First estimates of age, growth, and maturity of boarfish (*Capros aper*): a species newly exploited in the Northeast Atlantic

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Abstract

Boarfish from the Northeast Atlantic have recently been commercially exploited for fishmeal. This sexually dimorphic species is estimated to have a maximum age of 26 yr, a late age at maturity (A_{50} = 5.25 yr), a relatively fast rate of growth (K = 0.186 yr^{-1}), and a small asymptotic length (L_{∞} = 128.9mm).

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Introduction

The boarfish, *Capros aper* (Linnaeus 1758), is a small, laterally compressed, well-armoured, gregarious, mesopelagic species, distributed at depths of 40-600m (Heemstra, 1999; Whitehead *et al.*, 1986). The species occurs in the Mediterranean and in the Northeast Atlantic from Norway to Senegal over rock, coral and sand (Blanchard and Vandermeirsch, 2005). It is locally abundant throughout its range and is particularly associated with the shelf edge (Tidd and Warnes, 2006) and zones of high offshore productivity (Lopes *et al.*, 2006a).

Much of the biological information available for *C. aper* is limited to trophic analyses (Lopes *et al.*, 2006a; Blanchard and Vandermeirsch, 2005; Santos and Borges, 2001; Morato *et al.*, 2000).

Boarfish exhibit size-related sexual dimorphism. Females are slightly larger than males (Maigret and Ly, 1986) with the largest female recorded to date occurring in the Mediterranean (101mm, Total Length; 17g, Total Weight) (Filiz and Bilge, 2004). Age estimates are limited to estimations from whole otoliths from Turkish waters, where age at maturity and maximum age were estimated at 2 and 4 years, respectively (Kaya and Özaydin, 1996).

Morphotypes of *C. aper* have been identified off the coast of Portugal (Lopes *et al.*, 2006b), and although they tend to aggregate separately, and as a result are landed separately, the types may not be reproductively isolated.

In the northeast Atlantic, spawning aggregations form off the southwest coast of Ireland from June to August (Blanchard and Vandermeirsch, 2005). The abundance of boarfish appears to be increasing in most regions e.g. the Celtic Sea (Pinnegar *et al.*, 2002; Trenkel

et al., 2004; Tidd and Warnes, 2006; ICES, 2008); the Bay of Biscay (Farina *et al.*, 1997; Blanchard and Vandermeirsch, 2005); and offshore seamounts (Fock *et al.*, 2002). Hypotheses for the increase include the effect of climate change/variability on distribution (ICES, 2008; Blanchard and Vandermeirsch, 2005).

Previously described as a nuisance by-catch in the mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*) and crustacean-trawl fisheries (Fonseca *et al.*, 2005), spawning aggregations have recently become the target of a directed commercial fishery for fishmeal off the west coast of Ireland by Irish and Danish vessels. Landings of the Irish fleet have increased from 600 tonnes in 2004 to 21 584 tonnes in 2008 (Marine Institute, 2008; Anon., 2009), as a result of displacement and diversification of the pelagic fleet from traditional species. In 2009 and 2010 Danish vessels joined the fishery. Boarfish landings from both fleets constitute the raw material for Danish fishmeal plants, replacing sandeel (Ammodytidae), as the primary input species.

Fishing restrictions and the associated displacement of fishing effort, drive the exploitation and harvest of non-traditional species; often those on or over the continental slope (Bergstad, 1995; Merrett and Haedrich, 1997).

In the absence of life history information for this species in the Northeast Atlantic, the potential impact of the relatively recent commercial exploitation on the dynamics of *Capros aper* in this area, is unknown. The objective of this study is to correct this deficiency by providing the first estimates of the age, growth and maturity of boarfish in the northeast Atlantic.

Materials and Methods

868 specimens of *Capros aper* were collected from whole-haul (for juveniles) and random samples (for adults) of commercial and research fishing vessel catches in May, June, October and November, 2007, from ICES areas VIaS, VIIb, VIIg, VIIh and VIIj, off the south and west coast of Ireland, using midwater single-trawl, midwater pair-trawl and bottom otter-trawl gears. Samples were frozen onboard prior to further analysis.

The standard length (SL, nearest mm below, SL chosen due to the fragility of the tail fin rays), thawed weight (± 0.01g), sex and maturity stage (Cailliet *et al*., 1996) of each individual was recorded in the laboratory. Morphotypes were not distinguished in the present study. Otoliths were removed from samples of ten individuals within each 5mm size class over the SL range. Otoliths were cleaned of any adhering gelatinous material and stored dry in plastic vials before being weighed (± 0.0001g).

Otolith preparation

Otoliths from individuals ≤ 23mm SL, were transparent enough to be read whole when covered in a drop of mineral oil and viewed under a microscope using reflected light. Larger otoliths were embedded in SP320 clear epoxy resin (Marine and Industrial Ltd., www.mid.ie) and cut in oblique, transverse section (Figure 1).

In order to improve increment resolution, otoliths were ground and polished using P800 and P2500 carborundum paper, and mounted on a glass slide using a fast-setting, acrylic adhesive (Loctite® Super Glue). The unmounted surface of the block was ground to a final thickness of approximately 1mm, to maximise translucency.

The glass mounted face of each section was examined under transmitted light using an Olympus BX41 microscope at 10x0.25 magnification. For the purposes of age estimation, a growth increment was defined as a light translucent zone with an adjoining, dark, opaque zone, under transmitted light. Increments were counted across the section and no increments were interpreted in any area of the otolith that was obscured. All otolith sections received a confidence score reflecting the resolution of increments within the otolith section (0; Increments obscure to 4; Strong increments).

Precision and bias of ageing

A preliminary comparison of the age estimates from 43 otolith sections, read on three separate occasions by the primary reader and three additional readers, established good agreement between readers with little evidence of bias and high precision. Due to difficulties achieving the target sample size in all 5mm SL size-classes, particularly at the extremes of the distribution, a total of 168 from a target of 250 otoliths were collected. Age estimates for this sample were subsequently made by the primary reader, on three independent occasions and were assessed for precision, intra-reader bias and confidence.

Models

Multiple age readings per otolith were included in the estimation of the fitted growth curve using the likelihood of Cope and Punt (2007), modified to include the confidence scores. Three functional forms (von Bertalanffy, Gompertz and Logisitc) were used to accommodate potential variations in the shape of the growth curve. Akaike's Information Criterion was used as an estimate of goodness of fit. The likelihood method of Kimura

(1980) was implemented to test for differences in the growth parameters between the sexes. Weight (W_i) was modelled as a function of age, using the four parameter von Bertalanffy and Gompertz models. All growth models were fitted using the random effects module of *AD-Model Builder* (ADMB-RE; Otter Research Ltd. 2005).

The relationship between otolith weight and average age (average of the three readings per otolith) was estimated using a linear regression. The relationship between length and weight was modelled using a gamma-distributed, power function fit, using a generalized linear model.

Maturity ogives were estimated between maturity (mature = stage III and above) and age and length using logistic regression. Ogives were fitted for the entire population and by sex, where recorded. Likelihood ratio tests were used to test for differences in the maturity ogives between the sexes.

Results and Discussion

The standard length of individuals in commercial samples ranged from 15 - 140mm (males 55 - 120mm (mean 90.7mm); females 50 - 140mm (mean 106.7mm)). Total weight ranged from 0.63 - 91g (males 5.5 - 59.3g (mean 29.9g); females 4.4 - 91g (mean 47.91g)). The ageing sample consisted of saggital otoliths from 68 females, 50 males and 50 juveniles. Confidence scores for the 168 otolith age estimates, over three readings were: 0 (1%), 1 (16%), 2 (48%), 3 (31%) and 4 (4%). The maximum estimated age for males and females was 25 and 26 years, respectively. Juvenile (immature) age estimates ranged from 0 to 6 years.

The age-length data exhibited a strong asymptote (Figure 2, panel A). Of the three growth models fitted to the complete dataset; von Bertalanffy, Gompertz and Logistic (Figure 2), the Gompertz growth model had the lowest Akaike's Information Criterion (AIC) value (Table 1 and Figure 2), indicating the best fitting function, although the AIC values, for all three fitted models, were close (Table 1).

When the von Bertalanffy fits were compared between the sexes, they differed significantly in the asymptotic length (χ^2 =12.3, df=1, p<0.001, Figure 2 panel B). Females had a greater asymptotic length (L_∞ = 130.0mm) than males (L_∞ = 110.8mm).

The relationship between age and weight was adequately described using either the four parameter von Bertalanffy or Gompertz growth models (Table 1 and Figure 2, panel C).

A significant linear relationship was estimated between otolith weight and estimated age (r^2=0.917, Table 1). A significant relationship was also estimated between body length and weight using a power law function (r^2=0.994, Table 1).

The overall age (A_{50}) and standard length (L_{50}) at 50% maturity, estimated for the sexes and juveniles combined, were 5.25 yr and 85.7mm, respectively. Female A_{50} was estimated at 4.60 yr (95% CI = 4.05 - 5.16 yr) and males at 5.25 yr (95% CI = 4.64 - 5.85 yr, Figure 3, panels A and C). Female L_{50} was estimated at 80.5mm SL (95% CI = 75.5 - 85.5mm) and male L_{50} was estimated at 87.8mm SL (95% CI = 83.8 - 91.7mm, Figure 3, panel D). There were no significant differences between the sexes in either the age-related or length-related maturity ogives, or the individual parameters therein.

Growth increments within the otolith of *C. aper* can be consistently determined with a high degree of precision and low bias and are present in both immature and mature individuals of *C. aper*. Increments appear associated with regular patterns of seasonal

growth, rather than being formed in response to endogenic disruption of otolith calcification related to reproductive activity (Newman *et al.*, 2000).

Comparative analyses suggest that in the majority of deepwater and coastal species examined, calcified and radiometric age determinations typically agree (Caillet *et al.*, 2001). On this basis, and pending validatory evidence from radiometric analysis, it is assumed that the growth zones evident in the otoliths of *Capros aper* and conforming in appearance and structure to those present in other validated species, are deposited on an annual basis.

A striking feature of the growth pattern exhibited by *C. aper* is the well defined asymptotic length. This indicates that it is optimal in this species to reach the asymptotic size relatively quickly and thereafter allocate surplus energy elsewhere, e.g. into reproduction. *C. aper* is very well equipped with dorsal and pelvic fin spines along with spinules, barbs and barblets on scales, spines and operculae. Strong protective armour is an important investment for a relatively small species and may represent a key factor in allowing for the re-direction of the majority of energies away from the soma, to the gonads, after the onset of maturity and into considerable longevity, as inferred from the strong asymptote.

Although whole-otolith age estimates for the species from the Turkish Mediterranean population propose an age at maturity of 2 years and a maximum age of 4 years (Kaya and Özaydin, 1996), the interpretation of otolith thin sections suggest that *C. aper* in the Northeast Atlantic, is a relatively long-lived species (maximum age 26 yr). This study assumes that each ring counted was an annual one. Future studies should aim to test this hypothesis.

Longevity is often associated with a facultative and adaptive life history strategy, in which the effect of high, inter-annual, environmental variability on pre-recruit survival, is buffered by a reserve of individuals across a wide range of ages (Ebert, 1982). The occurrence of very old individuals in this study suggests that the populations sampled, which undergo directed but occasional fishing pressure and unknown discard mortality, have not yet shown the age truncation typical of long-fished species (Ottersen *et al.*, 2006) e.g. horse mackerel (*Trachurus trachurus*), which can reach ages of 40 years but are rarely encountered at older ages.

Although the growth rate of *C. aper* is similar to that of co-occuring pelagic species in the area (Kerstan, 1985), the relatively small size and late age at maturity of *C. aper* suggest that the species is less productive and, therefore, more sensitive to fishing pressure than the larger and earlier maturing herring (*Clupea harengus*), mackerel (*Scomber scombrus*), horse mackerel (*T. trachurus*) and blue whiting (*Micromesistius poutassou*).

The estimated late age at maturity may be an important life history feature of this species when compared with more typical pelagic fishmeal species, such as anchovies (*Engraulis spp.*), sardines (various genera) and Atlantic menhaden (*Brevoortia tyrannus*), which are all characterised by fast growth rates and early maturation schedules.

As a low trophic level species, boarfish may also be more susceptible to environmental variation (Blanchard and Vandermeirsch, 2005) than species with greater trophic plasticity. As such, an holistic evaluation of the role of the species as a prey item within the ecosystem should form an important management objective.

Although no single ageing study can, in itself, provide the basis for sound fisheries management, the current study provides the means to assess the somatic growth and maturation schedule of *C. aper*. When coupled with fisheries independent surveys and

commercial catch-at-age data, to estimate absolute population size and variability, fecundity and juvenile survival leading to recruitment, this will result in a basis for the holistic management of the fishery for *C. aper* in the northeast Atlantic. However, as insufficient data exist to allow the developing fishery to be managed within defined limits, swift implementation of a precautionary level of fishing effort, consistent with the objectives of rational management for the sustainability of the stock, is proposed.

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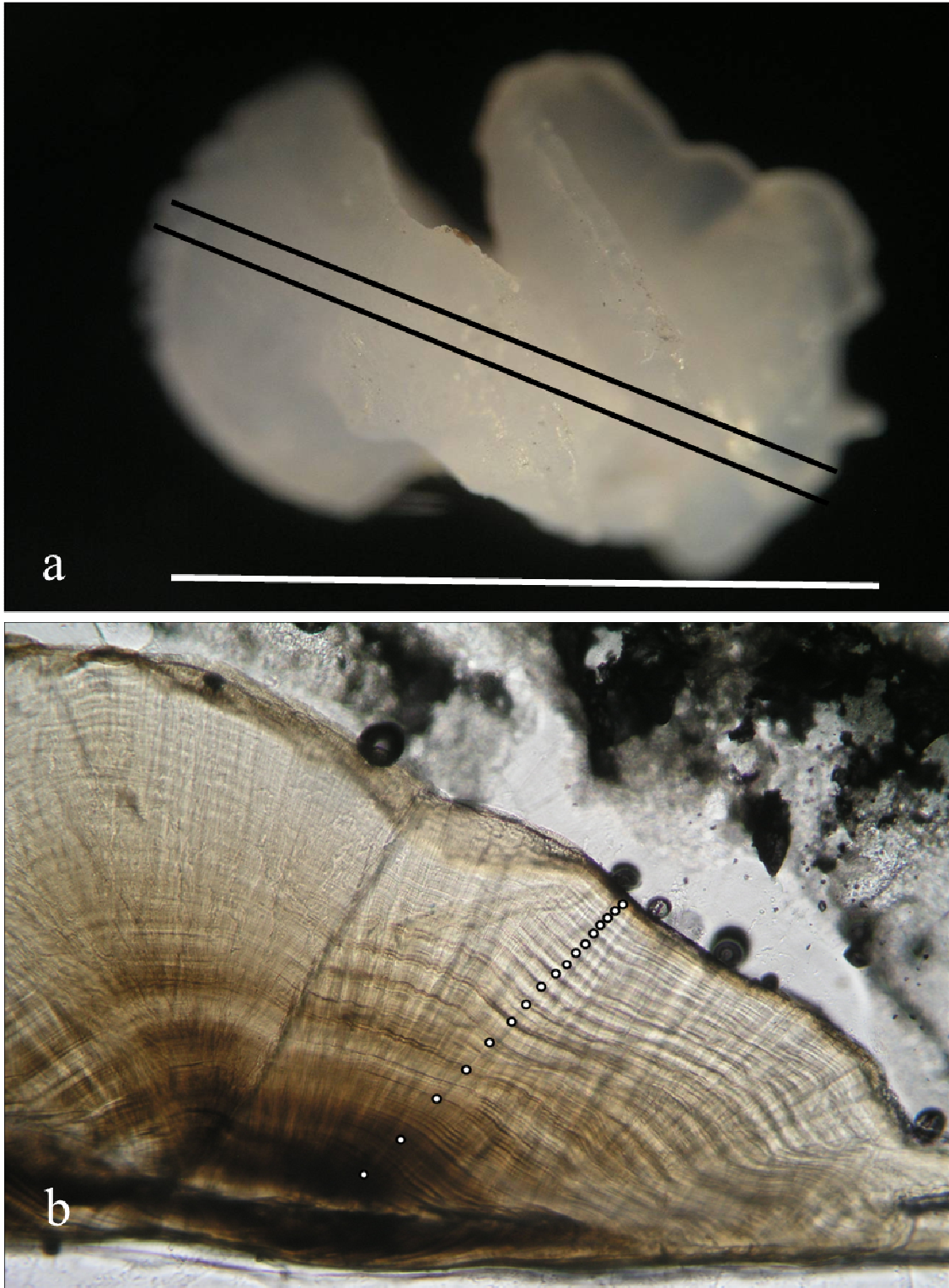
Figure 1. (a) Whole saggital otolith of *Capros aper* with the lines indicating the position through which the transverse section should be made (scale bar, 2.5 mm). (b) Transverse section of the otolith, with the dots identifying the annuli.
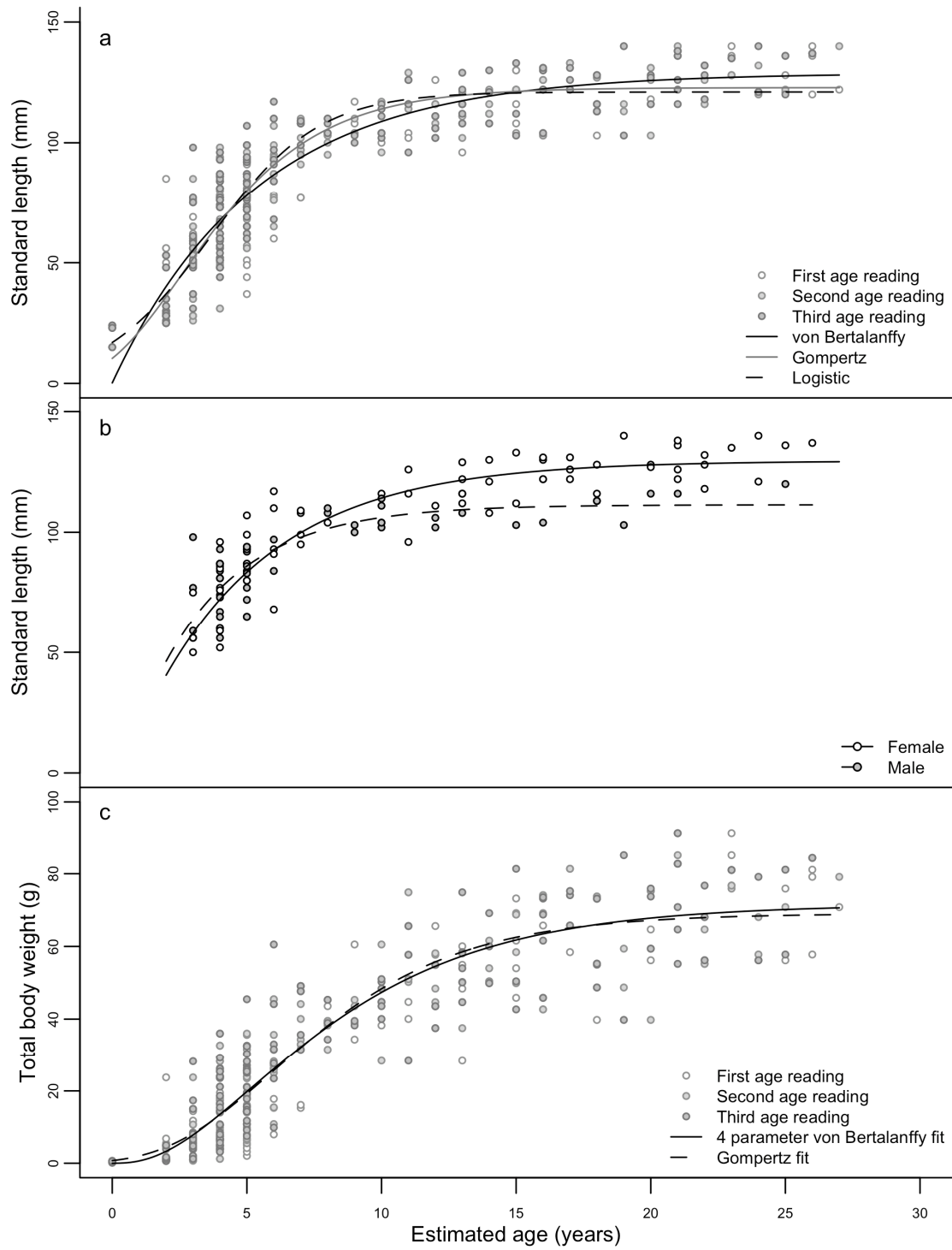
Figure 2. Age–length and –weight data and fitted growth curves of *Capros aper*, as listed in Table 1. Age–length data for (a) all fish (*n* = 168) and (b) by sex (*n* = 68 females and 50 males), and (c) age–weight relationships for all fish.
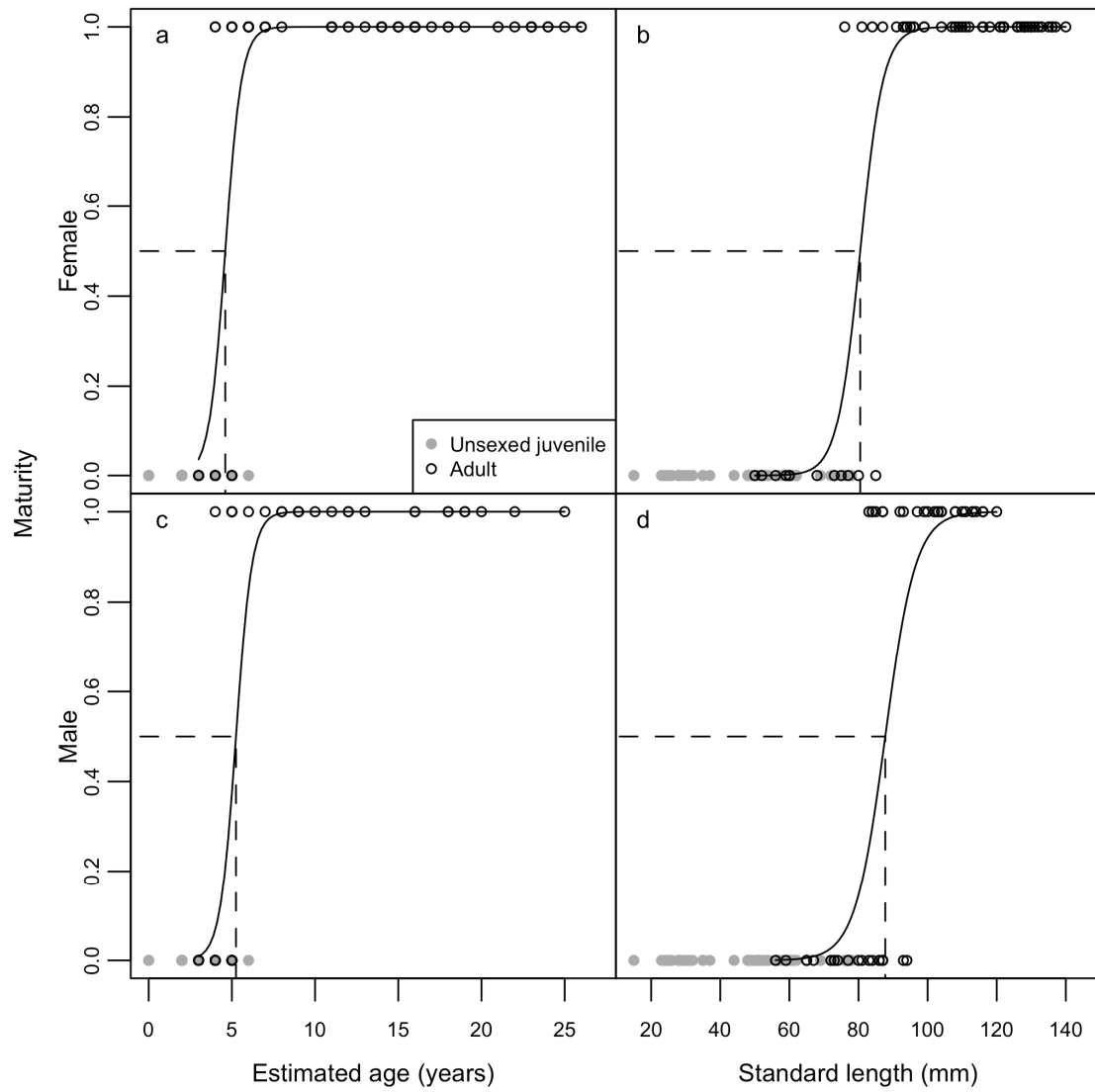
Figure 3. *Capros aper* maturity data (female, male, unsexed juveniles) and fitted ogives. (a) Female and (c) male maturity-at-age data (n = 67 and 49, respectively). (b) Female and (d) male maturity-at-length data (n = 72 and 54, respectively). Solid lines represent fitted logistic curves (ogives) and dashed lines the A_{50} and L_{50} values. Unsexed juvenile data (n = 50, grey dots) are plotted for illustration, but were not included in estimating the sex-specific curves.

Table 1. *Capros aper* maximum likelihood parameter estimates for the fitted morphometric models. MLE, maximum likelihood estimate; *A*, estimated age (years); AIC, Akaike's information criterion; *L*, standard length; *M*, proportion mature; *O*, otolith weight; PEV, proportion of explained variance = 1–sum of squares(residual)/sum of squares(total), analogous to an r^2 value (*); *W*, total weight (g).

Relationship	Functional form	MLE equation	PEV	AIC
Age-length	von Bertalanffy (vB)	$L = 128.9(1 - \exp(-0.186(A - 0.01))$	0.983	3764
Age-length	Gompertz	$L = 122.8\exp(-\exp(0.91 - 0.35A))$	0.985	3752
Age-length	Logistic	$L = 121/(1 + 6.14\exp(-0.5A))$	0.984	3756
Age-weight	Gompertz	$W = 69.1\exp(-\exp(1.52 - 0.255A))$	0.946	3677.4
Age-weight	4 parameter vB	$W = 71.6(1 - \exp(-0.197(A - 0)))^{2.74}$	0.948	3674.5
Otolith weight-age	Linear regression	$A = 0.86 + 1848.3O$	0.918*	699.8
Length-weight	Power-law	$W = 0.000054L^{2.91}$	0.994	609.77
Age-maturity	Logistic ogive	$M = 1/(1 + \exp(-(-11.1 + 2.11A)))$	0.907	13.37
Length-maturity	Logistic ogive	$M = 1/(1 + \exp(-(-21.4 + 0.25L)))$	0.890	31.95