity stages. Thus, the *GSI* is a valid metric to analyse the reproductive condition in Chilean hake (see Figure 1). European hake (*Merluccius merluccius*), another species of the same genus, also showed independence between *GSI* and the size of the females (Korta *et al.*, 2010). This is probably because they have the same reproductive strategy to Chilean hake being as asynchronous with indeterminate fecundity.

The application of the macroscopic maturity scale is suitable for studies of seasonal patterns of gonadal development (West, 1990). However, accuracy of maturity staging is highly dependent on the experience and training of scientific observers to avoid the use of subjective criteria. The most common sources of error and bias in macroscopic analysis are related to a lack of standardisation in the criteria used for maturity staging, poor interchange of criteria among observers, and morphological differences between fresh and frozen gonads (Vitale *et al.*, 2006; McPherson *et al.*, 2011; Burchard *et al.*, 2013). Thus, the use of macroscopic analysis should have a mechanism to assure quality control to evaluate accuracy, precision, and bias of maturity studies (Gerritsen and McGrath, 2006). In Chilean hake, the macroscopic staging agreed well with histology for fish of lengths <35 cm, but for larger sizes, macroscopic staging showed bigger differences with histology because of the confounding effect between immature and spent fish. Females >35 cm have high reproductive activity and multiple spawning events which may change the external characteristics of the gonad, making the macroscopic staging difficult (Costa, 2009).

In Chilean hake, $GSI_{\text{cut-off}}$ analysis showed high level of agreement with histological staging, performing even better than macroscopic analysis. We remark that in the application of $GSI_{\text{cut-off}}$, the choice of the appropriate period of analysis is a crucial step in obtaining unbiased maturity ogives. For example, in asynchronous fish such as the Chilean hake, immature females are found throughout the reproductive season, thus inactive mature (spent/recovering) and immature fish may share a similar *GSI* value and increase the chances of misclassification. This potential error can be reduced by choosing the beginning of the reproductive season as the period of analysis, as we have demonstrated here in our comparison of females collected during winter with those from spring. Several studies recommended that the maturity ogive should be assessed at the start of the reproductive season when the probability of sampling regenerating females is low and thereby minimising the chance of misclassification when using both macroscopic and histology staging (Hunter and Macewicz, 2003; Vitale *et al.*, 2006; Lowerre-Barbieri *et al.*, 2009). In Chilean hake, the maturity ogive based on macroscopy was significantly different ($p < 0.05$) from the ogives computed using histology staging in both seasons. Macroscopic analysis overestimated the probability of maturity in most length strata. The effect on sampling periods when using the $GSI_{\text{cut-off}}$ was clear, because the maturity ogive computed with data from the start of the spawning season (winter) was not significantly different ($p > 0.05$) to those results from histology staging, but there was a significant difference when using data from the end of the reproductive season (spring).

Table 3. Summary of maturity ogive estimates by methods and seasons for samples collected during 2001.

Season	Method	β_1 (s.e.)	β_2 (s.e.)	*p*-value *HL*	$L_{50\%}$ (95% *CI*)
Winter	Histology	8.45 (0.96)	0.18 (0.02)	0.10	46.2 (43.9 – 48.0)
	$GSI_{\text{cut-off}}$	9.99 (1.03)	0.21 (0.02)	0.45	47.1 (45.2 – 48.5)
	Macroscopy	14.21 (1.55)	0.33 (0.04)	0.58	42.5 (40.8 – 44.9)
Spring	Histology	9.38 (1.23)	0.20 (0.03)	0.19	47.9 (45.5 – 51.3)
	$GSI_{\text{cut-off}}$	11.72 (1.47)	0.23 (0.03)	0.12	51.3 (48.2 – 53.6)
	Macroscopy	15.98 (1.90)	0.37 (0.04)	0.21	43.5 (41.4 – 45.4)

The values of β_1 and β_2 are the estimated parameters of the logistic function. s.e. is the standard error, *p*-value *HL* is significance level of goodness of fit of Hosmer – Lemeshow test. The value of $L_{50\%}$ is the length (cm) at 50% maturity and its 95% *CI* is in brackets.

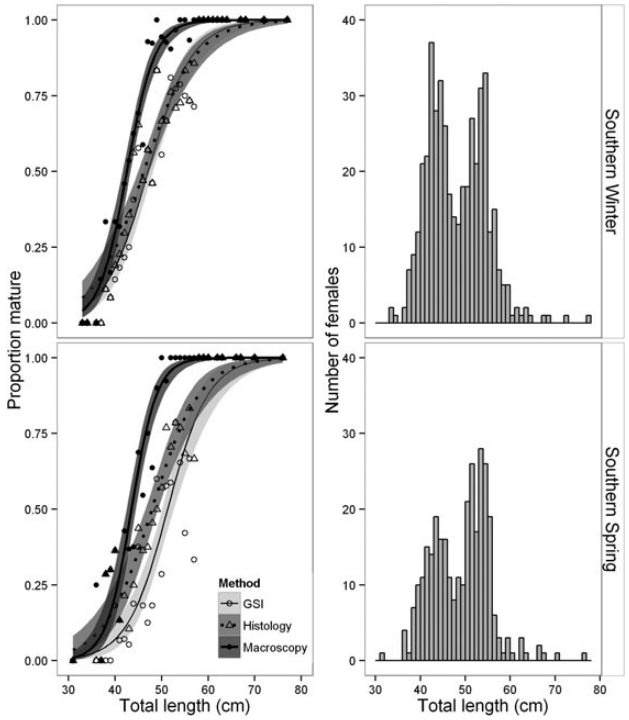

Figure 5. Left hand-side plot: observed proportion of maturity at length and estimated maturity ogives across methods used for maturity staging and seasons for the samples collected during 2001. Grey areas correspond to standard errors. Right hand-side plot: Frequency of analysed females by length strata.

Estimates of $L_{50\%}$ reported here for all methods analysed and in the two seasons were much larger than those reported in Lillo *et al.* (2002) and actually used in the stock assessment. Here, using histology we estimated $L_{50\%}$ to be 46 cm of TL, whereas for the same period Lillo *et al.* (2002) estimated $L_{50\%}$ to be 37 cm of TL. However, our estimates of $L_{50\%}$ agreed with those reported in Tascheri *et al.* (2001), for the same area in the same year. According to Tascheri *et al.* (2001), smaller estimates of $L_{50\%}$ reported by Lillo *et al.* (2002) can be explained by two main factors. First, maturity stage in Lillo *et al.* (2002) was based on macroscopic analysis in combination with oocyte measurements, while Tascheri *et al.* (2001) used histology. Second, data used in Lillo *et al.* (2002) considered only information from the acoustic surveys where spatial and temporal coverage of sampling is narrow, thus increasing the chances of missing the maximum reproductive activity when collecting individuals. Although the dissentangling of the causes underpinning these differences in $L_{50\%}$ across time, space, and methods to assign maturity by different reports is interesting in the context of the stock assessment of Chilean hake, it is beyond the methodological scope of this paper. Because of the importance of unbiased estimates of $L_{50\%}$ in the conservation and management of this species, we recommend further analyses to be carry out to ensure the best estimate of maturity ogive for Chilean hake is achieved.

$L_{50\%}$ based on *GSI* has been estimated in other exploited fish populations by either modelling the relationship between length and *GSI* (Hossain *et al.*, 2010, 2012) or using the relative increment of *GSI* between consecutive lengths (Arancibia *et al.*, 1994; Flores and Smith, 2010). However, these methodologies only provide a point estimate of $L_{50\%}$. The $GSI_{\text{cut-off}}$ method proposed here not only allows us to estimate $L_{50\%}$ but also the proportion of mature fish for each length strata in a similar way that macroscopic or histological staging is used when computing maturity ogives. For Chilean hake, the $GSI_{\text{cut-off}}$ performed better than macroscopic staging. In addition, because the $GSI_{\text{cut-off}}$ is inexpensive and easy to compute, it has the potential to be widely applied to estimate maturity ogives in data-poor or data-limited species for which basic biological information regarding maturity is usually lacking. Maturity-related parameters are important in such stocks because they usually define a baseline for conservation measurements (Froese, 2004). We proposed a new method based on the cut-off value of a *GSI* analysis and demonstrated that it is a promising tool to estimate the proportion of maturity at length. This method has the potential to be widely applied in such cases where histology staging is lacking or fragmentary or when macroscopic staging involves a large amount of errors. When using this methodology, special attention needs that the assumption of isometry between gonad and gutted weight holds and the selection of an appropriate reproductive season to minimise the frequency of spent or recovering fish. Finally, a detailed analysis of the reproductive season and species-specific cut-off value for *GSI* should be assessed in each stock where this methodology is applied.

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