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Journal of Applied Ichthyology

DOI:
10.1111/jai.13614

Published: 01/06/2018

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Accepted/In press: 12/12/2017

Age, growth and maturity of tub gurnard (*Chelidonichthys lucerna* Linnaeus 1758; Triglidae) in the inshore coastal waters of Northwest Wales, UK.

Running Title: Population biology of tub gurnard

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Summary

The tub gurnard *Chelidonichthys lucerna* has been identified by ICES as a potential commercial species in the northeast Atlantic with recommendations made to monitor landings and discards and to derive information on population biology for stock assessment purposes, however, data are lacking for the species in the northeast Atlantic. Therefore, aims of this study were to provide data on the size/age-structure and patterns of growth, maturity and mortality of *C. lucerna* in Northwest Wales, UK, and in doing so to provide data on the biological characteristics of the most northerly population studied to date for comparison with the existing data for southerly Mediterranean populations. Data on the age, growth and maturity of *C. lucerna* were collected by otter trawling (73 mm cod-end stretched mesh size) in the coastal waters of Northwest Wales, UK in October (2000-2011, excluding 2006). Total length (TL) of fish sampled ranged between

10.5-41.0 cm (males) and 10.4-57.5 cm (females). The majority of the female fish were between 20-30cm TL (60.2%) and the majority of the male fish between 20-30cm TL (58.3%) respectively. TL/weight (W) relations for male and female fish were similar and the combined data was described by $W = 0.0067\ TL^{3.10}$. Age of fish ranged between 1-7 years old for female fish and 1-5 years old for male fish respectively with the majority of female fish 3 years old (40%) and the majority of male fish 3 years old (37%). The age structures of female and male tub gurnards were not significantly different with the older age classes consisting predominantly of female fish. Both males and females exhibited similar asymptotic growth patterns and the combined von Bertalanffy growth function was $TL_t = 51.6\ (1- e^{[-0.25(t + 0.41)]})$. Instantaneous rates of total mortality were calculated as 1.04 $year^{-1}$ for males and 1.11 $year^{-1}$ for females. The size (L_{50}) and age at first maturity (A_{50}) were estimated to be 29.1 cm TL and 2.8 years for males, 27.7 cm TL and 2.7 years for females and 28.0 cm TL and 2.8 years for both sexes combined. The results of this study provide the first information on the biology and population dynamics of *C. lucerna* in the Irish Sea, the first data collected in the northeast Atlantic since 1985 and the most northerly population studied to date.

1 | INTRODUCTION

The tub gurnard *Chelidonichthys lucerna* L. (Triglidae) is a nektobenthic marine teleost found inhabiting the Mediterranean Sea, Sea of Marmara, Black Sea, and the eastern Atlantic Ocean from Norway to Senegal in West Africa including the coastal waters of the British Isles (Froese & Pauly, 2017). *C. lucerna* inhabits a range of benthic substrata such as sand, muddy sand and gravel bottoms at depths ranging from *ca.* 20 m to *ca.* 300 m (Froese & Pauly, 2017). Diet consists predominantly of epibenthic and nektobenthic organisms and tub gurnard feed mainly on crustaceans (Amphipoda, Decapoda) and small teleosts whilst occasionally feeding on molluscs and polychaetes (Colloca, Ardizzone & Gravina, 1994; Stagioni, Montanini & Vallisneri, 2012; Froese & Pauly, 2017). Although *C. lucerna* has been described as being a Lusitanian species (Yang, 1982) with a predominantly southern distribution in coastal waters around the UK (Corten & van de Kamp, 1996; Rogers, Milner & Read, 1998), its distribution is shifting northwards and it is increasing in abundance in the central North Sea (Beare et al., 2004).

The commercial catch of tub gurnard is not high with average declared global landings between 2011 and 2015 of 4429 tonnes in (FAO, 2017), the majority of which come from the North Sea and the eastern English Channel (52% and 37% respectively; ICES, 2013) but actual landings are difficult to quantify as gurnards are often not sorted by species when they are landed (ICES, 2013). However, tub gurnard, along with the red gurnard *Chelidonichthys cuculus* and grey gurnard *Eutrigla gurnardus*, have been recognized as new MoU species (ICES, 2006) and interest in all 3 gurnard species as potential commercial species has increased with recommendations made by ICES to monitor landings and discards and to derive information on population biology for stock assessment purposes (ICES, 2010, 2013, 2015, 2016). The problem remains that this information is lacking for all three species and for tub gurnard in particular (ICES, 2013).

For any exploited fish species, understanding its ecology and population biology is critical in the development of sustainable management plans (King, 2007). For the tub gurnard, the stocks in the Mediterranean Sea have been the focus of most research effort and consequently the most detailed knowledge on biology and ecology are known for these warmer water stocks (Table 1) with fewer studies conducted on populations outside the Mediterranean (Table 1). There is little published information on tub gurnard stocks in UK coastal waters other than basic information such as distribution data, size-frequencies and length-weight relations (e.g. Coull, Jermyn, Newton, Henderson & Hall, 1989; Parker-Humphreys, 2004a, 2004b, 2005; ICES, 2010). To the authors' knowledge, there has been no detailed study of the population biology (i.e. patterns of growth, mortality and reproduction) of tub gurnard in UK waters and no detailed study on the population biology of tub gurnard on the Atlantic coast of Europe since Baron (1985a, 1985b) in the Bay of Douarnenez, France. Therefore, aims of the study are to (1) to provide data on the population biology (specifically the size/age-structure and patterns of growth, maturity and mortality) of tub gurnard *Chelidonichthys lucerna* within the coastal waters of eastern Anglesey and north west Wales and (2) to provide data on the biological characteristics of the most northerly population of the species studied to date for comparison with the existing data for southerly Mediterranean populations of tub gurnard.

2 | MATERIALS AND METHODS

2.1 | Sample collection

Fish were collected between 2000 and 2011 (excluding 2006) using the Bangor University School of Ocean Sciences research vessel *RV Prince Madog* as part of the ongoing survey (conducted from 1972 to date) of local demersal fish stocks in the coastal waters around Eastern Anglesey and North West Wales (Figure 1). Surveys were conducted during October of each year in the same five areas: (A) Red Wharf Bay, (B) Conwy Bay and (C) Inshore Colwyn Bay and (D) Offshore Point Lynas and (E) Offshore Colwyn Bay (A-C designated as 'inshore' sites and D-E designated as 'offshore' site; see Marriott, Latchford & McCarthy, 2010). Trawl depths were between 10.0 and 32.3 m in inshore sites (62 trawls) and between 17.2 and 45.2 m in offshore sites (31 trawls) respectively. The substrate in the five sampling areas is similar with most sites comprising of gravelly sand, medium sand and broken shells, with the sites around Point Lynas and Red Wharf Bay comprising mainly of sandy gravel and sand respectively (Rees, 2004). Trawls of approximately 1 hour duration towed at 2-3 knots were conducted using a rockhopper otter trawl (cod end stretched mesh size of 73 mm), in the five survey areas. On completion of the trawl, the catch was sorted and the total length (TL) of each tub gurnard caught was measured to the nearest cm and a length-stratified subsample consisting of the first 3 fish in each 1 cm size class were retained for dissection. The following data were collected from each fish in the length-stratified subsample: TL (to nearest 0.1 mm), total weight (TW, to nearest 0.1 g), sex and maturity status (immature or mature based on macroscopic examination of the gonads; Booth, 1997; King, 2007). Finally, the sagittal otoliths were removed and stored in paper envelopes until subsequent ageing. The age of each fish was determined as described by Marriott et al. (2010) using digital imaging techniques with one pair of opaque/hyaline bands formed each year (Colloca, Cardinale, Marcello & Ardizzone, 2003).

2.2 | Data analysis

The length-weight relationship was described using the power function $W = aL^b$ (Froese, 2006; King, 2007), where W is the TW (g), L is the TL (cm), and a and b are constants. The length-weight relationships for females and males were examined separately and the slopes of the regression lines for the log-transformed data were compared using a GLM to test for differences between the sexes. The *b*-values for males and females were also tested against a value of b=3 to test for isometric growth. The relationship between mean length at age for male and female tub gurnard was described using the von Bertalanffy growth equation, $L_t = L_\infty[1-e^{-k(t-t_o)}]$ (King, 2007), where L_t is the average TL (cm) at age t (years), k is the growth coefficient (year^{-1}), L_∞ is the asymptotic total length and t_o is the theoretical age at length zero (year). The growth curves for male and female tub gurnard were compared using the likelihood ratio test (Kimura, 1980). The total instantaneous mortality rates (Z, year^{-1}) were calculated from the linearised catch curve data (King, 2007) for females and males combined since gurnards caught by fishing activity are not discriminated by sex. The instantaneous rates of natural mortality (M, year^{-1}) for females and males combined was calculated using the Pauly (1980) equation based on growth in length and the average surface seawater temperature for the area (10.66°C; Moelfre and Amlwch stations; Joyce, 2006). The TL at 50% maturity (L_{50}, cm) was calculated using the logistic equation $Y = 1/[1+e^{-r(L - L_{50})}]$ (King, 2007), where Y is the proportion of fish mature in the total length class L (cm) and r is a constant. Age at 50% maturity (A_{50}, years) was calculated using the Chen and Paloheimo (1994) equation, $A_{50} = t_0 - (1/k)ln[1 - (L_{50}/L_\infty)]$, where L_{50} is the length at 50% maturity and t_o and k are constants from the von Bertalanffy growth equation. All data are presented and mean values ± SD with statistical analyses conducted in SPSS v22.

3 | RESULTS

A total of 970 fish were caught in 92 trawls (mean trawl length, 3.4±1.1 nautical miles; mean trawl duration, 62±13 minutes). Catch rates of tub gurnard were higher offshore (OPL, 12 fish/tow; OCB, 26 fish/tow) compared to inshore (RWB, 19 fish/tow; ICB, 7 fish/tow; CON, 3 fish/tow) with an overall average catch of 11 fish/tow. 44,1% of the fish were caught inshore and 55.1% caught at offshore sites. In total, 804 tub gurnard were subsampled: 497 females and 307 males.

Fish in the length-stratified subsamples ranged in TL from 10.4-57.5 cm for females and 10.5-41.0 cm for males (Figure 2A). The majority of female (60.2%) and male fish (58.3%) were between 20-30 cm TL (Figure 2A), with the average TL for female tub gurnard (28.7±5.9 cm) being significantly larger (t_{660}=3.52 P<0.001) than male tub gurnard (27.3±5.8 cm). The majority of fish >25 cm TL were female (78.7%, Figure 2A). TW for female and male tub gurnard in the stratified subsample ranged from 12.0-1940.6 g for females and 8.0-807.4 g for males, with the majority of female (58.6 %) and male fish (64.5%) <250 g.

A total of 790 fish could be aged (490 female, 300 male) and age ranges in the length-stratified subsample were 1-7 years and 1-5 years old for female and male fish (Figure 2B). For both females (40%) and males (37%), the majority of fish were 3 years old. The age structure of female and male tub gurnards in the subsample were significantly different (χ^2_6=20.14, P<0.003), with the older age classes consisting predominantly of female fish (Figure 2B).

The length-weight relationships for female and male tub gurnard and for both sexes combined are presented in Figure 3. Both males and females exhibited positive allometric growth with b values significantly different from 3 (♂; t_{305}=5.79, P<0.001; ♀; t_{495}=4.44, P<0.001). The slope values for the log-transformed linearised length-weight data for both female and male tub gurnard were similar ($F_{1,802}$=1.04, P=0.31). The length-weight relationship for the combined data was described by $W = 0.007L^{3.10}$ (SE_b=0.04, r^2=0.966, P<0.001), with the b value significantly different from 3 (t_{802}=2.48, P=0.013). Von Bertalanffy growth curves for female and male tub gurnard are presented in Figure 4. Growth parameters for the females and males were similar (χ^2_3=2.37, P=0.50) with the growth curve for the combined male and female data described by $TL_t = 51.6[1-e^{-0.25(t + 0.41)}]$ (r^2=0.992, P<0.001). The instantaneous rate of total mortality for the combined data set was Z=1.18 year^{-1}.with the instantaneous rates of natural mortality calculated as M=0.40 year^{-1}.

Maturity ogives for male and female tub gurnard and for both sexes combined are presented in Figure 5. The calculated L_{50} values for female, male and combined sexes were in close agreement (♀; 27.7 cm: ♂; 29.1 cm: combined sexes; 28.0 cm). The A_{50} values for female and male tub gurnard and for the combined data set were calculated as 2.7 years (female), 2.8 years (male) and 2.8 years (males and females combined).

4 | DISCUSSION

4.1 | Tub gurnard population biology

In this study, the population biology of tub gurnard in the inshore waters of Northwest Wales and Eastern Anglesey is reported from data collected from autumnal (October) fishing surveys conducted by Bangor University between 2000 and 2011 (excluding 2006). This study provides the first population biology data for this species in the Irish Sea and the first data for the species in the Northeast Atlantic since that reported by Baron (1985a, 1985b) for the Bay of Douarnenez in Brittany, France.

The population biology data available for tub gurnard are summarised in Table 1. Although there are many studies which present length-weight relationships for the species [see Froese and Pauly (2017) for references], the number of studies where other biological parameters, e.g. growth and reproduction (Table 1) are examined are more limited. This is especially the case for Atlantic populations of tub gurnard with most of the detailed studies on the population biology of tub gurnard focussed on Mediterranean populations (including the Sea of Marmara), particularly in Turkey (Table 1). In contrast, information for tub gurnard in the Northeast Atlantic is limited to 2 studies plus a single study in the Eastern Central Atlantic (Morocco) (Table 1). In the UK, only basic data such as presence in trawl catches and size structure of the catch are available (e.g. Beare et al., 2004; Parker-Humphreys, 2004, 2005a, 2005b) with a single study reporting length-weight data (Coull et al., 1989) have been published. However, although data are limited and the samples sizes for the Atlantic gurnard population preclude statistical comparisons, there are some general comparisons that can be made between the population biology parameters of North Atlantic and Mediterranean tub gurnard.

In general, tub gurnard in the Mediterranean regions do not attain as large a size compared to Atlantic populations and mature at a smaller size (Table 1). The average L_∞ value for Mediterranean (including the Sea of Marmara) tub gurnard populations is 49.6 ± 9.9 cm compared to 58.0 ± 9.3 cm values for Atlantic populations (Table 1). Similarly the length at 50% maturity is smaller in Mediterranean populations compared to Atlantic populations with average L_{50} values of 22.0 and 20.4 cm respectively for males and females in the Mediterranean compared to values of 34.6 and 31.6 cm in the Northeast Atlantic (Table 1). In most studies presented in Table 1, tub gurnard exhibit positive allometric growth with an average 'b' value for the length-weight relationship of 3.03 ±

0.17. This agrees well with the value of 3.03 derived by Froese (2006) from a meta-analysis of the length-weight relationships for 1773 species of fish.

To enable comparisons of growth performance of tub gurnard across the different populations, the phi prime growth performance index of ($\Phi' = 2\log_{10}L_\infty + \log_{10}k$) of Pauly and Munro (1984) was calculated and the data are presented in Table 1. The average Φ' value for Mediterranean (including the Sea of Marmara) tub gurnard populations is 2.60±0.33 (n=9) compared to 2.60±0.33 (n=3) for Atlantic populations (Table 1). Growth performance index for tub gurnard was significantly correlated with latitude ($r = 0.64$, $n = 14$, $p = 0.014$) with Φ' values increasing with increasing latitude. Similarly, L_{50} values for male and female tub gurnard were correlated with latitude (♂, $r = 0.71$, $n = 9$, $p = 0.051$; ♀, $r = 0.77$, $n = 9$, $p = 0.023$) with L_{50} values increasing with increasing latitude. Latitudinal variations in growth and maturity have been reported for a number of marine species, for example Atlantic cod *Gadus morhua* (Brander, 2005), European hake *Merluccius merluccius* (Ragonese, Vitale, Mazzola, Pagliarino & Bianchini, 2012), English sole *Pleuronectes vetulus* (Sampson & Al-Jufaily, 1999), European plaice *Pleuronectes platessa* (Bromley, 2000), and yellowfin tuna *Thunnus albacares* (Zhu, Xu, Dai & Liu, 2011) and was also reported for red gurnard *C. cuculus* by Marriott et al. (2010). The general patterns observed are for more northerly stocks to exhibit decreased growth rates and an increase in size at first maturity due to differences in growth opportunity related to changes in thermal regime, and the length of the growing season, with latitude.

4.2 | Tub gurnard fisheries

The three main gurnard species in the northeast Atlantic, red gurnard *C. cuculus*, tub gurnard, *C. lucerna* and grey gurnard *E. gurnardus*, have all been identified by ICES as potential new species for commercial exploitation (ICES 2006, 2013). However, detailed information on the population biology and landings/discard data for stock assessment purposes for each species in the different ICES subareas in the Northeast Atlantic are currently lacking. Previously, gurnard landings were not sorted by species and were often reported as the generic category 'gurnards' with species-specific data are only available from all countries participating in gurnard fisheries since 2010 (ICES, 2015). The issue of accurately quantifying discard rates for each gurnard species in other demersal fisheries still remains unresolved although discard rates are thought to be very high (ICES, 2015, 2016). For example, the average discard rate for grey gurnards is estimated at 80% (ICES, 2016). As a result, the management advice provided for red gurnard (ICES, 2015) and grey gurnard (ICES 2016) is limited and advises a precautionary approach with reduced landings until more detailed information on stock size, fishing pressure and discard rates are determined as these are currently unknown. In contrast, there is no such advice is available for tub gurnard with the limited data available last reviewed by ICES in 2013 (ICES, 2013).

For tub gurnard, declared catches have increased in recent years from 3325t in 2011 to 6885t in 2015, notably with a 50% increase in catches between 2014 (4600t) and 2015 (FAO, 2017), most likely as a result of improved landings data rather than increased fishing activity. The Netherlands (2984t), France (1382t), Italy (964t) and Belgium (950t) currently land 91% of the declared tub gurnard catch (FAO, 2017) with the UK accounting for 5.7% (392t). Among the fishing areas, the North Sea and the eastern English Channel account for the majority of landings (52% and 37% respectively in 2011; ICES, 2013). ICES (2013) reports that the only population biology parameters available are from a small southern part of ICES Division VIIe (Bay of Douarnenez, Brittany, France) and have not been updated in over 30 years (Baron, 1985a, 1985b). The results of the present study provide the first population biology details for the species since 1985, but also highlight the paucity of biological data available for this species for stock assessment purposes. Clearly, more detailed studies of the population biology of the tub gurnard in the coastal shelf seas of the Northeast Atlantic, together with a more detailed assessment of discarding, are a priority to support the sustainable expansion of this fishery in the Northeast Atlantic.

ACKNOWLEDGEMENTS

The authors wish to thank the crew of the RV *Prince Madog* and the staff and students from the School of Ocean Sciences who conducted the fisheries surveys and collected much of the raw data used in this study.

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FIGURE LEGENDS

FIGURE 1 Location of sampling sites trawled for tub gurnard *Chelidonichthys lucerna* in the coastal waters of Northwest Wales, UK. Inshore sites: (**A**) Red Wharf Bay; (**B**) Conwy Bay; (**C**) Colwyn Bay; Offshore sites: (**D**) Colwyn Bay (North of the Constable Bank); (**E**) Offshore Point Lynas.

FIGURE 2 Size/age structure of male and female tub gurnard *Chelidonichthys lucerna* sampled in October in the coastal waters of Northwest Wales, UK, between 2000 and 2011 (excluding 2006). Data are presented for (**A**) Length-frequency distributions (Total Length, cm) and (B) Age-frequency distributions of female (solid bars) and male (open bars) fish.

FIGURE 3 Length-weight relationships for tub gurnard *Chelidonichthys lucerna* sampled in October in the coastal waters of Northwest Wales, UK, between 2000 and 2011 (excluding 2006). Data are presented for (**A**) female, (**B**) male and (**C**) male and female combined.

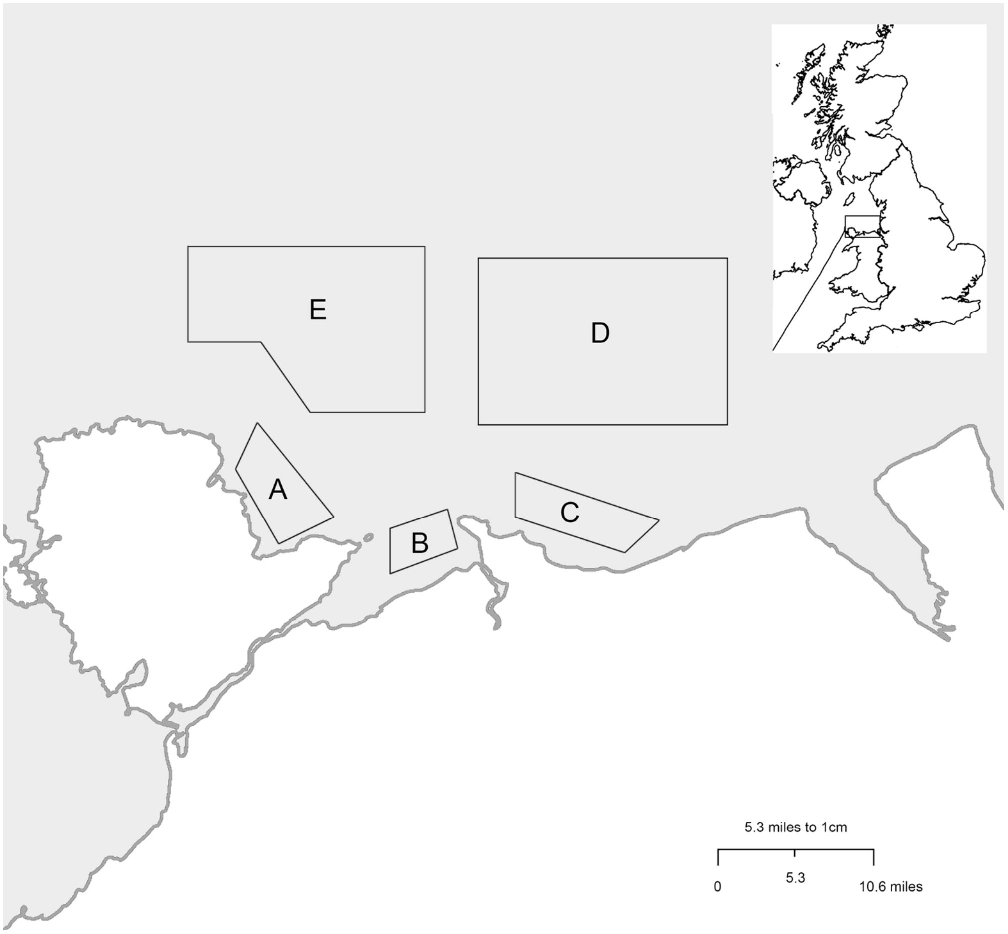
FIGURE 4 Length-at-age relationships for female (solid circles) and male (open circles) tub gurnard *Chelidonichthys lucerna* sampled in October in the coastal waters of Northwest Wales, UK, between 2000 and 2011 (excluding 2006). Data are presented as mean values ± SD for each age class.

FIGURE 5 Maturity ogives for tub gurnard *Chelidonichthys lucerna* sampled in October in the coastal waters of Northwest Wales, UK, between 2000 and 2011 (excluding 2006). Data are presented for (**A**) female, (**B**) male and (**C**) female and male combined. The total length at 50% maturity (L_{50}) are indicated on each plot.

TABLE 1. Summary of population biology data for tub gurnard *Chelidonichthys lucerna.* Data are presented for the coefficients from the length-weight relationship (a, b), the von Bertalanffy growth function (L_∞, k, t_0), the growth performance index Φ' (Pauly & Munro, 1984) and length at 50% maturity (L_{50}). All length values are Total Length [*Fork Length converted to TL, x 1.027 (Froese & Pauly, 2017); ** = not known if TL or FL].

Region/Location (latitude)	Sex	a	b	L_∞	k	t_o	Φ'	L_{50}
a) Northeast Atlantic								
North West Wales, UK (53.1°N)[a]	♂	0.007	3.09	43.9	0.36	-0.17	2.84	29.1
	♀	0.007	3.11	50.7	0.26	-0.33	2.82	27.7
	♂+♀	0.007	3.10	51.6	0.25	-0.41	2.82	28.0
Brittany, France (48.1°N)[b]	♂	-	-	48.4	0.46	-0.41	3.03	40.1
	♀	-	-	66.8	0.32	0.46	3.16	35.5
b) E. Central Atlantic								
Morocco (34.0°N)[c]	♂+♀	-	-	65.0**	0.15	-1.10	2.80**	-
c) W. Mediterranean								
Gulf of Gabès, Tunisia (34.2°N)[d]	♂	0.007	3.04	40.3	0.06	-1.32	2.00	19.2
	♀	0.016	2.83	46.2	0.05	-3.03	2.04	21.6
d) E. Mediterranean								
Tuscany, Italy (43.3°N)[e]	♂+♀	0.014	2.86	65.9	0.39	-	3.23	-
Adriatic Sea (43.3°N)[f]		-	-	-	-	-	-	♂ 22.1, ♀24.3
Thermaikos Gulf, Greece (40.3°N)[g]	♂	5 x 10^{-6}	3.15*	-	-	-	-	31.7*
	♀	6 x 10^{-6}	3.11*	-	-	-	-	26.0*
Edremit Bay,Turkey (40.0°N)[h]	♂+♀	0.005	3.21*	59.0*	0.11	-2.55	2.58*	-
Izmir Bay, Turkey (38.4°N)[i]	♂+♀	0.005	3.24*	52.1*	0.16	-1.61	2.65*	♂ 19.0* ♀18.5*
Babadillimani Bight, Turkey (36.1°N)[j]	♂+♀	0.013	2.87	42.3	0.20	-	2.54	-
Yumurtalik Bight, Turkey (36.8°N)[k]	♂+♀	0.113	3.09	40.9**	0.14	-	2.36**	
Iskenderun Bay, Turkey (36.6°N)[l]	♂+♀	0.009	2.99	45.0	0.22	-0.58	2.57	♂ 20.0 ♀18.0
Alexandria, Egypt (31.2°N)[m,n]	♂+♀			40.3	0.29	-	2.67	♂ 17.0 ♀15.6
	♂+♀	0.03	2.63					
e) Sea of Marmara								
Turkey (40.4°N)[o]	♂+♀	0.009	3.02	61.3	0.17	-0.04	2.81	♂ 19.9, ♀17.7

[a]This study. [b]Baron (1985a, 1985b).[c]Colligon (1968). [d]Boudaya et al. (2008). [e]Serena, Voliani & Auteri (1998). [f]Vallisneri, Montanini, & Stagioni (2012). [g]Papaconstantinou (1984). [h]Ucken (2005). [i]Ilhan & Tolgulga (2007). [j]Cicek, Avsar, Ozyurt, Yeldan & Manasiri.et al. (2008). [k]Altun, Goksu, Tureli, & Erdem (1997). [l]Işmen, Işmen & Başusta (2004). [m]Faltas & Abdullah (1997). [n]Abdullah (2002). [o]Eryilmaz & Meric (2005).



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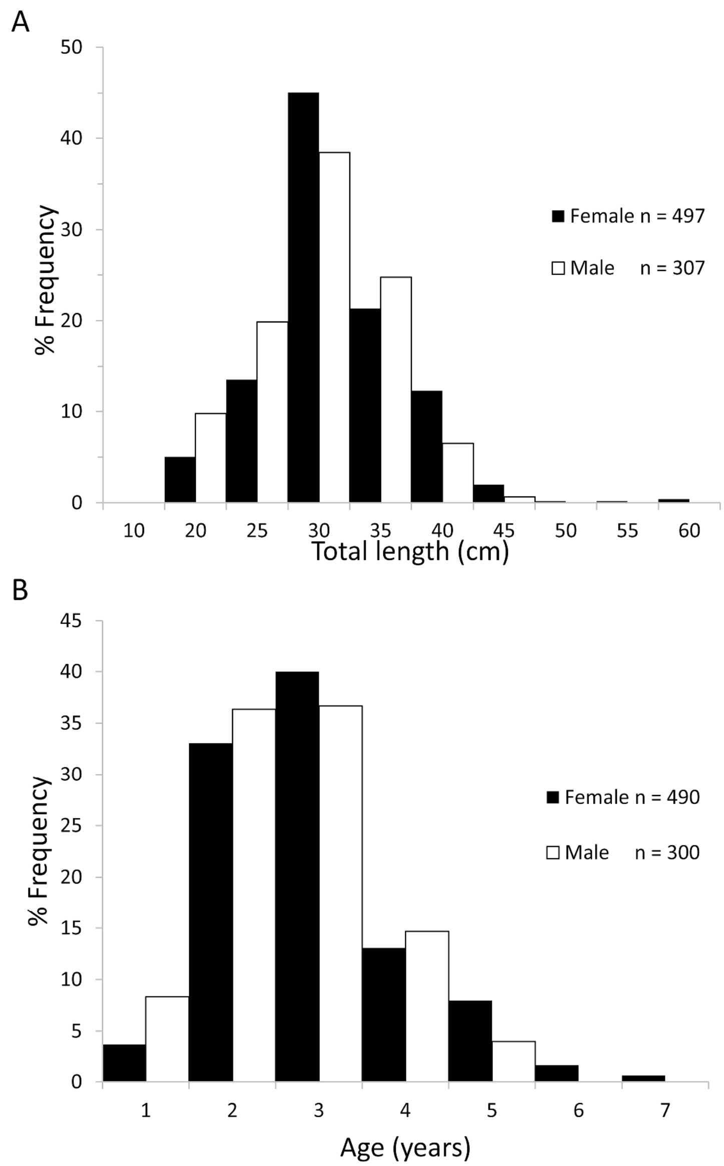

FIGURE 2 Size/age structure of male and female tub gurnard *Chelidonichthys lucerna* sampled in October in the coastal waters of Northwest Wales, UK, between 2000 and 2011 (excluding 2006). Data are presented for (A) Length-frequency distributions (Total Length, cm) and (B) Age-frequency distributions of female (solid bars) and male (open bars) fish.

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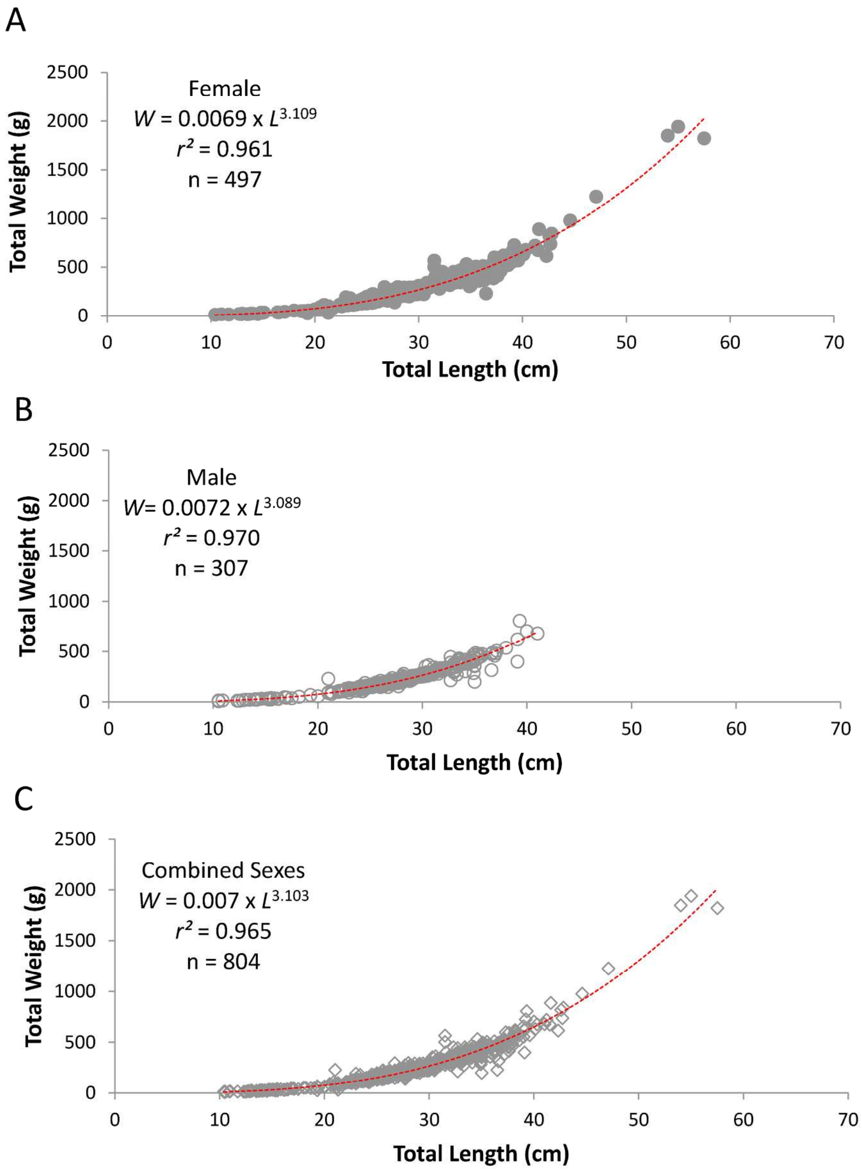

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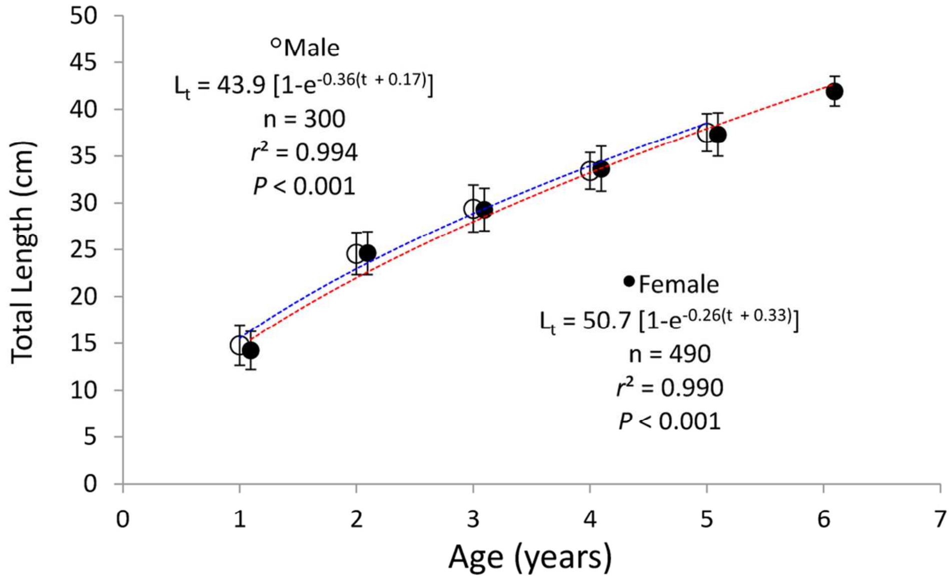

FIGURE 4 Length-at-age relationships for female (solid circles) and male (open circles) tub gurnard *Chelidonichthys lucerna* sampled in October in the coastal waters of Northwest Wales, UK, between 2000 and 2011 (excluding 2006). Data are presented as mean values ± SD for each age class.

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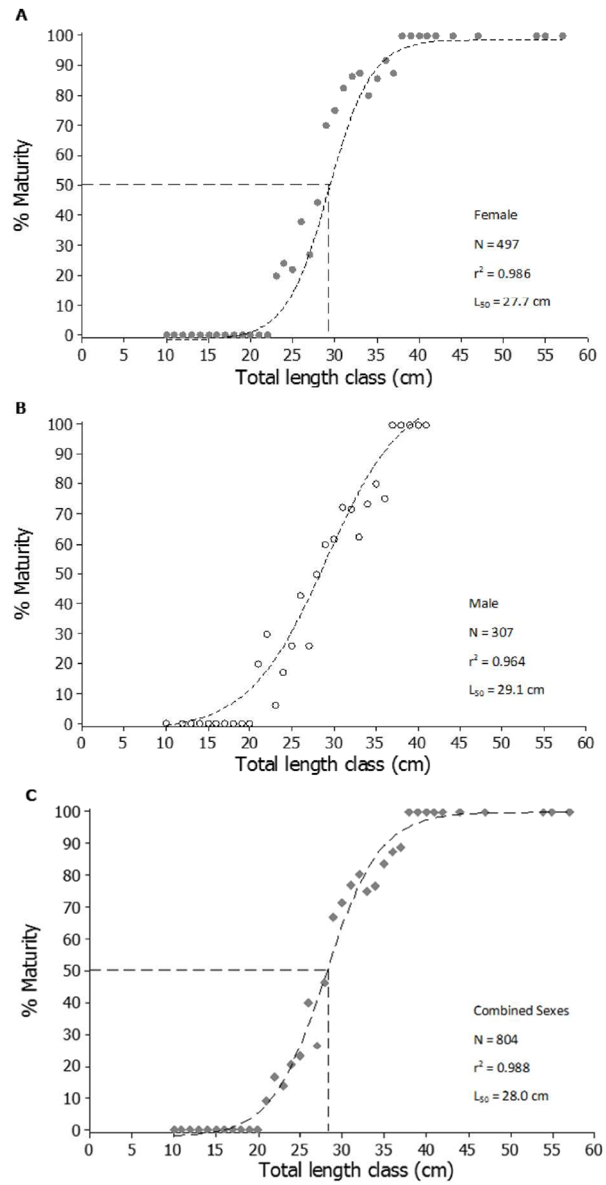

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