Fisheries & Conservation Science

Population dynamics of the European sea bass (*Dicentrarchus labrax*) in Welsh waters and management implications

PRIFYSGOL BANGOR UNIVERSITY

Giulia Cambiè, Michel J. Kaiser, Jan G. Hiddink, Harriet Salomonsen,

Julia R. Pantin & Ian McCarthy

School of Ocean Sciences, College of Natural Sciences, Bangor University

To be cited as follows: Cambiè, G., Kaiser, M.J., Hiddink, J.G., Salomonsen, H., Pantin, J.R., McCarthy, I. (2015). Fisheries & Conservation report No. 56, Bangor University. Pp.76

Funded By:

Y Gronfa Pysgodfeydd Ewropeaidd:
Buddsoddi mewn Pysgodfeydd Cynaliadwy
European Fisheries Fund:
Investing in Sustainable Fisheries

Llywodraeth Cymru
Welsh Government

Contents

Executive summary

- While most of the life history parameters are consistent with those estimated for the general stock unit of ICES Divisions VIIafg (ICES, 2013), the size at maturity of female bass appeared significantly lower than the ICES estimate. The decline in the current size at maturity compared to previous published studies could indicate potential compensatory effects in this life history parameter in response to over-exploitation.

- If the MLS was increased to 40 cm it would allow 82% of the females to spawn at least once. If a 40 cm MLS was adopted, in the short term fishers using gillnets will lose 11.6% of their catch, with peaks losses in the summer and autumn (19.8% and 14.5%, respectively). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 14.8% of their catch with peak losses in the summer and autumn (19.9% and 18.5%, respectively).

- If the MLS were to increase to 42 cm, the short-term losses of fishers will be much higher. In this case the annual loss of catch for fishers using gillnets will be 22.3% of their catch in terms of number of fish. However, their losses will be different by season, with peak losses in summer (40.7%) and autumn (30.9%). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 28.1% of their catch. These losses will be different by season, with peaks in summer (37.1%) and autumn (35.8%). Regional differences in catch losses will also occur (47.2% in North and Mid Wales and 29% in South Wales).

- All estimated catch losses will occur in the short-term after implementation of a new MLS. The loss of catches should decrease over time. In particular, we estimated that the increase of the MLS to 40 cm could result in a decrease of 17% of the total number of bass caught one year after implementation (the time required for fish to grow from 36 to 40 cm), whilst no difference is expected in terms of landed biomass. The increase of the MLS from 36 to 42 cm will cause a decrease of 25% of the total number of bass one and a half years after the implementation (the time required for fish to grow from 36 to 42 cm), whilst no difference is expected in terms of landed biomass. However, the model used for these estimates could be biased and the figure presented should be considered to provide a general indication of the effects of new MLS and the timescales involved. An increase of the MLS could benefit the recreational angling sector, as it would results in an increase of large bass and thus could improve the angling experience.

- Specific features of the bass stock and fisheries in Wales may have implications for management. In North Wales, the sex ratio was highly skewed towards females across all seasons. If the protection of female bass (e.g. old female spawners) is a management target, precautionary measures may be required in North Wales in winter and spring when the proportion of females caught is higher.

- The spawning season of bass around Welsh waters has been estimated to be between January and May. All five months may need to be considered if the aim is to protect bass during the whole spawning period. However, in the long term, an overall reduction in fishing mortality could be a better target than specific management measures during the spawning period.

- Bass recruits (0-group) have been found not only in South Wales, but also in Mid and North Wales. This finding suggests the possible presence of local spawning grounds in Mid and North Wales, a finding that should be further investigated in the future.

- The analysis of the stable isotope of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) signatures in adult bass collected around Welsh waters showed the presence of connectivity between North and Mid Wales for feeding behaviour of adult bass, whilst fish from South Wales appeared more isolated and characterised by a very distinctive isotopic signature. This finding suggests the possible presence of two separated sub-populations of bass in Welsh waters with little mixing between bass in South Wales with those in Mid and North Wales. This finding may indicate the need for different management units.

- Stable isotopes analysis also suggested that a portion of the largest bass adopt estuaries as preferential feeding areas even when they are a large size. Thus management measures focused on estuaries may act to conserve large bass. Large bass spawners produce large numbers of eggs, as suggested by the analysis of the gonad somatic index. Other management measures that could achieve protection of the largest fish might include consideration of a possible maximum landing size.

GENERAL INTRODUCTION

The European sea bass *(Dicentrarchus labrax*) is a commercial species exploited by multiple fishing fleets such as pelagic pair trawlers on offshore spawning grounds and inshore vessels using a variety of gears, particularly rod and line, longline and gillnets.

The stock structure of this species is currently uncertain although there is evidence that sea bass around southern Ireland and in the Bay of Biscay could be treated as two populations separate from sea bass in the eastern Celtic Sea, English Channel, and North Sea (Fritsch et al., 2008; ICES, 2012). The Inter-Benchmark Protocol on New Species (2012) agreed that sea bass in the North Sea (ICES Division IVb&c) and in the Irish Sea, Channel and Celtic Sea (Ices Divisions VIIa,d,e,f,g&h) would be treated as a functional stock unit as there is no clear basis at present to subdivide them into independent stock units (ICES, 2013).

Data at UK levels can be divided into: (i) UK landings statistics, (ii) Cefas logbook scheme, used to adjust the inaccuracy of the landings data, (iii) Cefas data collection on bass caught around England and Wales since 1985, and (iv) Cefas trawls surveys of young bass in the Solent and Thames estuary. For Wales, there is little information available on the size distribution of catches by gear, sex ratio, maturity, movements and other life history parameters for the bass that occur in Welsh waters.

The aim of this study is to provide information on the current life history parameters and other key biological aspects of sea bass in Wales, the size and age distribution of the catches by inshore gears, the movements, and the recruitment of the species around Welsh waters. The study is therefore divided into five main sections:

1. Life history parameters of bass that occur in Welsh waters
2. The bass fisheries in Wales and the implications of increasing MLS
3. Bass movements around Welsh waters
4. Geographic variation in the sex ratio
5. Recruitment patterns

Whilst the first two sections focused on bass life history, particularly the size at maturity and the possible effects of increasing the Minimum Landing Size (MLS) for the local inshore fishery (a potential scenario under the emergency management measures promoted by the European Commission http://ec.europa.eu/newsroom/mare/itemdetail.cfm?item_id=20186), the last three sections concentrate on the specific features of bass that occur in Welsh waters and the potential management implications of these findings.

1. LIFE HISTORY PARAMETERS OF BASS THAT OCCUR IN WELSH WATERS

1.1 Introduction

The sea bass life cycle is characterised by four broad phases: eggs and larvae, juvenile, adolescent and adult (Dando & Demir, 1985). Historical data suggests that sea bass reach maturity between 4 and 7 years of age (~35 cm for males and 42 cm for females) and can continue to reproduce for up to 20 years (Pawson & Pickett, 1987). The oldest sea bass recorded was thought to be 28 years old (ICES, 2013). Sea bass exhibit sexual growth dimorphism where female bass mature at a greater size and age than males (Kennedy & Fitzmaurice, 1972).

This section provides biological parameters of the length-weight relationship, growth, spawning season, maturity stages and size at maturity of bass caught around Welsh waters and a comparison with the values estimated for the combined stocks for the ICES Divisions VIIagf (ICES, 2013) and with historical data.

1.2 Materials and methods

- *Length-weight relationship*

Total length and weight of 2541 bass were recorded during the periods 2013, 2014 and 2015. 2313 of these data records were derived from fish processors and fishers around Wales (111 in Mid Wales, 700 in North Wales and 1502 in South Wales, Figure 1.1) and 228 records were for bass recruits collected during July-October 2014. The length-weight relationship ($Weight=a*Length^b$) was assessed from these fish.

Length and weight were log transformed to assess the possible change in the slope by location (North and South Wales). For this analysis recruits were not taken into account as most of the recruits for which we had weight data were caught in North Wales.

Analysis of covariance (ANCOVA) was used to compare the two regression lines, one for North and one for South Wales. The interaction length*location was assessed. The same analysis was performed to compare the L~W relationship by sex from North and South Wales. In this case all fish < 30 cm TL were removed as most of these came from South Wales.

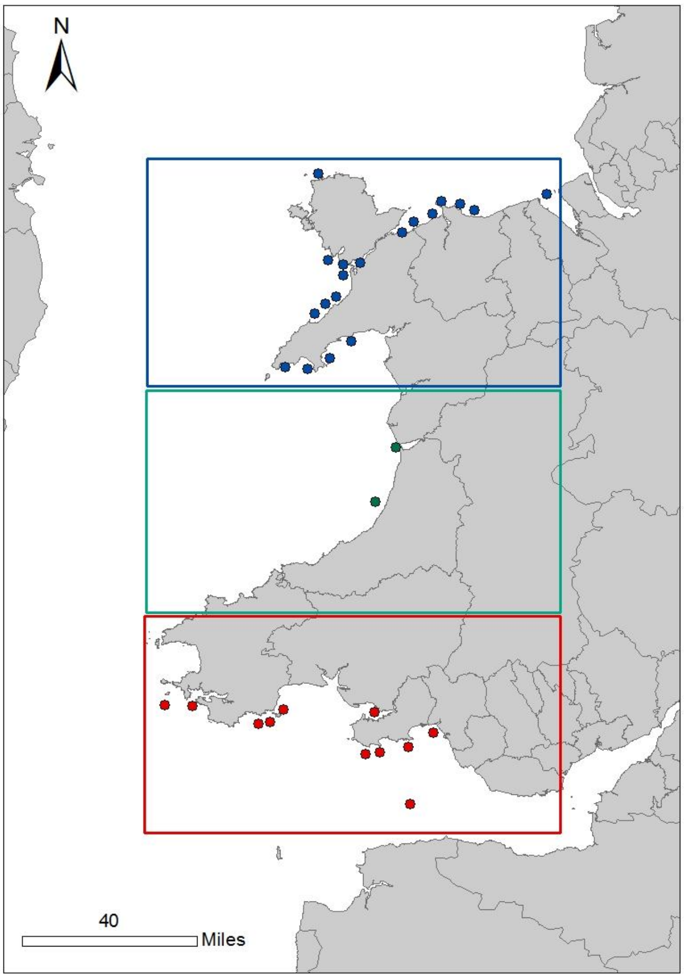


Figure 1.1. Map of Wales showing the locations of bass samples (blue, North Wales; green, Mid Wales and red, South Wales)

- *Von Bertalanffy growth function*

Information on length (total length to the nearest mm) and age was collected for 1855 bass caught around Welsh waters. Of these, 1196 fish were sexed (523 males and 673 females).

All ageing was performed by reading scales, excluding scales that were considered to have re-grown (Fritsch, 2005). From the reading process, we found the last scale annulus was fully identifiable in July. June was thus the month corresponding to the new age of the fish and July was considered the first month of the new age (e.g. one fish aged 4 years old and caught in July was considered as aged 4.083, corresponding at 4 years and 1 month). The estimation of fish age in terms of years and months allowed not only better calibration of the growth curve, but also allowed the use of the length data of the 0-group bass (bass recruits) collected between July and October of 2013 and 2014.

The Von Bertalanffy growth function (1) was estimated for males, females and for the combined sex data:

$$L_t = L_\infty\,(1 - \exp(-K(t - t_0))) \qquad (1)$$

where L_t is the fish length (in cm) at age t (in years), L_∞ is the asymptotic length (in cm), K is the growth coefficient (in y^{-1}) and t_0 is the age of the fish when length=0.

The curve was fitted on the average value of length for each age. Analyses were made by using the Fisheries Stock Assessment package (FSA) (version 0.4.1) (Ogle, 2009) in R software (R version 3.0.2 Development Core Team, 2013).

Finally, to assess possible differences in the growth function between North and South Wales, length data of females between 6 and 10 years old and of males between 5 and 9 years old were compared between the two areas. The Bartlett's and Levene's tests were performed to assess the homogeneity of variance of bass length by age and the Kolmogorov-Smirnov test was used to test for normality. A one-way ANOVA was applied if the data met the assumptions of normality and homogeneity of variance, otherwise a non-parametric test (e.g. Kruskal-Wallis) was performed.

- *Gonad-somatic index and spawning season*

The Gonad Somatic Index (GSI (%) = gonad weight (g) x 100 x fish weight $(g)^{-1}$) is an indicator of spawning activity and it was therefore only calculated for adult bass (length ≥40 cm for females and ≥36 cm for males) for a total of 1027 individuals (538 females and 489 males). The relationship between GSI and body weight was also analysed to assess if the reproductive investment increased with the size of the fish.

- *Maturity stages and size at maturity*

Maturity stages were defined by using the maturity key from Pawson and Pickett (1996) (Table 1.1). An additional maturity key is provided by the present study, with photographs of gonads by sex for each stage (Annex I). To assess the trend of the maturity stages of adult bass, stage I (immature) was first removed from the data.

The size at maturity was estimated only from fish caught during the second half of the spawning season (March-May), thus allowing fish at stage III to be considered as immature. It is unlikely that fish at stage III during March will reach stage VI in May. Fish at stage I and III were thus considered immature whilst fish at stages IV, V, VI, VII and II were considered mature. A logistic regression model was used to predict the probability of being mature as a function of size (to the nearest mm). The curve describing this probability as a function of size is called a maturity ogive and is defined by equation (2)

$$P_{mat}(L) = 1/(1+e^{-(a+bL)}) \quad (2)$$

Where P_{mat} is the probability of being mature, b is the slope and a is the intercept.

The goodness of fit was tested using the le Cessie–van Houwelingen–Copas–Hosmer test (Hosmer et al., 1997; Hosmer and Lemeshow, 2000) and the area under the ROC curve (AUC) was used to measure the discrimination capacity of the model (Zweig and Campbell, 1993; Sing et al., 2005). To determine the predictive capacity of the model, the probability of maturing of each bass caught, as calculated using the logistic model, was converted to a binary outcome (mature vs immature) by selecting a threshold cut-off value. The best mature/immature model was derived from the cut-off that maximises the sum between sensitivity (the ability of the model to find mature bass) and specificity (the ability of the model to find immature bass) (Jımenez-Valverde and Lobo, 2006). In the presence of unbalanced data (e.g. more mature fish than immature) this last analysis has been suggested as an essential tool to validate the model (Jımenez-Valverde and Lobo, 2006). In fact, probability values are highly dependent on the relative proportion of each event in the sample, being biased toward the highest number of either mature or immature, where they differ.

Finally, the estimation of age at maturity was performed only for female bass, as males were characterised by a small sample size of aged fish during the second half of the spawning season.

Table 1.1. Macroscopic characteristics of the maturity stages of the ovary and testes of bass (Pawson and Pickett, 1996)

MATURITY STAGE		OVARY	TESTIS
I	Immature	Small thread-like ovary, reddish-pink	Small, colourless, thread-like; testis not practical to differentiate macroscopically <TL 20 cm
II	Recovering spent	Ovaries one-third length of ventral cavity, opaque, pink with thickened walls and may have atretic eggs	Testis one-third length of ventral cavity, often bloodshot with parts dark grey
III	Developing (early)	Ovaries up to one-half length of ventral cavity, orange-red, slight granular appearance, thin, translucent walls	Testes thickness 10–20% of length, dirty white, tinged grey or pink
IV	Developing (late)	Ovaries greater than one-third length of ventral cavity, orange-red; eggs clearly visible, but none hyaline	Testes flat-oval in cross-section and thickness >20% of length, half to two-thirds of ventral cavity. White colour and milt expressed from vent if pressure applied to abdomen
V	Gravid (ripe)	Swollen ovaries two-thirds length of ventral cavity, pale yellow-orange; opaque eggs clearly visible with some hyaline	Testes bright white and more rounded-oval in cross-section. Only light pressure required to cause milt to flow from vent
VI	Running	Ovaries very swollen; both opaque and larger hyaline eggs clearly visible beneath thin almost transparent ovary wall, and expressed freely with light pressure	Testes becoming grey-white and less turgid. Milt extruded spontaneously
VII	Spent	Ovary flaccid but not empty, deep red; very thick ovary wall; dense yellow atretic eggs may be visible	Testes flattened and grey, flushed with red or pink, larger than those at stage II or III

1.3 Results

- *Length-weight relationship*

The length-weight relationship of the 2541 bass collected around Wales is presented in Figure 1.2. The analysis of covariance (ANCOVA) to assess the interaction length * location showed that no significant difference in the slope of the regression line (log (weight) ~ log (length)) was found between North and South Wales and thus no significant difference in the length-weight relationship was found between locations. No significant difference was found in the length-weight relationship for both males and females between North and South Wales.

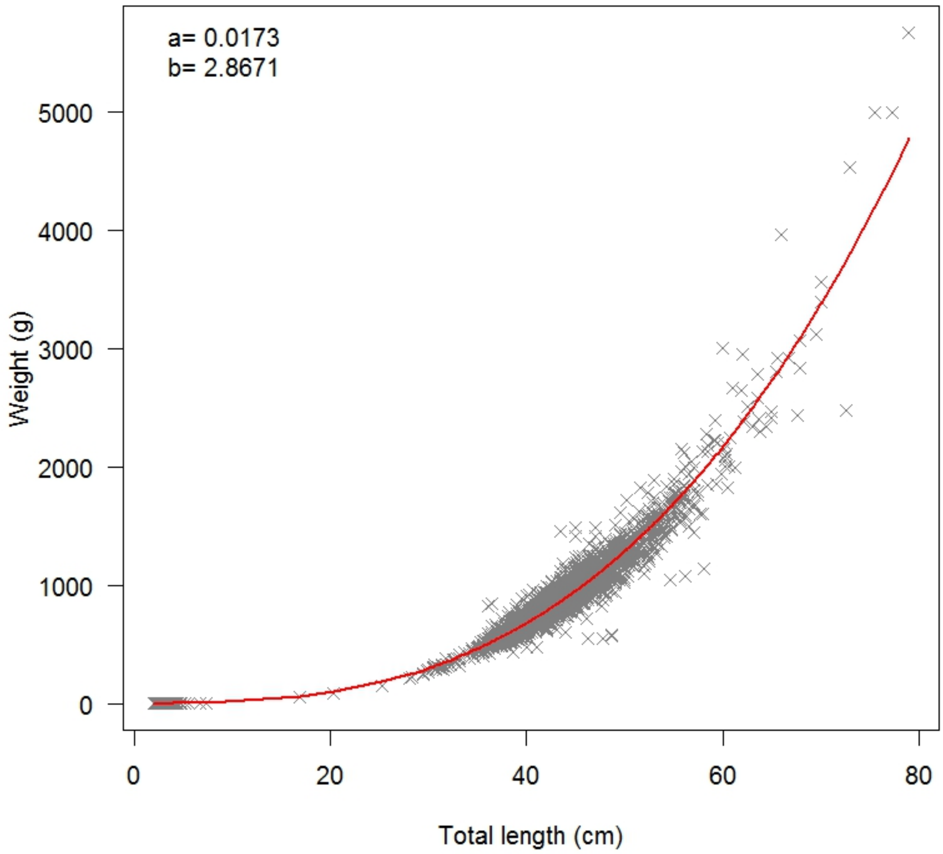


Figure 1.2. Length-weight relationship for the bass population in Wales

- *Von Bertalanffy growth function*

The Von Bertalanffy growth function was calculated for the combined sexes and for males and females separately (Figure 1.3 and Figure 1.4). Comparison with the ICES stock assessment (ICES, 2013) was possible only for the sexes combined, as the ICES assessment did not provide estimates for each sex. The sampled sea bass showed sexual dimorphism of growth from about six years of age onwards (Figure 1.4). The oldest fish were predominantly females from around 14 years of age (Figure 1.4).

For the sexes combined, our estimates showed a mean asymptotic length 3 cm smaller than the asymptotic length estimated for the ICES Divisions VIIa, VIIf and VIIg (altogether) (Table 1.2). However, the mean asymptotic length estimated by ICES fell into the upper confidence limit of our estimates (Table 1.2) and therefore the difference between our estimates and ICES is not statistically significant.

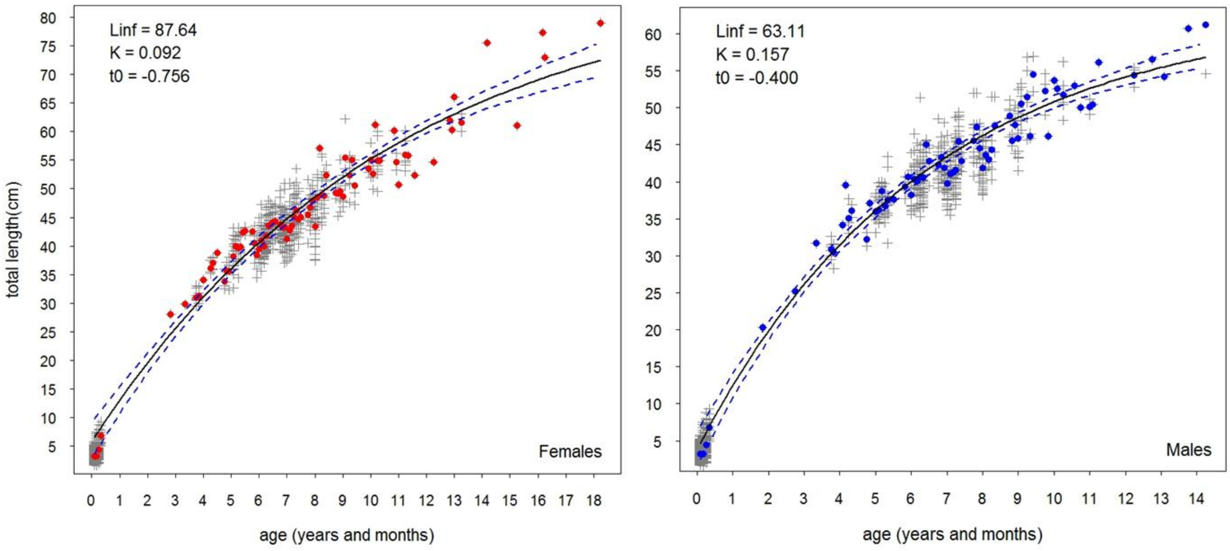


Figure 1.3. Left. The Von Bertalanffy growth function for females; grey points: single observations (n=673), red points: mean value of length for each age class, black line: growth curve; blue lines: confidence interval. Right. The Von Bertalanffy growth function for males; grey points: single observations (n=523), blue points: mean value of length for each age class, black line: growth curve; blue lines: confidence interval. Data collected around Welsh waters during 2013, 2014 and 2015.

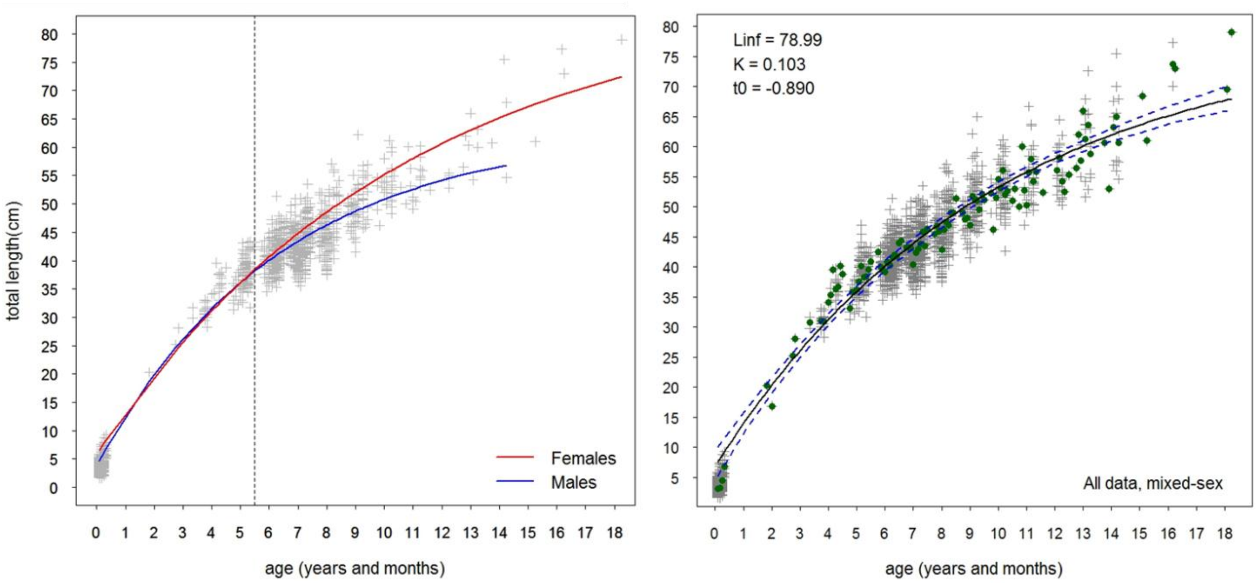


Figure 1.4. Left. The Von Bertalanffy growth function comparing males and females; grey points: single observations (n=1196); dashed line indicates the age when the two curves start to diverge. Right. The Von Bertalanffy growth function for sex combined; grey points: single observations (n=1855), green points: mean value of length for each age class, black line: growth curve; blue lines: confidence interval.

Table 1.2. Comparisons of life history parameters between Wales and ICES areas VIIafg. NA = this parameter not reported by ICES.

sex	Von Bertalanffy parameters	Average Wales (present study)	Confidence interval (present study) 2.5%	97.5%	p-value (present study)	Average ICES area VIIafg (ICES, 2013)
males	L_∞	63.11	59.06	67.16	<0.0001	NA
	K	0.157	0.132	0.182	<0.0001	NA
	t0	-0.400	-0.692	-0.108	0.0080	NA
females	L_∞	87.64	77.61	97.68	<0.0001	NA
	K	0.092	0.071	0.113	<0.0001	NA
	t0	-0.756	-1.265	-0.246	0.0042	NA
Sex combined	L_∞	78.99	72.51	85.48	<0.0001	81.87
	K	0.103	0.084	0.122	<0.0001	0.092
	t0	-0.890	-1.359	-0.421	0.0003	-1.066

For both males and females significant differences of length by age between North and South Wales was found only for one age class (10 years for females and 5 years for males) and therefore we do not have enough evidence to suggest the presence of a significant difference in the growth function between North and South Wales (Table 1.3) .

Table 1.3. Average length by age calculated for the most frequent age classes of males and females. One-way ANOVA to assess the difference between North and South Wales.

sex	age	n	Average length (cm) ± SD		F value	p-value
females			South	North		
	6	287	42.75 (±2.32)	42.60 (±2.65)	0.19	0.66
	7	132	45.03 (±2.95)	44.80 (±3.21)	0.16	0.69
	8	38	49.70 (±2.99)	49.81 (±3.45)	0.01	0.92
	9	17	53.12 (±2.92)	53.26 (±5.65)	0.01	0.95
	10	15	53.32 (±2.17)	57.92 (±3.49)	10.02	0.007
males			South	North		
	5	54	36.81 (±1.88)	39.22 (±2.13)	19.05	<0.0001
	6	190	40.82 (±2.92)	40.95 (±2.50)	0.10	0.76
	7	130	43.09 (±3.37)	42.82 (±3.07)	0.20	0.65
	8	44	45.61 (±3.17)	46.18 (±3.44)	0.28	0.60
	9	18	51.42 (±3.48)	51.83 (±3.40)	0.06	0.81

- *Gonad-somatic index and spawning season*

Both females and males exhibited the same pattern of seasonal change in gonad-somatic index (GSI), with the highest values from January to May and the peak in March (Figure 1.5). We therefore identified January-May as the spawning season of bass in Wales. A similar picture is presented in the stock assessment, where the main spawning season has been identified between January and May from the UK data (ICES, 2013). No difference in the spawning season was found between North and South Wales, therefore the difference in water temperature between the two areas did not produce a shift in the relative spawning period (Figure 1.6 and Figure 1.7). However GSI in North Wales appeared lower than in South Wales, possibly due a fewer number of fish spawning in the North Wales.

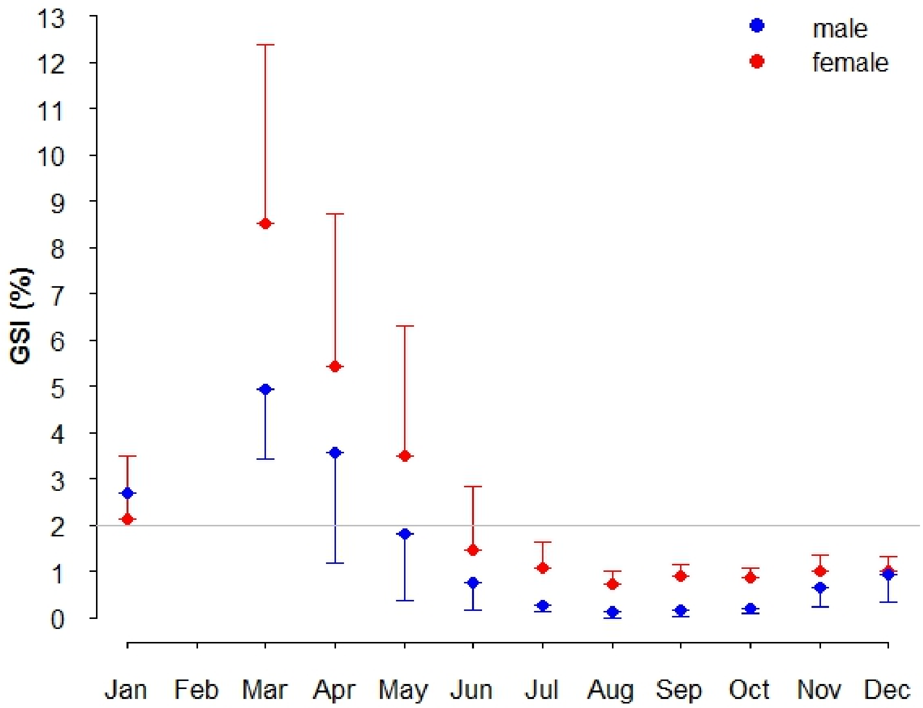


Figure 1.5. Gonad Somatic Index (%) (mean value with error bars indicating standard deviation) by sex and month of bass caught around Welsh waters. Higher values of GSI above the grey line (January-May) correspond to the spawning season.

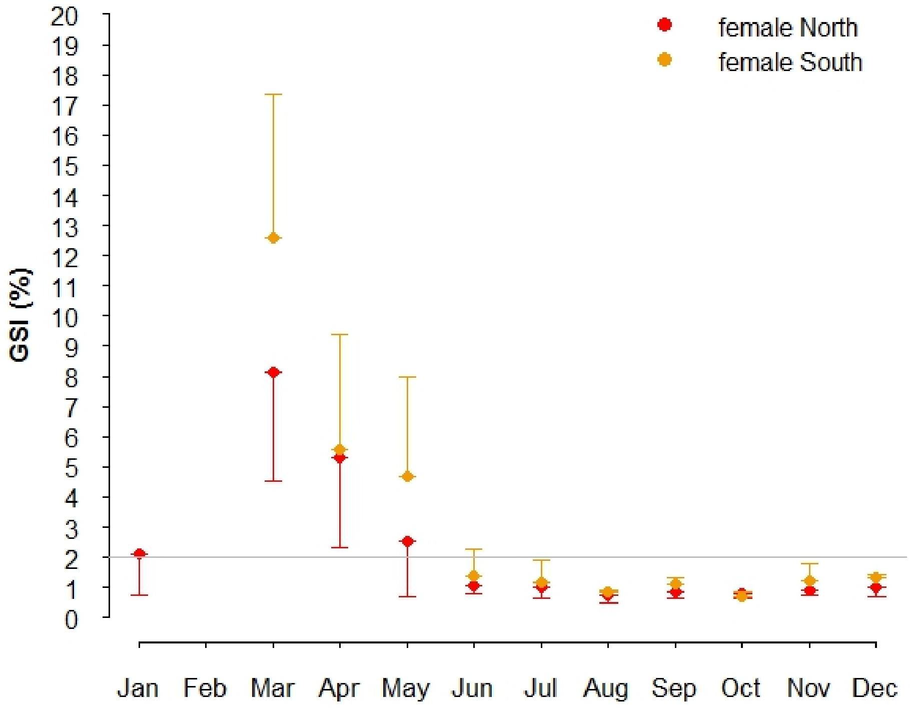


Figure 1.6. Gonad Somatic Index (%) (mean value with error bars indicating standard deviation) of female bass in North and South Wales. Higher values of GSI above the grey line (January-May) correspond to the spawning season.

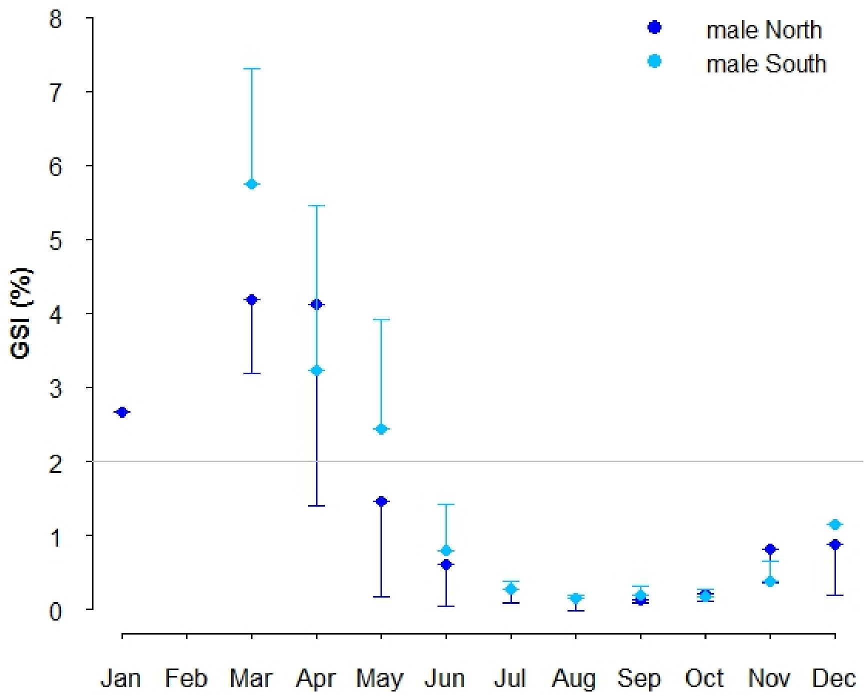


Figure 1.7. Gonad Somatic Index (%) (mean value with error bars indicating standard deviation) of male bass in North and South Wales. Higher values of GSI above the grey line (January-May) correspond to the spawning season.

A significant relationship was found between the GSI and the size of bass (Figure 1.8). In particular, during the period of July-October the relationship was always significant for females and it was significant for males in August, September and October. During the rest of the year this relationship was not significant due to the small amount of data and to the effect of the asynchronous spawning behaviours between individuals. The significant relationship found outside the spawning period between size of the fish and GSI clearly indicates that bigger bass invest proportionally more energy in gonadal development as they produce large numbers of eggs. In fact for every unit increase in length, the average GSI increased by a factor of 0.024 and 0.005 for females and males respectively.

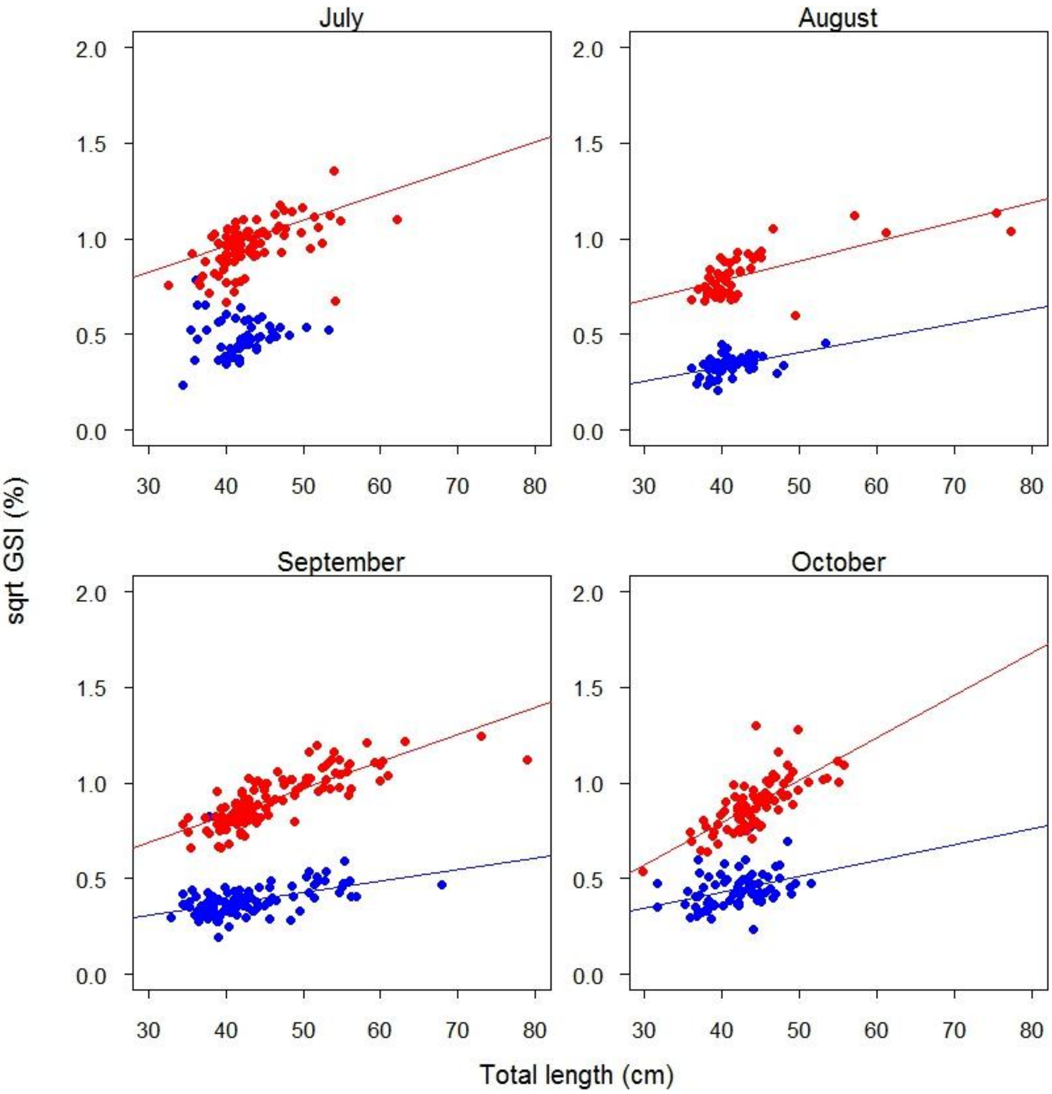


Figure 1.8 Plot of bass total length (cm) against the Gonad Somatic Index (square root transformed), showing the significant increase of the GSI (%) with the length of the fish (blue=males; red=females). This relationship indicates that the reproductive investment increases with the size of the fish.

- *Maturity stages*

The maturity stage of 1126 adult bass (610 females and 516 males) caught around Wales during 2013, 2014 and 2015 shows a clear pattern in the gonad development between months for both males and females (Figure 1.9).

For female bass, stage III (early development) was predominant from August to January. Stages V and VI became predominant (together) during March and April whilst in May the main stage was VII - spent (but stages V and VI were still present). Finally, the "recovery spent" stage (stage II) became predominant during June and July. A similar pattern has been found for male bass, except for stages II and III, as it appears that male bass need more time to recover after spawning (stage II was predominant during four months, July-October) than females (stage II appeared predominant during two months, June-July) (Figure 1.9) or males possibly delay the process of re-maturation as the energetic investment is less.

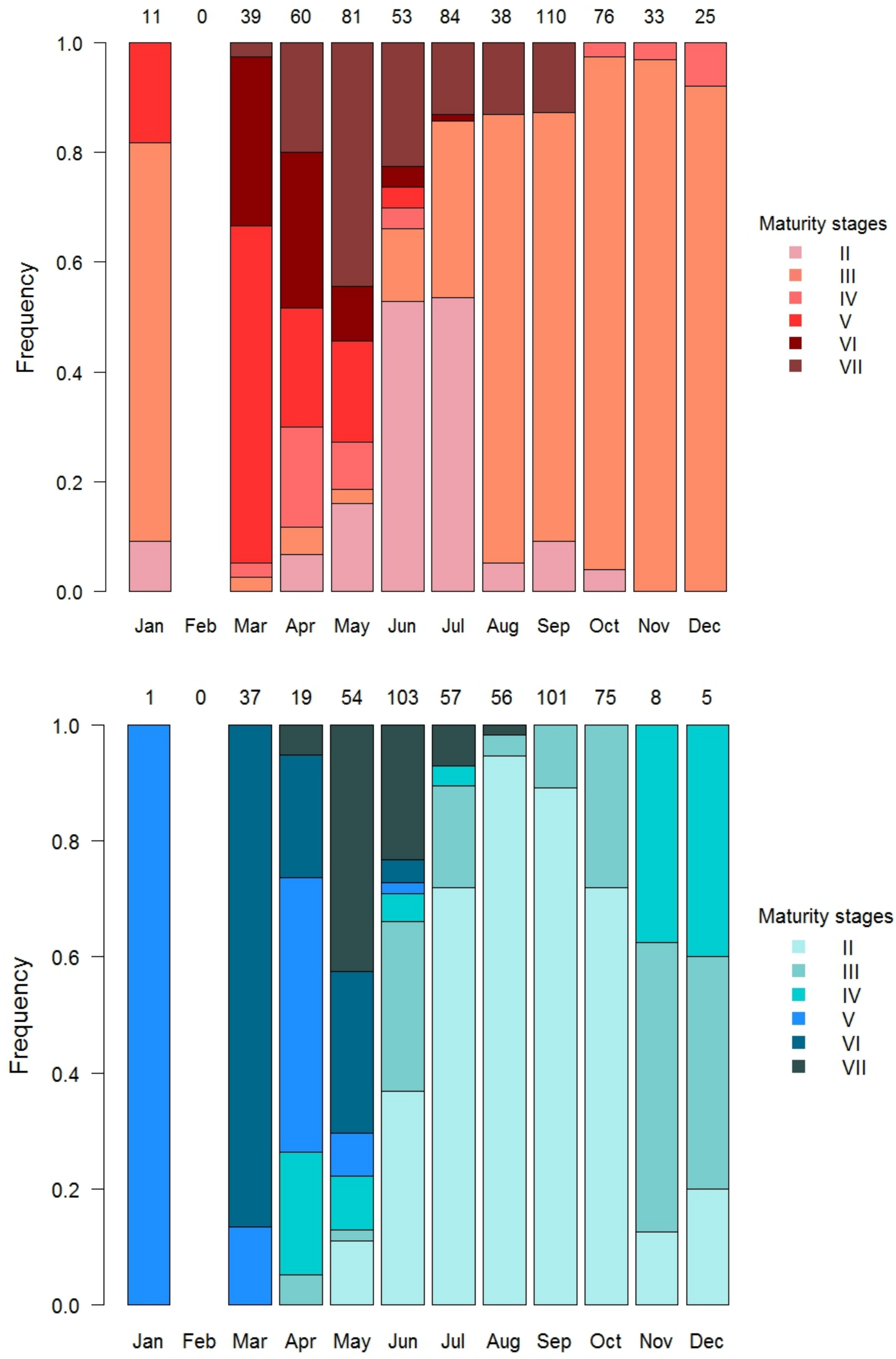


Figure 1.9. Sequence of changes in maturity stage during the year for females (upper graph) and males (lower graph). Numbers on top of each bar represent the sample size for each month. No data for February.

- *Size at maturity*

A total of 329 fish caught between March and May were sexed and the maturity stage was established, 207 females and 122 males. Of the 207 females caught between March and May, 33 were found to be immature (10 at stage I and 23 at stage III) and 174 mature (17 at stage II, 18 stage IV, 52 stage V, 37 stage VI and 50 stage VII). Of the 122 males, 11 were immature (7 at stage I and 4 at stage III) and 111 were mature (7 stage II, 10 stage IV, 18 stage V, 51 stage VI and 25 stage VII).

The logistic regression model used to assess the probability of being mature as a function of size has been estimated for females (Figure 1.10) and males (Figure 1.11)

The le Cessie–van Houwelingen–Copas–Hosmer test confirmed that this model fits the data well (p=0.75 for females and p=0.76 for males, under the assumption of the null hypothesis that the values estimated by the model are similar to those observed).

For females the value of 0.84 was the length coefficient in the logistic regression analysis, thus the exponential of 0.84 represented the odds ratio corresponding to a one unit change in length, which equals 2.31. Thus, for every unit increase in length, the odds of maturing (vs non-maturing) increased by a factor of 2.31.

For males the value of 0.69 was the length coefficient in the logistic regression analysis, thus the exponential of 0.69 represented the odds ratio corresponding to a one unit change in length, which equals 2.0. Thus, for every unit increase in length, the odds of maturing (vs non-maturing) increased by a factor of 2.0.

The area under the ROC curve (AUC) was 0.977 for females and 0.989 for males (Figure 1.12): not only are these value greater than 0.5 (that which represents the non-discriminating capacity of the models), they are significantly different from the area under the diagonal (in both cases P-value <0.0001). The AUC values were greater than 0.7, indicating that the model provides adequate discrimination between bass that are mature or non-mature in both sexes (Hosmer and Lemeshow, 2000).

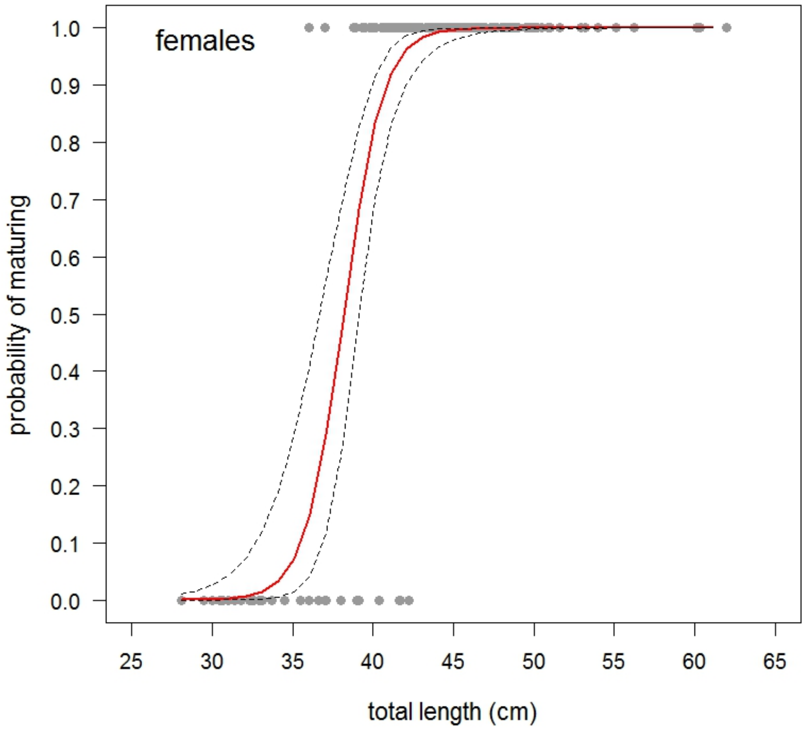


Figure 1.10. Fitted logistic regression of the probability of female bass being mature against their size (with 95% confidence intervals, dashed lines). Grey points: data of mature and immature female bass.

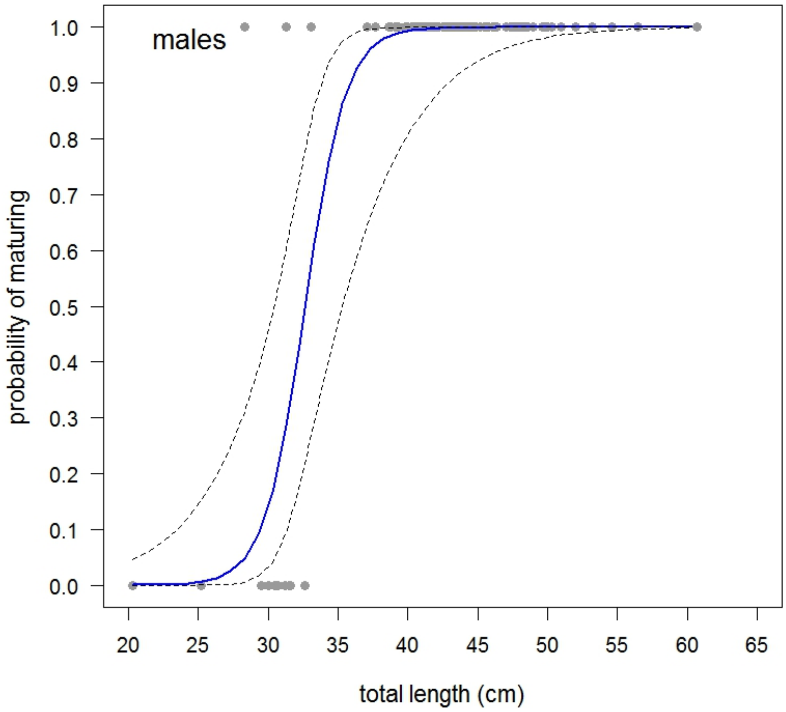


Figure 1.11. Fitted logistic regression of the probability of male bass being mature against their size (with 95% confidence intervals, dashed lines). Grey points: data of mature and immature male bass.

For females, the predictive capacity of the model was tested by selecting the cut-off of probability of maturing P=0.68 corresponding to 39.1 cm TL. This cut-off maximised the sum between sensitivity and specificity and converts the decimal fraction probabilities into a binary variable: above this value, all female bass caught were estimated to be mature whilst below this value, female bass were estimated to be immature. At P=0.68 the specificity was 87.9% and sensitivity was 97.7% (Figure 1.12 left): the model was successful in identifying both females that are mature (87.9%) and females that are immature (97.7%). Therefore, 39.1 cm TL represents the size at maturity identified by our model, which corresponds to 68% of the proportion of mature females. On the other hand, the size at maturity corresponding to a 50% probability of a female bass being mature (50% of mature females) is 38.2 cm. Even though this value corresponds to the % generally used to describe the size at maturity (50%), it does not represent the best cut-off, as it does not maximise the predictive ability of our model.

For males, the predictive capacity of the model was tested by selecting the cut-off of probability of maturing P=0.50 corresponding to 32.6 cm TL. This cut-off maximised the sum between sensitivity and specificity and converted the decimal fraction probabilities into a binary variable: above this value all the male bass caught were estimated to be mature whilst below this value, male bass were estimated to be immature. At P=0.50 the specificity was 100% and sensitivity was 98.2% (Figure 1.12 right): the model was successful in identifying both males that are mature (100%) and males that are immature (98.2%). Therefore, 32.6 cm TL represents the size at maturity identified by our model, which corresponds to 50% of the proportion of mature males.

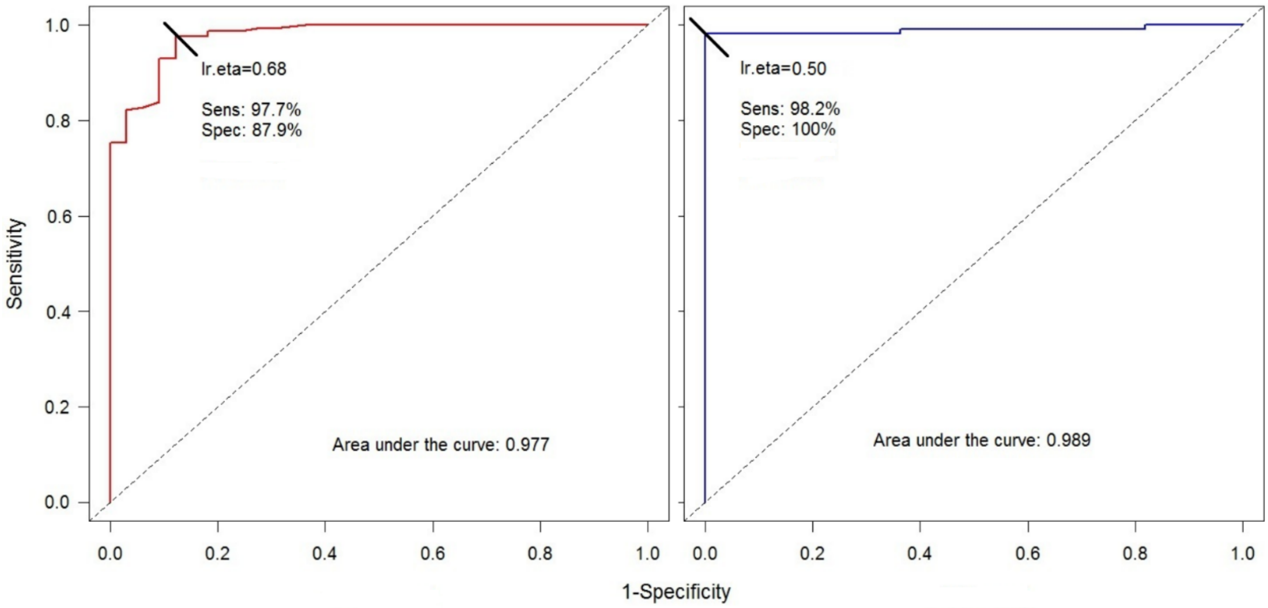


Figure 1.12. Receiving operating characteristic (ROC) curves of the predicted probabilities of being mature for females (left) and males (right). The value denoted by lr.eta is the cut-off where the sum of specificity and sensitivity is maximised.

The maturation range for females occurs at ages 4 to 6 (Table 1.4). The cut-off that maximised the sum between sensitivity and specificity of the logistic regression model (Figure 1.13) corresponded to the age 5 years and 11 months.

Table 1.4. Raw proportion mature at-age in 2014-2015 Welsh samples.

age	Proportion of mature females
2	0.00
3	0.00
4	0.10
5	0.75
6	0.95
7	1.00
8	1.00
9	1.00
10+	1.00

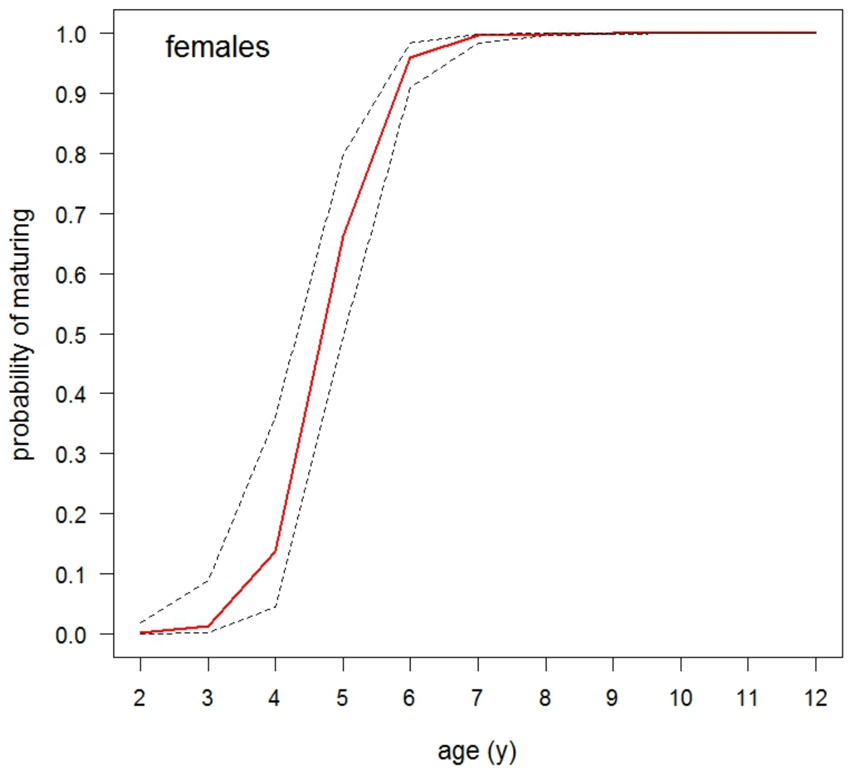


Figure 1.13 Fitted logistic regression of the probability of female bass being mature against their age (with 95% confidence intervals, dashed lines).

1.4 Discussion

Most of the life history parameters estimated for the bass stock in Wales are consistent with those estimated for the ICES Divisions VIIafg, in particular the Von Bertalanffy growth curve for the combined sex, the identification of the spawning season (January-May), and the size at maturity of male bass. The size at maturity of male bass estimated for the ICES Divisions VIIafg (34.67 cm) is inside the confidence interval corresponding to the size at maturity (32.7 cm) identified by our model and thus does not appear significantly different from our estimate.

Conversely, the size at maturity of female bass estimated for the ICES Divisions VIIafg (40.65 cm) is outside the confidence interval corresponding to the size at maturity (39.1 cm) identified by our model and thus appears significantly higher than our estimate. This difference could be due to the different areas compared (Wales only vs all of ICES area VIIafg), to the different time scale (2014-2015 - Bangor University vs 1985-2011 - ICES 2013), and to the different methodology applied. This study considered only fish caught between March and May and we treated stage III as "immature", whilst ICES (2013) considered all fish between January and

April and treated stage III as “mature”. The significantly lower size at maturity found through our model has important management implications, mainly related to the definition of the Minimum Landing Size (MLS).

Our data also show that bigger bass invest more energy in gonadal development as they produce large numbers of eggs. Therefore, larger fish could be considered more important within the stock in terms of spawning ability and demographic contribution. This suggest that a maximum landing size to protect large spawners may be a beneficial conservation measure if it could be made a practical option in the context of enforcement. This measure would need to ensure that there was a mechanism to release (with high survivorship) or avoid catching larger fish.

2. THE BASS FISHERY IN WALES AND IMPLICATIONS OF INCREASING MLS

2.1 Introduction

The bass fishery around Welsh waters is characterised by many small (10 m and under) vessels using a variety of fishing methods, particularly rod and line and gillnets. From the official census of Welsh vessels registered in 2012 (European Fleet Register, http://ec.europa.eu/fisheries/fleet), 188 vessels had gillnets on their fishing licence and 110 were licensed for the line fishery (98 handline-rod and line and 12 longline). From these data we derived that the potential population of inshore vessels targeting bass in Welsh waters using gillnet, line or both fisheries for part of the year could be up to 267 units. Most of these vessels are located in South Wales (n=208, 78%) followed by North Wales (n=44, 16%) and Mid Wales (n=15, 6%).

Commercial fisheries management measures currently in place in Wales include a Minimum Landing Size (MLS) and a landings limit. MLS of bass in Wales differs between areas, being 37.5 cm in South Wales (between the point 52°07.10'N, 04°43.85'W and the point 51°29.40'N, 03°07.10'W) and 36 cm in Mid and North Wales. A landings limit of 5 tonnes per vessel per week has been also introduced across Wales and a minimum gill net mesh size of 100 mm has been introduced in South Wales.

In this chapter we present data on: (i) catch at length by season and fishing area for the two main fisheries (gillnet and line) and (ii) catch at age matrix for 2013 and 2014. We then modelled the short-term and long-term effects on catches derived from the potential increase of the MLS. We first modelled 40 cm MLS (which correspond to a precautionary limit based on the size at maturity of female bass estimated by this study) and then 42 cm (which correspond to the previous size at maturity of female bass estimated by Pawson and Pickett, 1996).

2.2 Materials and methods

- *Length frequency*

Catch at length data was collected from fish processors and fishers during 2013 and 2014 for a total of 1984 fish with information on length, gear, season and fishing area. When in the fish processors, subsamples were necessary due to the amount of catches, bass were randomly chosen from the catch of each fisher choosing a minimum of 50 individuals.

Length frequency distribution by gear (line and gillnet) and season and by gear and location was thus represented and the analysis of variance was performed to assess differences in the average length between seasons and locations. First the Levene's test was performed to assess the homogeneity of variance and the Kolmogorov-Smirnov test was performed to test for normality. A one-way ANOVA was applied in cases of normal data (or log transformed data) and equal variance, otherwise a non-parametric test (Kruskal-Wallis) followed by a post hoc Nemenyi test was performed (R package PMCMR).

The proportion of catch losses from applying a new MLS of 40 or 42 cm was then estimated.

- *Catch at age analysis and model development*

A catch at age matrix based on 880 bass caught with gillnet and 649 caught with line (rod and longline) during 2013 and 2014 was determined. To assess the short-term and long-term effects on catches from a change in MLS we first estimated the instantaneous total mortality (Z= natural mortality (M) + fishing mortality (F)) (y^{-1}) from the line fishery, which was considered non size-selective as a first approximation. The instantaneous total mortality (Z) was derived by using the catch curve (ln (numbers) versus age in a linear regression) and corresponded to the negative slope of the regression for the age groups that were fully recruited to the fishery (considering age categories with a plus group 15+).

The estimated Z was thus considered as a proxy of the total mortality (natural mortality + fishing mortality) for the bass population in Wales. Fishing mortality was then derived by removing the natural mortality (M=0.2, according to the stock assessment. ICES, 2013) from the total mortality Z. We then modelled changes in the relative number and relative biomass of the bass caught when increasing the MLS, based on our estimated Length-Weight relationships and the Von Bertalanffy growth function. In the model we assumed that fish below MLS only experience natural mortality (M) and above MLS they experience fishing mortality (F) + natural mortality (M). This very simple model does not capture density-dependent changes in growth and/or mortality with changing fish density, stock-recruitment relationships and variations in recruitment.

2.3 Results

The size distribution of bass landed around Welsh waters during 2013 and 2014 varied depending on the gear and season (Figure 2.1 and Figure 2.2) and on the gear and fishing area (Figure 2.3 and Figure 2.4).

Due to the non-homogeneity of variance (even after transformations), a non-parametric test (Kruskal-Wallis) was applied to assess differences in length between seasons for bass caught with gillnet and line. A significant but small difference of the average length of bass caught with gillnets was found between spring (average size (cm): 45.4 ± 4.5 SD) and summer (average size (cm): 44.4 ± 6.8 SD) and between spring and autumn (average size (cm): 43.8 ± 4.5 SD) (Figure 2.2, left). On the contrary, for line caught bass, no significant differences in the average size were found between seasons (Figure 2.2, right).

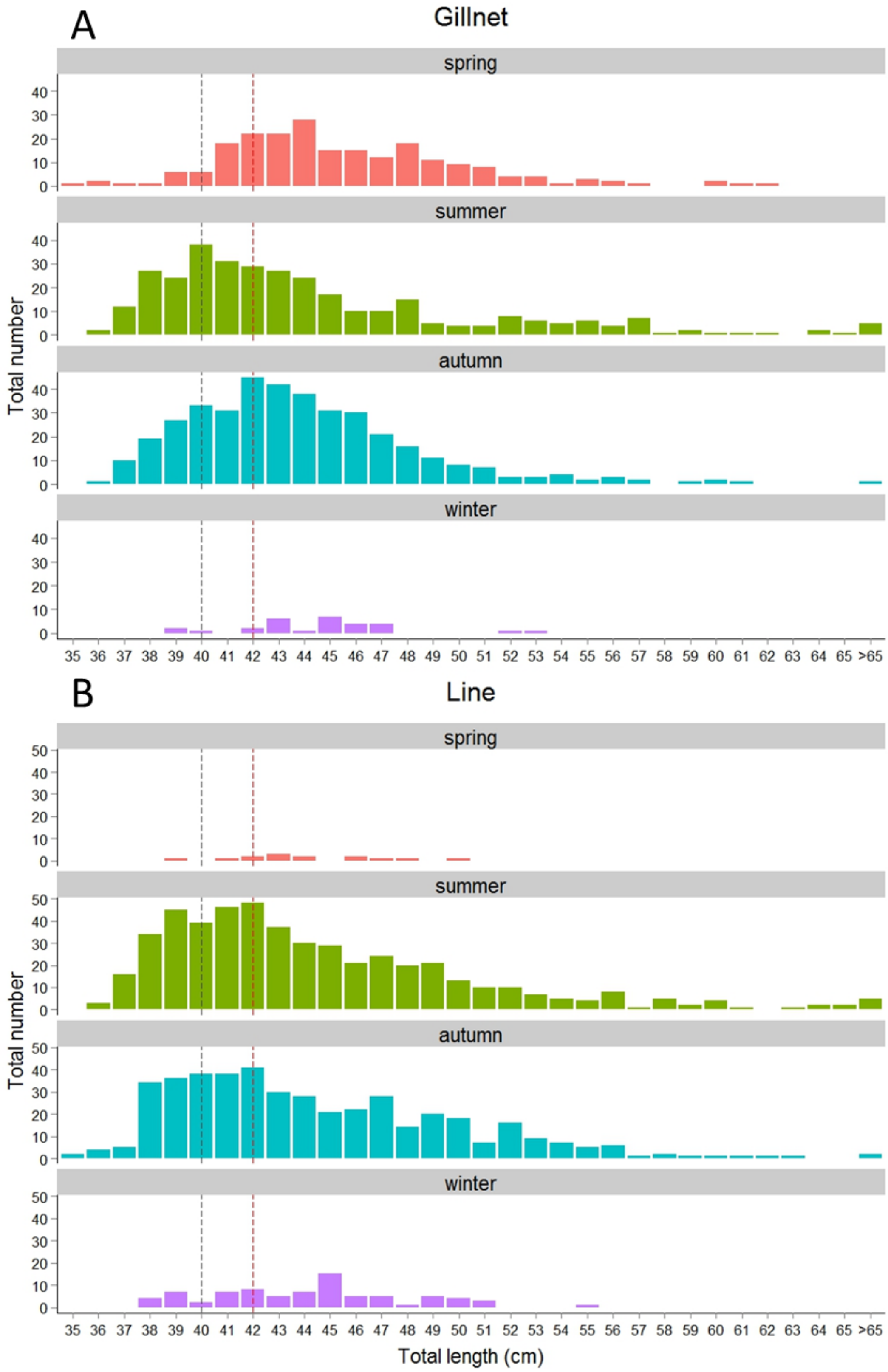


Figure 2.1. Length frequency distribution (in number) by season of sea bass caught and landed with A) gillnet (n=964) and B) line (n=1025) during the period 2013-2014. Grey and red dashed lines underline the proportion of bass < 40 cm length and < 42 cm respectively.

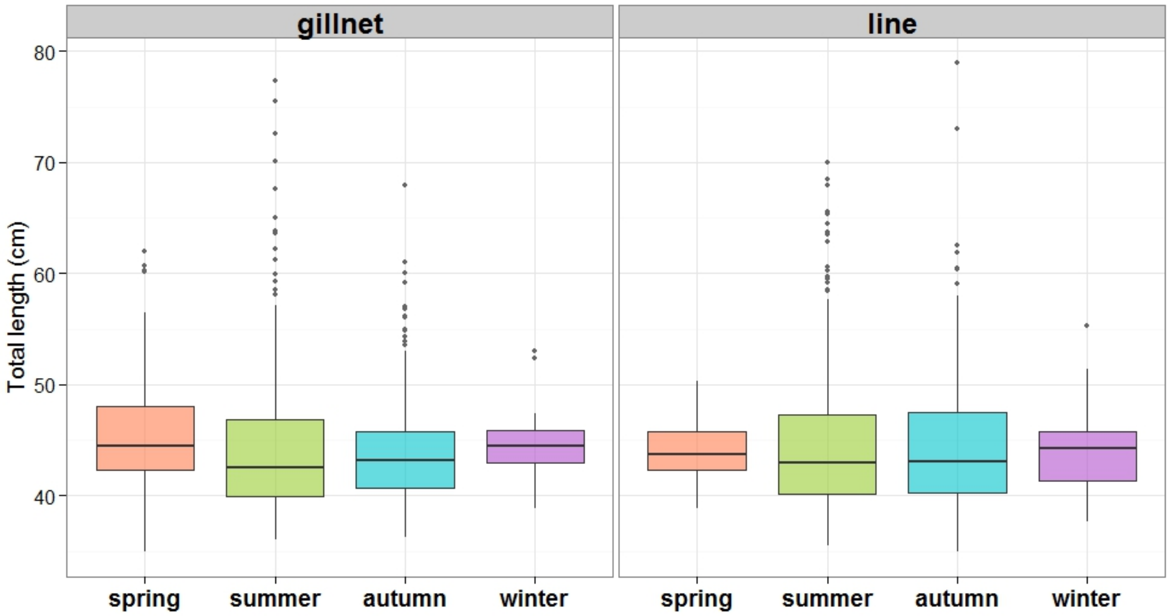


Figure 2.2. Boxplot of bass total length by season and gear for the period 2013-2014 for the whole of Wales.

The size distributions of bass caught and landed by area and gear were also analysed (Figure 2.3). Data from Mid and North Wales were aggregated in the same location category because these two areas were characterised by the same legislation (bylaws) and thus by the same MLS (36 cm) whilst South Wales was characterised by different bylaws and a bigger MLS (37.5 cm).

For both gears, the size distribution of bass caught in South Wales was characterised by a wider size range compared to Mid and North Wales (Figure 2.3). Significant differences between the two areas were identified for both gillnet (Kruskal-Wallis test, $p<0.0001$) and line (one-way ANOVA, $p<0.0001$), with the average size of bass caught in South Wales significantly larger than in Mid and North Wales (Figure 2.4). This difference can be related to the differences in the current MLS between the two areas.

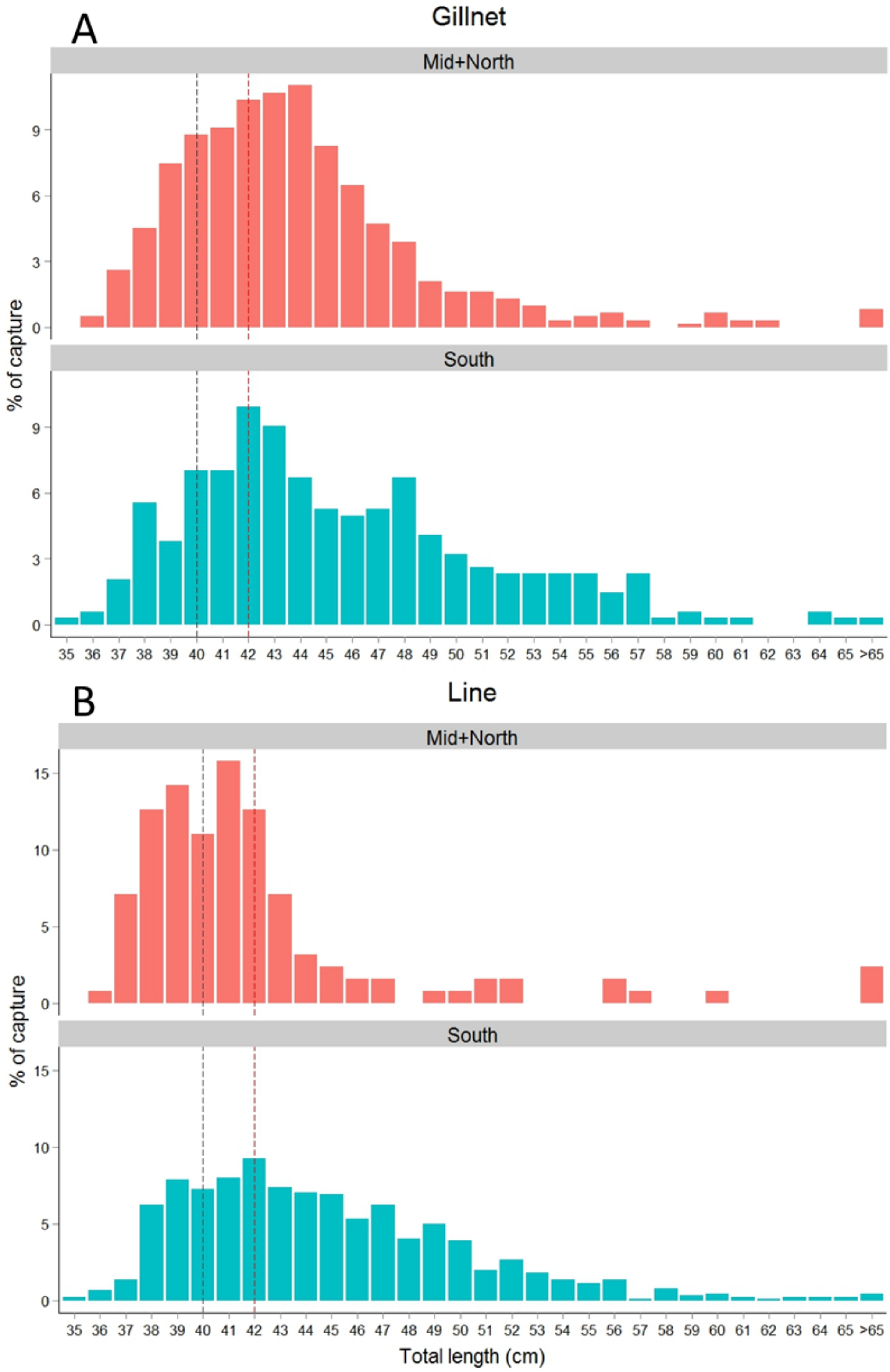


Figure 2.3. Length frequency distribution (% in terms of number of fish) by location of sea bass caught and landed with A) gillnet (Mid+North, n=617; South, n=342) and B) line (Mid+North, n=127; South, n=898) during the period 2013-2014. Grey and red dashed lines indicate the proportion of bass < 40 cm length and < 42 cm respectively.

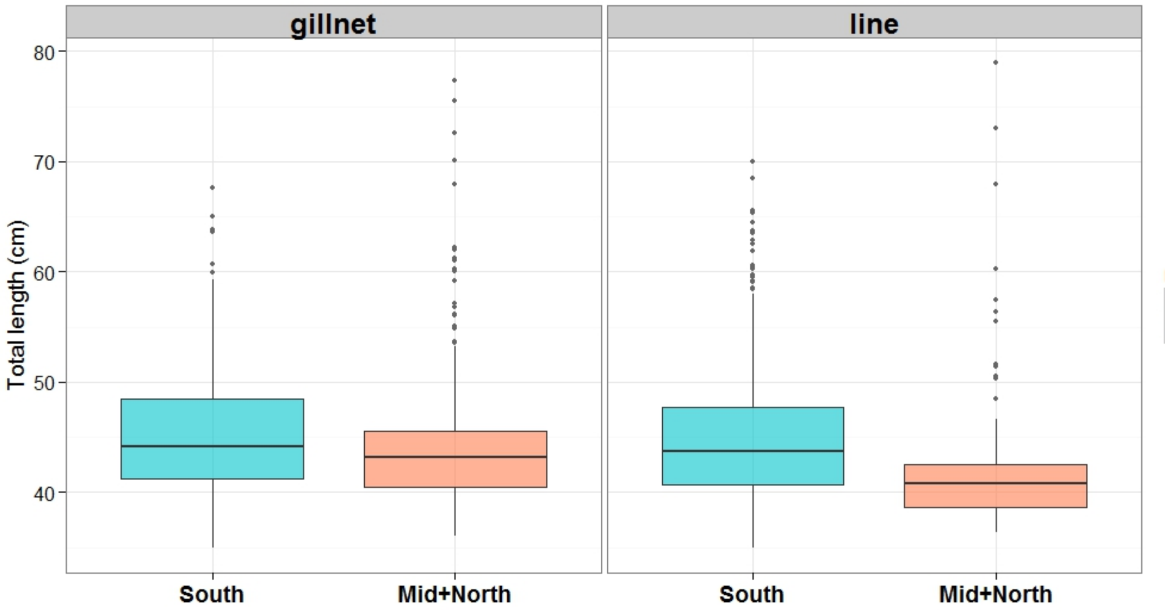


Figure 2.4. Boxplot of bass total length by fishing location and gear for the period 2013-2014.

The length frequency distribution showed that the increase in MLS would have a different effect depending on the gear used, the area fished and the season (Figure 2.1, Figure 2.2, Table 2.1 and Table 2.2). The effects of the new MLS were based on the current size distribution of the landed catches collected directly from fishers and fish processors around Wales during 2013 and 2014. The following estimates represent the effects (loss of catches) of the new MLS in the short-term after implementation, as the loss of landed catch should decrease over time, as fish grow through to the larger MLS (this assumes that the undersized fish are protected from fisheries related mortality i.e. due to discarding and that no modification in size-selectivity of gear used is applied).

With an increase in MLS to 40 cm, on a yearly basis fishers using gillnets will lose 11.6% of their landed catches, with peaks in summer and autumn (19.8% and 14.5%, respectively). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 14.8% of their catches with peaks in summer and autumn (19.9% and 18.5%, respectively) (Table 2.1). Fishers in North and Mid Wales will have a yearly loss of 24.6% of their catches. These losses will mainly affect fishers using rod and line (34.6% of losses). Fishers in South Wales will lose 14.3% of their catches on a yearly basis (12.3% of bass lost with gillnet and 16.4% with rod and line) (Table 2.2).

With an increase in MLS to 42 cm the annual loss for fishers using gillnets will be 22.3% of the landed catches in terms of number of fish. However, their losses will be different by season, with peaks in summer (40.7%) and autumn (30.9%). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 28.1% of their catches. Also, in this case, their losses will be different by season, with peaks in summer (37.1%) and autumn (35.8%) (Table 2.1). Fishers in North and Mid Wales will have a yearly loss of 47.2% of their catches. These losses will mainly affect fishers using rod and line (61.4% of losses). Fishers in South Wales will lose 29% of their catches on a yearly basis (26.3% of bass lost with gillnet and 31.6% with rod and line) (Table 2.2).

Table 2.1. Percentage loss of catch (in terms of number of fish) by gear and season in the short-term after implementation of each new MLS

gear	season	Capture loss (%) 40 cm MLS	Capture loss (%) 42 cm MLS
gillnet	spring	5.1	7.9
	summer	19.8	40.7
	autumn	14.5	30.9
	winter	6.9	10.3
line	spring	7.1	14.3
	summer	19.9	37.1
	autumn	18.5	35.8
	winter	13.9	25.3

Table 2.2 Percentage loss of landed catch (in terms of number of fish) by gear and area in the short-term after implementation of each new MLS.

gear	area	Capture loss (%) 40 cm MLS	Capture loss (%) 42 cm MLS
gillnet	Mid + North Wales	15.1	32.9
	South Wales	12.3	26.3
line	Mid + North Wales	34.6	61.4
	South Wales	16.4	31.6

The catch-at-age matrices by gear are presented in Annex II. From the catch at age matrix we derived the bubble plot for the two fisheries (line and gillnet) for 2013 and 2014 (Figure 2.5).

1,540 fish were aged, 881 caught with gillnet and 659 caught with line (figure slightly different from tables A2.1 and A2.2 in the Annex II because for 11 fish, fishers collected the scales but not the corresponding total length). The age structure of bass caught with gillnet differed between the surveyed years. In 2013, 50% of the catches with gillnet were bass of six years old. In 2014, the proportion was more evenly distributed between bass of six (35%) and seven (29%) years old (Figure 2.5 left). The catch composition of bass caught with line (rod and line + longline) was distributed over a wider range of ages than gillnet, with three main ages, six, seven and eight years old, representing altogether about 70% of the total catches in 2014.

The proportions of the catch-at-age therefore show the different selectivity of the two gears. While gillnets mostly catch bass aged six and seven years old, the line fishery appeared non age-selective. This age distribution also shows that a new MLS will cause high discard rates of bass in the gillnet fishery if not combined with an increase of the gear selectivity (by increasing mesh size).

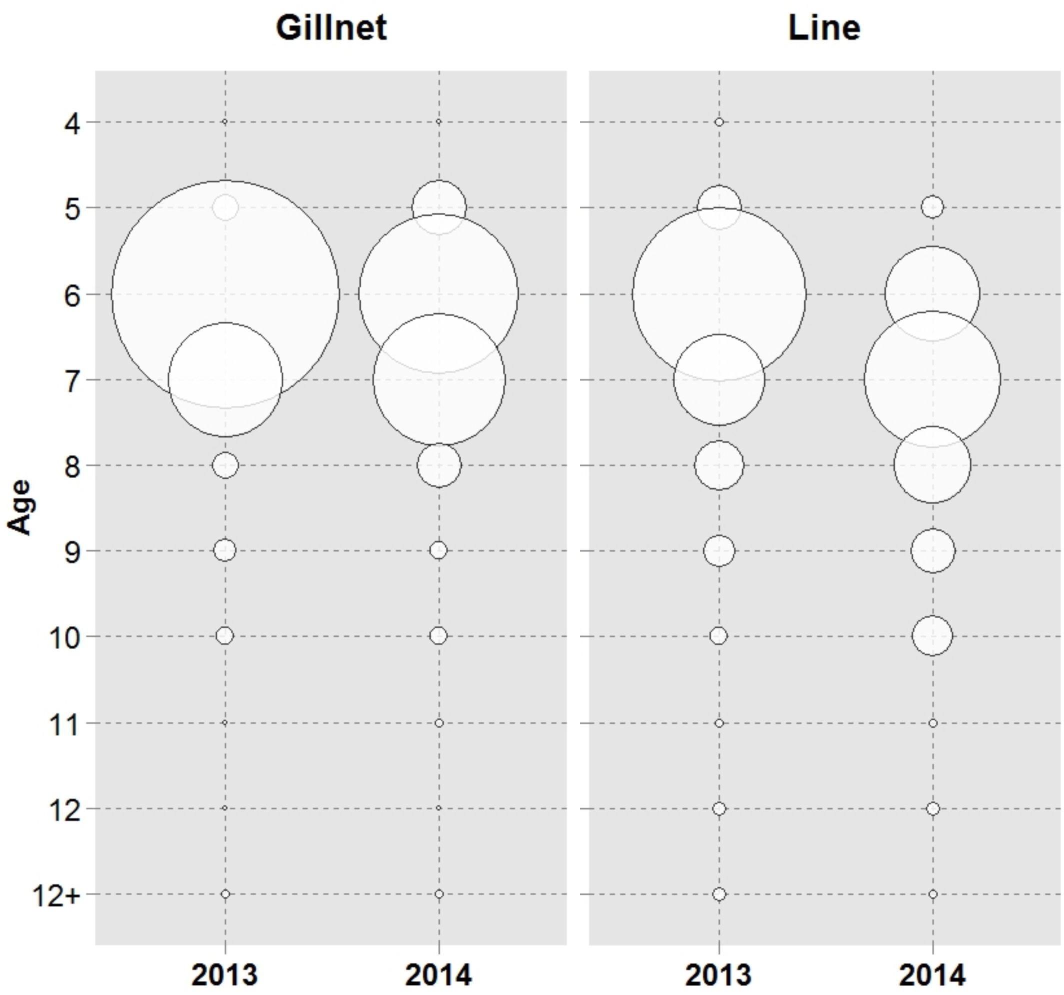


Figure 2.5. Proportions of bass caught at age (y) of sea bass caught with gillnets (left) and lines (right) around Welsh waters during 2013 and 2014.

As the line fishery for bass does not appear to be age or size selective (from our data and the gear characteristic), we considered the instantaneous mortality (Z) derived from its catch-at-age matrix (considering age categories with a plus group 15+) as a proxy of the total mortality for the bass population in Wales. Z from the line fishery was estimated to be 0.48 in 2013 and 0.49 in 2014. Considering natural mortality M=0.2 from the stock assessment data, fishing mortality was estimated to be low at 0.28 and 0.29 (y^{-1}) for 2013 and 2014, respectively. We then modelled the change of the relative number and relative biomass of the bass caught when increasing the MLS.

Figure 2.6 shows that the increase in MLS from 36 to 40 cm could result in a decrease of 17% in the total number of bass caught one year after implementation (the time required for fish to grow from 36 to 40 cm), whilst no difference is expected in terms of landed biomass. Figure 2.7 shows that the increase in MLS from 36 to 42 cm will cause a decrease of 25% in the total number of bass one year and half from the implementation (the time required for fish to grow from 36 to 42 cm), whilst no difference is expected in terms of landed biomass. With the new MLS (40 and 42 cm), in both cases fishers will catch fewer but bigger bass. However, the losses that fishers will face in the short term after the implementation will be different depending on the new MLS. With 40 cm MLS the losses in the first year will be 37% of the total number of bass caught and 24% of the total biomass. With 42 cm MLS the losses in the first year and half will be 51% of the total number of bass caught and 35% of the total biomass.

Figures 2.6 and 2.7 thus show the effect on catchable numbers and biomass of bass directly before and after the implementation of a new MLS and the long-term effect. The direct effect on catchable numbers and biomass will always be negative, whilst the long-term effect on biomass will depend on the mortality and growth functions of the population.

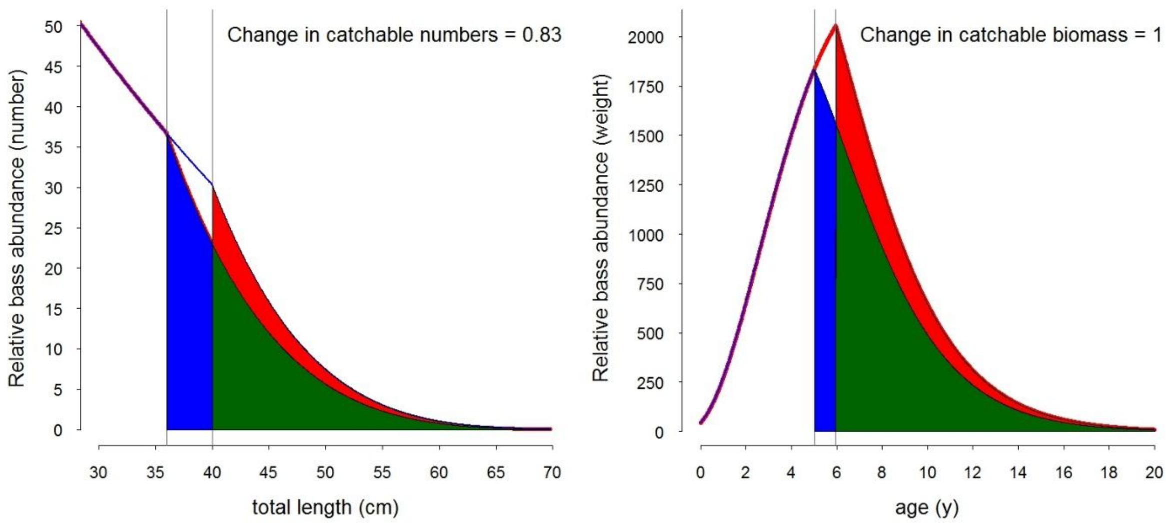


Figure 2.6. Effect of the implementation of the 40 cm MLS. Model based on the instantaneous total mortality (Z) estimated from the catch at age matrix of the line fishery in Wales, considered as a proxy of the total mortality for the bass population in Wales. In the applied model Z=0.49 and M=0.2 (y^{-1}) (according to the stock assessment data, ICES 2013). Area blue + area green = current relative number and biomass harvestable. Green area = relative number and biomass harvestable immediately after implementation. Area red + area green = relative number and biomass harvested one year after implementation.

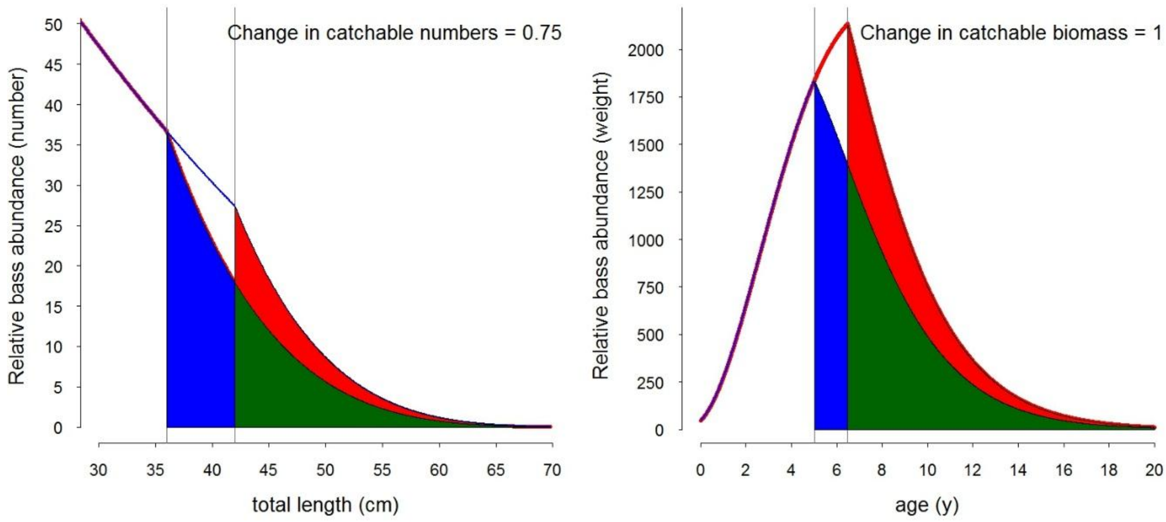


Figure 2.7. Effect of the implementation of the 42 cm MLS. Model based on the instantaneous total mortality (Z) estimated from the catch at age matrix of the line fishery in Wales, considered as a proxy of the total mortality for the bass population in Wales. In the applied model Z=0.49 and M=0.2 (y^{-1}) (according to the stock assessment data, ICES 2013). Area blue + area green = current relative number and biomass harvestable. Green area = relative number and biomass harvestable immediately after implementation. Area red + area green = relative number and biomass harvested one year and half after implementation.

2.4 Discussion

There would be short-term losses in catches after the imposition of a 42 cm MLS. For fishers using gillnets 22.3% of the catches would be lost in terms of number of fish. However, their losses will be different by season, with peaks in summer (40.7%) and autumn (30.9%). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 28.1% of their catches. Also, in this case, their losses will be different by season, with peaks in summer (37.1%) and autumn (35.8%). Regional differences in catch losses will also occur (47.2% in North and Mid Wales and 29% in South Wales).

A more gradual increase in MLS could be applied such that 40 cm could be a first step towards more conservative management, especially considering the size at maturity estimated for female bass in Wales (39.1 cm). With a 40 cm MLS fishers using gillnets will lose 11.6% of their catches, with peaks in summer and autumn (19.8% and 14.5%, respectively). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 14.8% of their catches with peaks in summer and autumn (19.9% and 18.5%, respectively).

All estimated catch losses will occur in the short-term after implementation of a new MLS. The loss of catches should decrease over time. In particular, we estimated that the increase of the MLS to 40 cm could result in a decrease of 17% of the total number of bass caught one year after implementation (the time required for fish to grow from 36 to 40 cm), whilst no difference is expected in terms of biomass. The increase in MLS from 36 to 42 cm will cause a decrease of 25% in the total number of bass one year and half from the implementation (the time required for fish to grow from 36 to 42 cm), whilst no difference is expected in terms of biomass. However, the model used for these estimates could be biased (see below) and the figure presented should be considered only as a general trend.

An increase of the MLS could benefit the recreational angling sector, as it would results in an increase of large bass and thus could improve the angling experience.

Limitation of the estimates and possible bias.

The model provided is the best picture available with the data collected. However, some limitations need to be underlined:

1. Total mortality Z (natural mortality + fishing mortality) derived from the catch at age matrix of the line fishery in Wales was considered as a proxy of the total mortality of the bass population in Wales. This was based on the assumption that the line fishery is not age or size selective for fish that are fully-recruited to the fishery (age 6 in 2013 and age 7 in 2014). However, the hook dimensions and the fishers' experience can play a role in selecting specific fish sizes, which could result in a slight difference between what is caught and what is in the natural population.

2. No data have been collected from restaurants, hotels, etc., which generally buy smaller bass (plate-sized fish) and thus the estimated Z applied in our model could be lower than the actual mortality. In this scenario (higher fishing mortality than the estimated), the increasing of MLS will result in more long-term benefit for fishers in terms of catchable biomass.

3. The model provided is a simplistic picture of the response of the stock to the increase of the MLS as no density dependent factors have been taken into account. In particular, raising length

at first catch can result in increases in intraspecific competition in size groups left unexploited as population density becomes higher, and consequently, in decreases in the growth potential of the stock (Svedäng and Hornborg, 2014).

4. In the model we assumed that fish below MLS only experience natural mortality (M) and above MLS they experience fishing mortality (F) + natural mortality (M). However in both cases (above and below MLS), information on mortality of discarded fish should be added.

5. Finally, the model applied referred to the Welsh stock but no information on possible recruitment of juvenile bass from outside Wales into Welsh waters is currently available. This possible recruitment would imply that the model referred to a mixed stock (Welsh + non-Welsh).

3. BASS MOVEMENTS AROUND WELSH WATERS

3.1 Introduction

In the past decades, different studies around England and Wales have shown a tendency of adult bass to migrate to the south and west during the autumn prior to spawning, with a return in spring north and eastwards to geographically discrete feeding areas (Pawson et al., 2007, Pawson et al., 2008). These cited studies thus show evidence of the presence of two separate units in UK, East/West (England/Wales) (Figure 3.1). These mark-recapture studies also show evidence of philopatry (the tendency of an individual to return to, or stay in its home area, natal site or other adopted locality, Mayr, 1963) of adult bass to specific feeding areas and protecting these areas could therefore imply a significant reduction of the fishing mortality (Pawson et al., 2007).

Tagging studies, however, do not represent the only technique to obtain insights on stock movements and are not always the best methodological option, as they are reliant on either a significant chance of recapture of the tagged animals, or the transmission of recorded information back to the researchers (Block et al., 2011).

Natural chemical tags are an attractive complement to tagging studies of stock structure. However, they are relatively underused for tracking migration and general movements in marine fish due to the uncertainties in the spatial distribution of stable-isotope values across ocean basins, in the mechanism of isotope fractionation in biological systems and how isotopic signatures vary temporally in relation to the body tissues in which they are expressed (Trueman et al., 2012). For example, muscle tissue is metabolically active and the time represented by any muscle sample can be difficult to estimate as they can reflect weeks or months of life. Incrementally growing hard tissue structures such as scales and otoliths provide an attractive solution to this problem (Trueman et al., 2012). Moreover, an isoscape map of predicted spatial variation in $\delta^{15}N$ has been produced for the North Sea, Irish Sea and English Channel which allowed a reduction in the uncertainties on the spatial distribution of the nitrogen isotope ratios of the bottom of the food web (Jennings and Warr, 2003).

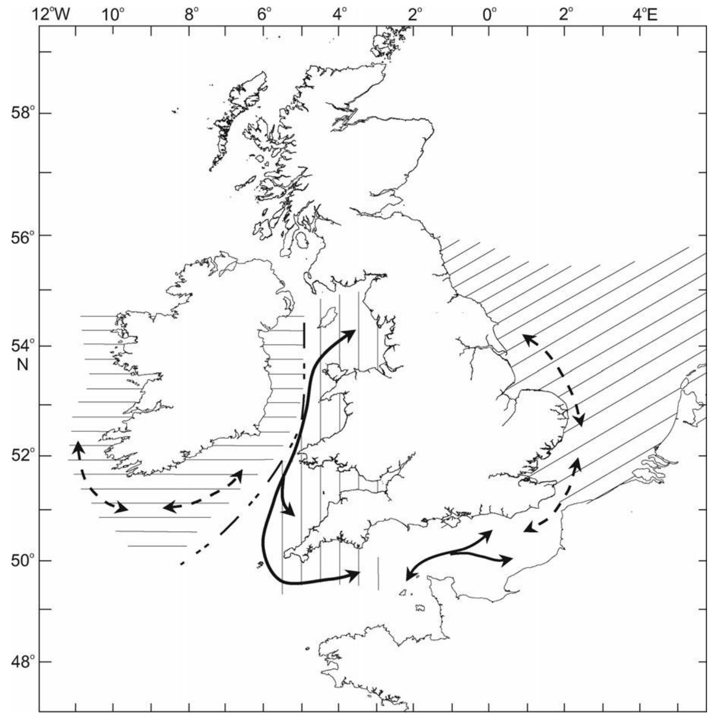


Figure 3.1 Main population movements and putative stock assessment units (hatched) for sea bass in ICES Subareas IV and VII (source: Pawson et al., 2007).

The aims of this study are: i) to identify the carbon and nitrogen isotope ratios of fish scales of adult bass caught around Wales and ii) to use the identified chemical tags to understand movements and connectivity between areas.

3.2. Materials and methods

- *Data collection and preparation of samples*

Scales from 189 adult bass were collected from a geographically diverse range of coastal areas in Wales (Figure 3.2), 101 during the feeding season (July-December 2013) and 88 during the spawning season (March-May 2014).

A typical bass scale consists of two portions: a hard upper layer composed of calcium phosphate (similar to the mineral apatite) overlying a poorly mineralised layer composed largely of collagen (Hutchinson and Trueman, 2006).

The collagenous layer grows by a process of underplating and for this reason only the most recent season of growth is characterised by younger collagen (Hutchinson and Trueman, 2006). Using the most recent season is the only way to provide an accurate isotope ratio that refers to the last season's growth. Although bass scales are relatively large, the last season is often thin (depending on the month of capture) and therefore several scales from each individual fish were used to gather enough material (0.6 mg) to be tested. A scalpel was used to trim the last season of growth from the top of the scale (Figure 3.3), the sample material was then weighed and placed into pre-weighed tin capsules. The samples were then sent to the British Geological Survey to be processed through a mass spectrometer.

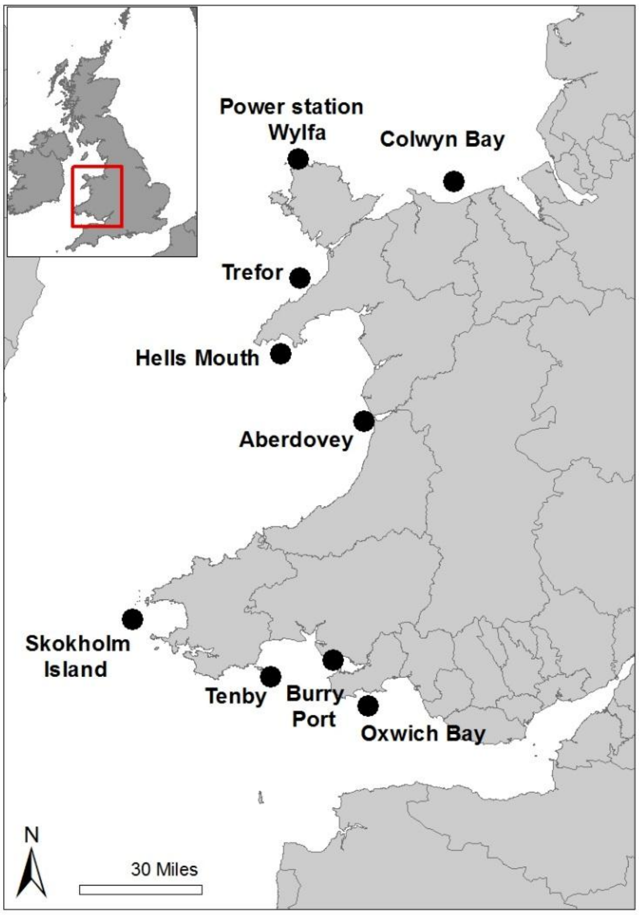


Figure 3.2. Map of Wales with the locations of bass caught and analysed for the carbon and nitrogen isotope ratios.

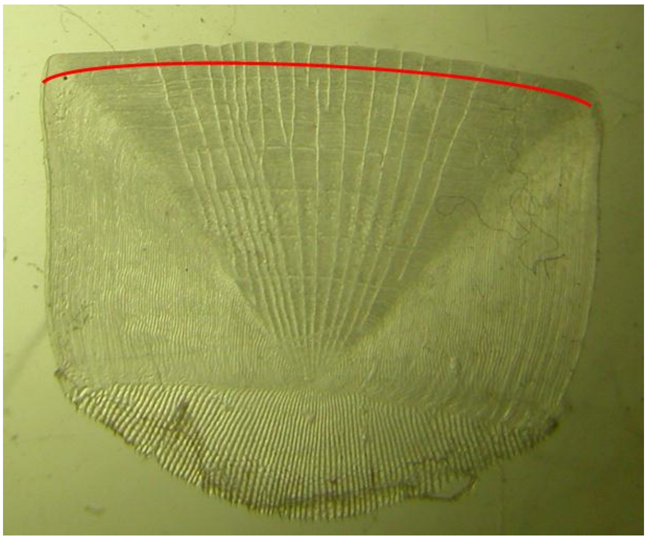


Figure 3.3. Scale of adult bass. The red line indicates the last growing season trimmed for the analysis.

- *Analysis*

We first estimated the intra fish variability to determine whether the use of a single sample per fish provides an accurate measurement of the isotopic signal. To this end, we tested seven fish. For each fish, we prepared three replicates of scales material (last growing season) of 0.6mg. A parametric repeated measures ANOVA was then applied to assess the presence of significant differences in the isotopic signal between samples.

Of the 189 fish analysed, statistical analysis was first restricted to fish with a similar size range, to remove the effect of the size in the variation of the $\delta^{15}N$ signal between individuals. The carbon and nitrogen isotope ratios of 156 bass between 40 and 50 cm length (98 caught during the feeding season and 58 during the spawning season) were then analysed.

To assess the possible differences in the isotopic signal between seasons (feeding season vs spawning season), bass from the same exactly location (Hells Mouth-Mid Wales, fish provided by the same fisher and caught in the same spot, n=30) were first compared through a one-way ANOVA in case of normal data and equal variance.

The nine different capture locations were first aggregated into three main groups: North, Mid and South Wales. A Random Forest Classification Model (R package "randomForest") was used to assess if the predictors $\delta^{15}N$ and $\delta^{13}C$ allowed for a correct classification of fish between North, Mid and South Wales.

Random forest analysis allows correlated predictor variables to be utilised without transformation or exclusion to obtain unbiased predictions and estimates of variable importance. The Random Forest model produces many classification trees. Each tree gives a classification and "votes" for that class (in our case location). Random forest analysis thus utilises an ensemble of classification to predict the dependent variable (in our case "location" of bass) as a result of majority vote or average assignment across trees (Strobl et al., 2007; Strobl et al., 2009).

By default, the Random Forest model partitions the data into training (generally 70% of data) and testing samples using random selection of cases from the data set. Whilst the training sample is used to build the model, the testing set is used to validate its performance.

The forest chooses the classification having the most votes (over all the trees in the forest). A sufficiently large number of trees (500) were used, the corresponding error was assessed and several different random seeds were tried to assure stability of results. Conditional variable importance was reported to show the relative contribution of each predictor variable ($\delta^{15}N$ and $\delta^{13}C$) to the classification performance. To evaluate the conditional variable importance we measured the Mean Decrease Accuracy (MDA) of the forest when the values of each predictor ($\delta^{13}C$ and $\delta^{15}N$) are randomly excluded (or permuted). The more the accuracy of the random forest decreases due to the exclusion (or permutation) of a single variable, the more important that variable is deemed, and therefore variables with a large mean decrease in accuracy are more important for classification of the data.

A conditional inference tree was finally used to identify the range of $\delta^{13}C$ and $\delta^{15}N$ values associated with each location. To this end, the "ctree" function for conditional inference trees in the party R package (Hothorn et al., 2006) was used.

We finally assessed the relationship between the average value of $\delta^{15}N$ by location estimated in this study and the values of predicted spatial variation in $\delta^{15}N$ baseline estimated from the isoscape map (Jennings and Warr, 2003).

3.3 Results

The repeated measures ANOVA showed that there was no significant difference between the three replicates of scales material for $\delta^{15}N$ ($F_{2,12}$=0.33, p=0.73) and $\delta^{13}C$ ($F_{2,12}$=1.14, p=0.35). This demonstrates that the use of a single sample per fish provides an accurate measurement of the isotopic signal.

No significant difference in the isotopic signal between feeding and spawning season was found for the fish sampled in Hells Mouth (North Wales) (One-way ANOVA, $F_{1,28}$=0.17 and p=0.68 for $\delta^{15}N$ and $F_{1,28}$=2.59 and p=0.12 for $\delta^{13}C$). This result suggests that adult bass caught in the same feeding areas exhibit similar isotopic signature even if caught at different times of the year.

The $\delta^{15}N$ vs $\delta^{13}C$ plots of the 101 bass caught during the feeding season and the 88 bass caught during the spawning season are presented in Figure 3.4 and 3.5, respectively. 28 bass caught in estuarine areas showed much lower $\delta^{13}C$ values than those caught in coastal areas (Figure 3.5). 28 bass had a total length >50 cm (thus outside the size range 40-50 cm) and were therefore removed from the dataset for the Random Forest classification analysis.

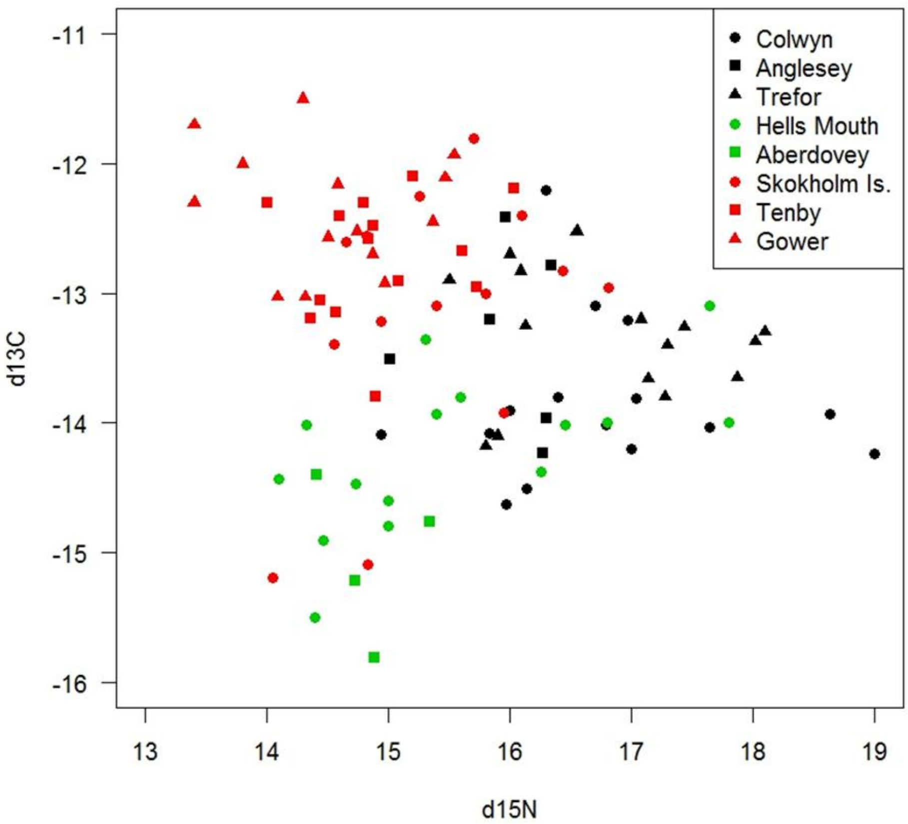


Figure 3.4. Combined δ^{13}C and δ^{15}N signatures of adult bass caught in eight different locations during the feeding season (July-December 2013). Red points, South Wales; green points, Mid Wales and black points, North Wales.

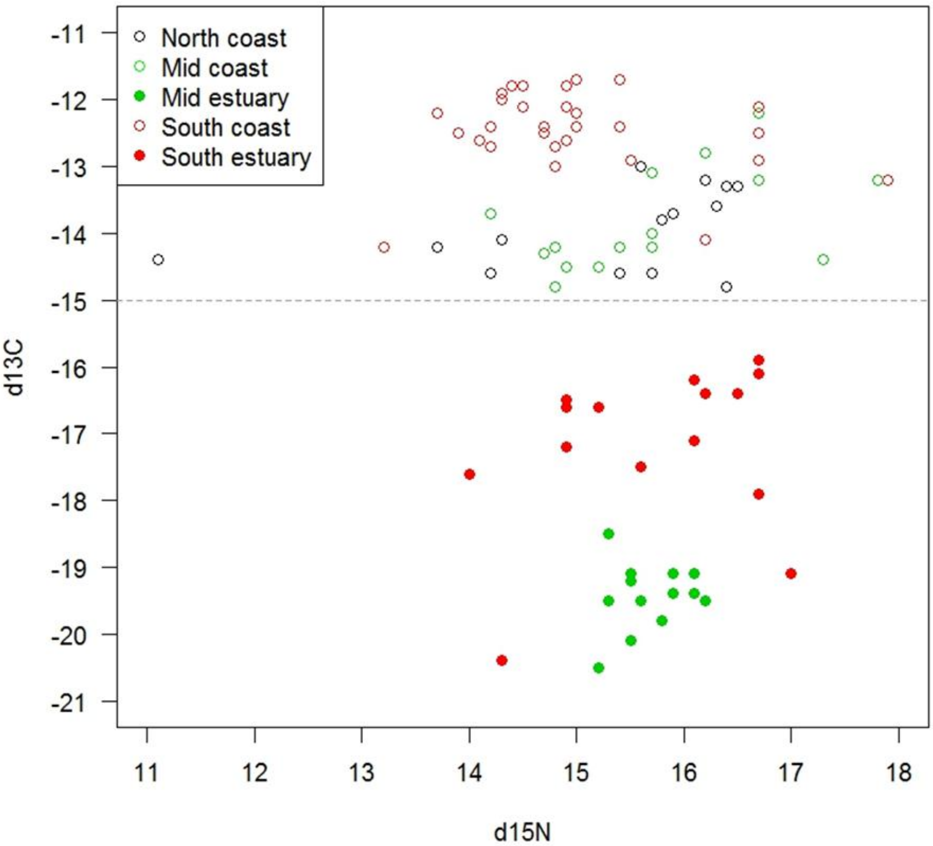


Figure 3.5. Combined $\delta^{13}C$ and $\delta^{15}N$ signatures of adult bass caught in coastal and estuarine areas during the spawning season (March-May 2014). Red points, South Wales; green points, Mid Wales and black points, North Wales. Closed red and green circles represent the isotopic signature of bass > 50 cm total length caught in estuarine areas.

After removing all bass outside the established size range of 40-50 cm length we plotted the $\delta^{15}N$ vs $\delta^{13}C$ values of the 156 bass analysed (Figure 3.6). The random forest classification model built on the training samples show a discrimination capacity of about 75%, which means that 75% of the fish caught were correctly classified between North, Mid and South Wales. For both training and testing data sets, the majority of the misclassifications of fish were fish from North Wales classifying to Mid Wales and vice versa, while the majority of fish from South Wales were correctly assigned (80%) (Table 3.1).

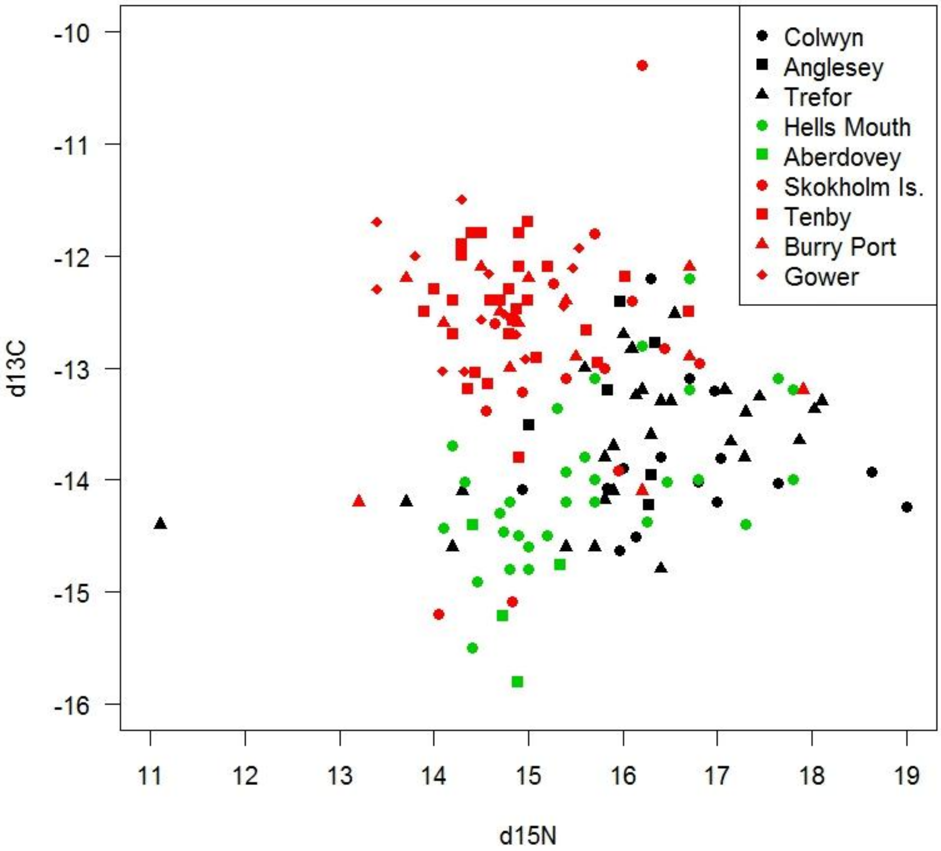


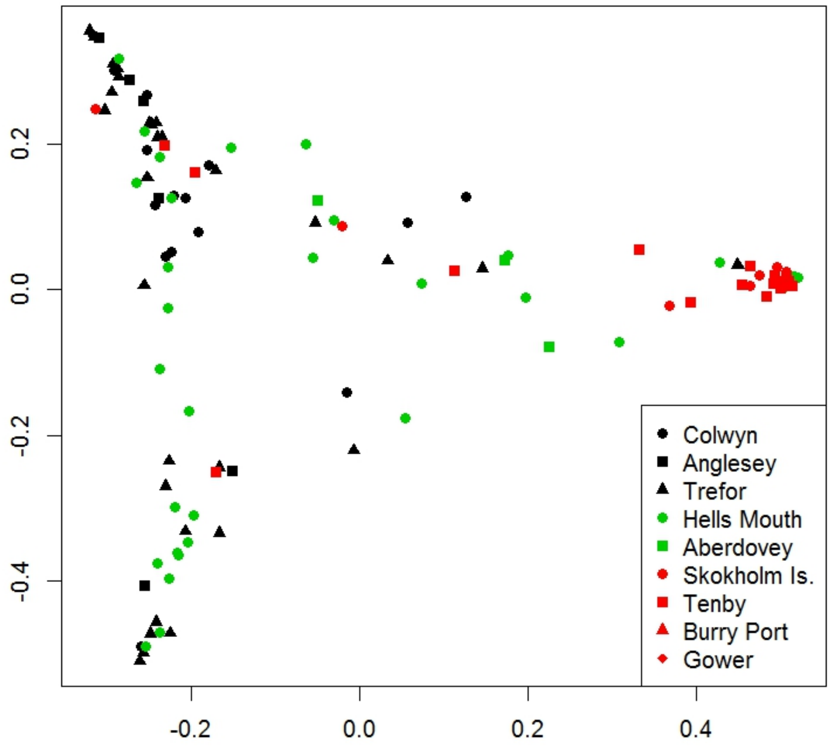
Figure 3.6 Combined $\delta^{13}C$ and $\delta^{15}N$ signatures of adult bass caught in nine different locations. Red points, South Wales; green points, Mid Wales and black points, North Wales.

Table 3.1. Predicted vs observed data from Random Forest Classification model for training and testing (cross-validation) data sets.

		Predicted							
		North		Mid		South		Error (%)	
		train	test	train	test	train	test	train	test
Observed	North	28	8	3	4	8	0	28.2	33
	Mid	8	1	18	4	2	1	35.7	33
	South	7	3	4	0	38	19	22.4	13.6

Points that in a large proportion of trees appear at the same terminal node are in some sense "close together", whereas points that rarely appear in the same terminal node are "far apart"[1]. A two-dimensional representation of the Random Forest analysis thus produces a plot in which the visual separation of the points reflects the accuracy with which the algorithm has been able to separate the points. The two dimensional representation of the Random Forest analysis also shows the degree of overlap of the isotopic signature between North (black points) and Mid (green points) Wales. Fish from South Wales (red points) appeared more separated from the rest (Figure 3.7). Moreover the few fish from South Wales misclassified corresponded to regions (Tenby and Skokholm Island) geographically closer to Mid Wales than the rest of the samples (Burry Port and Oxwich-Gower) (Figure 3.7).

As demonstrated from the error rate in relation to the number of trees used, the value of 500 trees appeared adequate to have reliable estimates (Figure 3.8).



[1] This is the motivation for subtracting the proximities from 1.0, and treating the values obtained as distances in Euclidean space.

Figure 3.7. Two-dimensional representation of the Random Forest analysis, showing the degree of separation between locations (black points, North Wales; green points, Mid wales; red points, South Wales) based on the isotopic signature of $\delta^{15}N$ and $\delta^{13}C$.

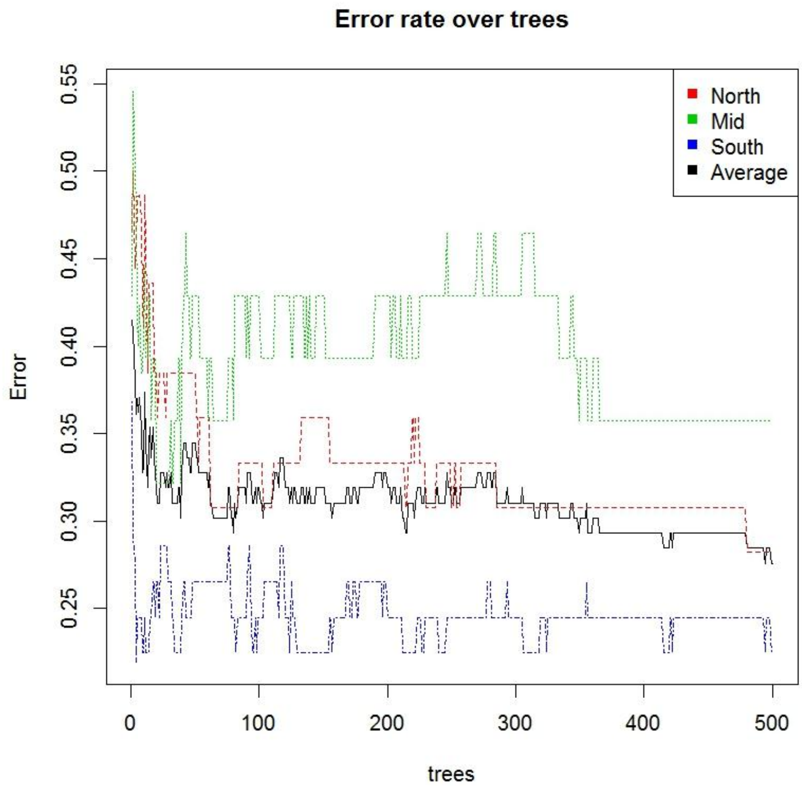


Figure 3.8. Error rate over trees showing that 500 trees is an adequate number to get reliable estimates from the predictions.

Mean Decrease Accuracy (MDA) of the forest shows that both variables ($\delta^{13}C$ and $\delta^{15}N$) were important for the classification process. On average, $\delta^{13}C$ seems slightly more important than $\delta^{15}N$ for classifying the data. However, a regional variation has been detected, with $\delta^{15}N$ more important for classifying fish in North Wales, $\delta^{13}C$ for Mid Wales and both for South Wales (but with higher importance of $\delta^{13}C$) (Table 3.2).

Table 3.2. Mean decrease accuracy of the random forest model associated to the removal of each predictor.

	North	Mid	South	Mean decrease accuracy
$\delta^{15}N$	33.20	5.98	21.53	31.36
$\delta^{13}C$	14.66	26.44	37.04	47.70

The conditional inference tree allowed the identification of the range of $\delta^{13}C$ and $\delta^{15}N$ values associated with each location (Figure 3.7). 100% of fish with $\delta^{13}C$ >-13.2 and $\delta^{15}N \leq 15.47$ were from South Wales. This specific signature characterised 68% of the total samples from South Wales (Figure 3.9).

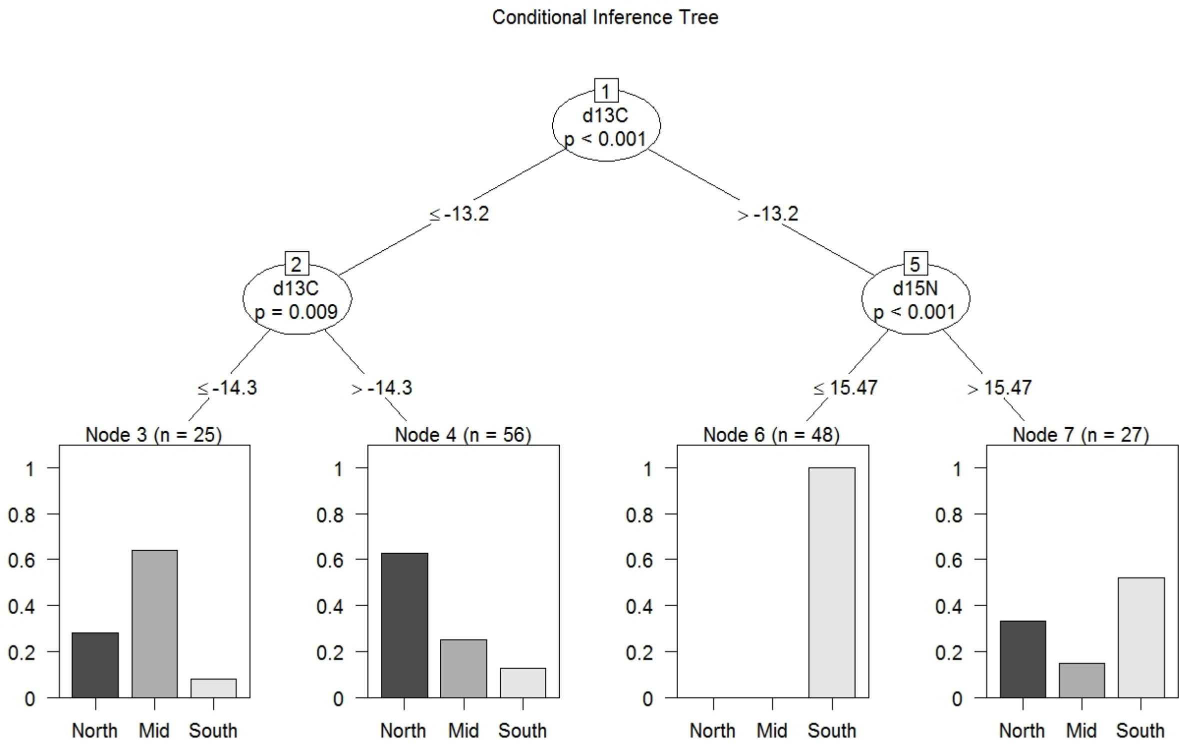


Figure 3.9. Conditional inference tree showing the isotopic signatures of the bass samples analysed.

The strong relationship between the average value of $\delta^{15}N$ by location estimated in this study and the corresponding value of the $\delta^{15}N$ baseline demonstrates that the spatial difference in the isotopic signature detected in this study are consistent with the spatial differences of the nitrogen isotope ratios of the bottom of the food web (Figure 3.10).

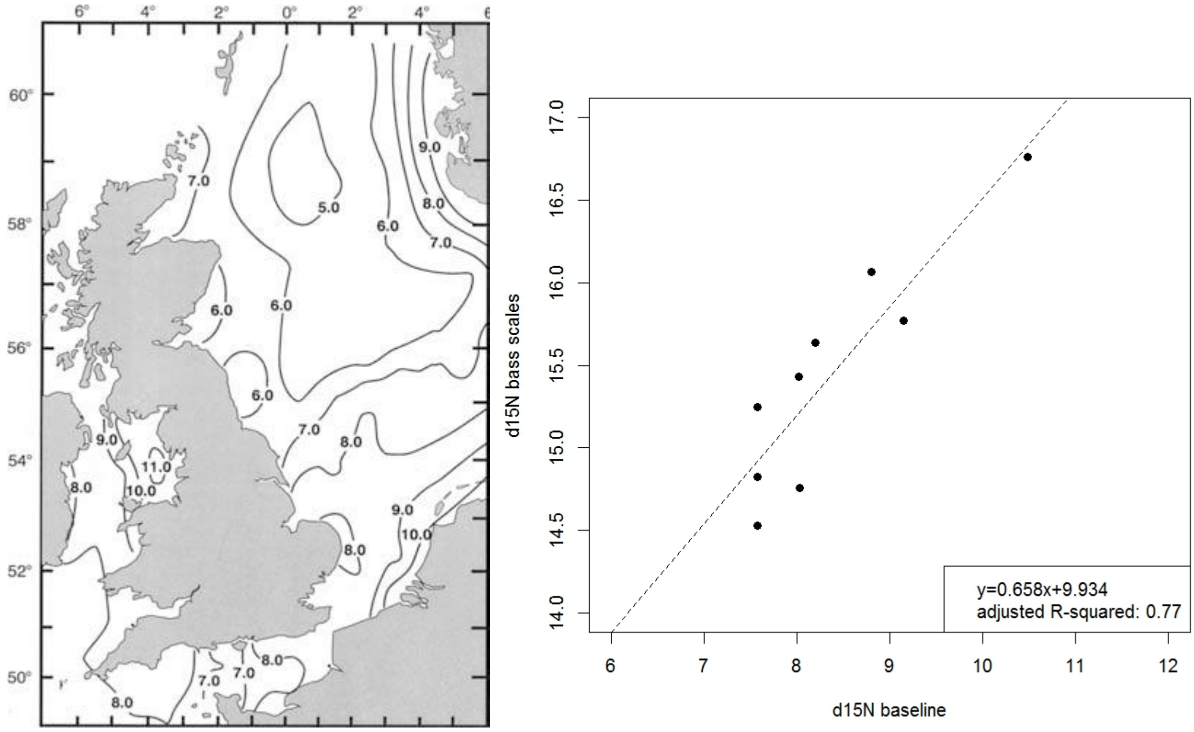


Figure 3.10. Left. Isoscape maps of the $\delta^{15}N$ baseline (Jennings and Warr, 2003). Right. Relationship between the average value of $\delta^{15}N$ by location estimated in this study and the value corresponding to the area from the isoscape map of predicted spatial variation in $\delta^{15}N$ baseline.

3.4 Discussion

The isotopic composition of carbon and nitrogen in tissue protein is controlled by the trophic level of the fish and the isotopic composition of primary production at the location occupied by the fish during tissue growth. The use of bass scales to infer movements through stable isotope analysis is therefore a valuable tool in understanding the ecology of the species.

Our results showed that stable isotopes analysis of fish scales represents a valid and cost effective technique to obtain insights on fish movement on a fine spatial scale (e.g. Welsh regional scale). The analysis of the $\delta^{13}C$ and $\delta^{15}N$ signatures in adult bass collected around Welsh waters showed the presence of connectivity between North and Mid Wales for feeding behaviour of adult bass, whilst fish from South Wales appeared more isolated and characterised by a very distinctive isotopic signature. This finding suggests the possible presence of two separated sub-populations of bass in Welsh waters with little mixing between bass in the south with those in mid and north Wales. This finding could also be translated into two possible different management units.

All fish with a total length >50 cm caught in estuarine areas showed a very low value of $\delta^{13}C$, indicating the primary use of estuaries as feeding areas. In fact, it is well known that differences exist between the carbon stable isotopic ratios ($^{13}C/^{12}C$) of freshwater and marine habitats with freshwater ecosystems generally ^{13}C-depleted relative to marine systems (Doucett et al., 1999).

It is possible that interspecific competition for resources has resulted in some big adult bass adopting an estuarine feeding habit. Our results thus suggest that a portion of the largest bass adopt estuaries as preferential feeding areas, which could therefore be characterised by higher protection levels, if protecting large bass (e.g. large spawners) is a management target. A more detailed investigation of the resource partitioning and feeding strategies of adult bass could provide a better picture in the future.

4. GEOGRAPHIC VARIATION IN THE SEX RATIO

4.1 Introduction

European sea bass are characterised by sexual growth dimorphism, where female mature at a greater size and age than males and they reach a bigger size (Chapter 1). The sex ratio of species characterised by sexual size dimorphism can be affected by a selective exploitation (e.g. gear size selectivity), which can cause a disproportionate removal of one sex than the other and ultimately lead to a reduction in population fecundity (Kendall & Quinn, 2013).

However, there is a wide variation in sex determination systems in fish, where sex can be determined by environmental factors (mainly temperature) as well as genetic factors or a combination of those (e.g. Baroiller et al., 2009). Therefore, skewed sex ratio can be the result of other factors than selective fishing pressure. In sea bass, temperature has been shown to be able to clearly influence sex ratios. The current hypothesis is that high temperatures early in development lead to decreased female rates (Piferrer et al., 2005).

In this chapter we analysed the regional differences in the sex ratio of bass caught with different gears and the possible management implications.

4.2. Materials and methods

A total of 113 samples, 52 with gillnet, 53 with line, 4 with trawl and 4 not identified were analysed. Each sample corresponded to the bass caught on a specific day, in a determined area and with a single gear as provided by fishers directly or collected from fish processors. Sex was determined for a total of 1147 fish; 640 females and 507 males.

Analysis of sex ratio (n. of males/(n. of males + n. of females)) was performed with a logistic regression model. This model allowed the inclusion of the sample size in the estimates and thus to weight the ratio of each sample by the corresponding size (total number of bass). The analysis thus involved a weighted regression using the individual sample sizes as weights and the logit link function to linearise the model, according to Wilson and Hardy (2002).

Location (North, Mid and South Wales), season (spring, summer, autumn and winter), gear (gillnet, line, trawl) and the interaction location*season were used as predictors of sex ratio in the model. A stepwise AIC (Akaike Information Criterion) method for variable selection was used to improve the model fit. In each step, one independent variable which was not significant in the start model was removed if the corresponding AIC was reduced. Dispersion parameter (φ) was calculated to assess the presence of possible over dispersion.

To assess the contribution of the different terms in the model a “termplot()” function was also used. This function gave a graphical summary useful in capturing the pattern of the model.

4.3 Results

Of the four predictors of sex ratio used in the model (location, season, gear, location*season), only location and season were significant. The independent variables that were not significant in the start model (gear and location*season) were removed, with a decrease in the AIC value from 418 to 416. The dispersion parameter was close to 1 (φ=1.7), so at first approximation data were not considered overdispersed.

The outputs of the model are shown in Table 4.1. The termplot graph showed the contributions of the individual linear terms (“effects") in the model (Figure 4.1)

Table 4.1 Estimated coefficients and significance level of categorical predictors (location, season) for the logistic regression model used to fit the data of sex ratio (lower sex ratio=more females).

Independent variables factors			Logistic regression model	
	reference level	other levels	estimates	p-value
location	South	North	-0.58	<0.0001
		Mid	-0.83	0.0004
	Mid	North	0.25	0.26
season	spring	summer	0.48	0.002
		autumn	0.46	0.006
		winter	-1.17	0.011
	summer	autumn	-0.02	0.88
		winter	-1.64	0.0003
	autumn	winter	-1.62	0.0003

A significant effect of the location and the season on the sex ratio was found. In particular the catches in North and Mid Wales were characterised by a significantly lower (more females) sex ratio than South Wales. Season also appeared to be a significant factor in determining the sex ratio of the catches. In particular, spring and winter were the seasons characterised by a significantly lower sex ratio than summer and autumn.

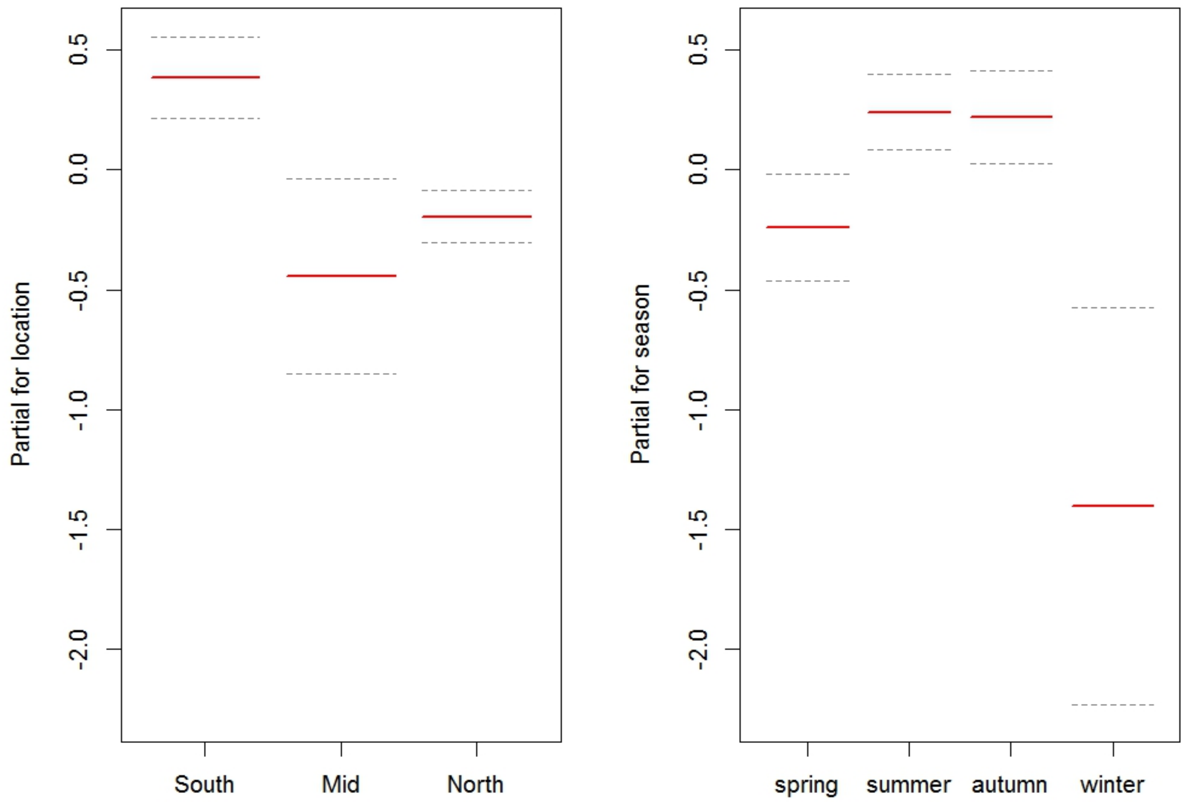


Figure 4.1. Termplot showing the contributions of the individual linear terms ("effects") in the model (red lines). The contributions of each term are shown after averaging over the contributions of all other terms. A relative lower value indicates more females. Grey dashed lines represent the SE.

The catches of bass in North Wales appeared to be female-skewed all year long, but with peaks in winter and spring. In North Wales, the peaks of males occurred during summer and autumn. In South Wales, the sex ratio appeared more balanced (50:50) during all seasons except winter, which was characterised by one single sample and thus not enough to give a representative picture (Figure 4.2).

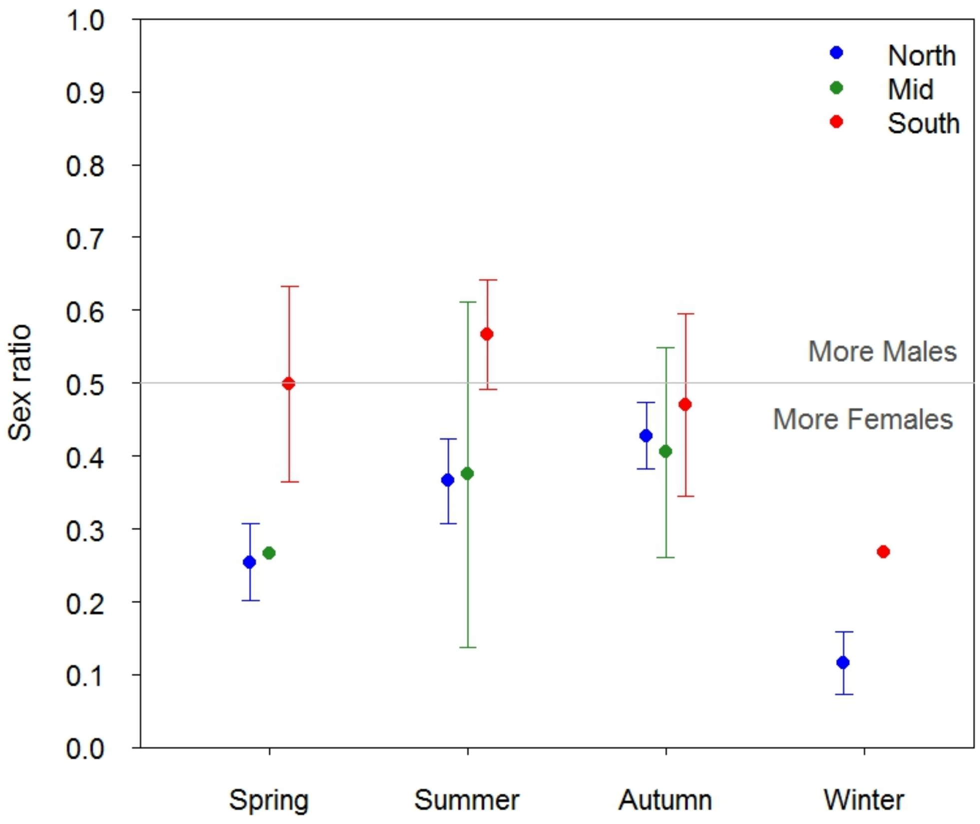


Figure 4.2. Plot of the average sex ratio (± SE) by area and season. No bass from Mid Wales were collected in winter.

4.4. Discussion

Skewed sex ratios have been observed by area and season. In North Wales the sex ratio was highly skewed in favour of females during all seasons. The catches in North and Mid Wales were characterised by a significantly lower sex ratio than South Wales. Season also appeared to be a significant factor in determining the sex ratio of the catches. In particular, spring and winter were the seasons characterised by a significantly lower sex ratio than summer and autumn. As fishery independent data on bass >25 cm were not collected, we are not able to assess if the skewed sex ratios found in the commercial capture of North Wales reflect the natural sex ratio of the stock in the area or if is the result of fisheries with harvesting biased towards females.

However, the fact that the covariate “gear” was not a significant factor in the model seems to suggest that the female-skewed sex ratio in the catches in North Wales was not related to a size selective fishery as it did not depend of any specific gear. Moreover, in North Wales samples came from 19 different locations, which appears to be a sufficiently large enough sample size to discard a possible bias related to the capture location (e.g. catches that come only from areas characterised by more females and not from areas where males are predominant).

As stressed in the introduction, temperature has been shown to be able to clearly influence sex ratios in sea bass. The current hypothesis is that high temperatures early in development lead to decreased female rates (Piferrer et al., 2005). In particular, exposure to low temperature starting at fertilization does not induce, but merely allow female development. In contrast, high temperatures masculinise, on average, over half of the females (Navarro-Martin et al., 2009). Therefore, it seems plausible that genetic variation and environmental influences on sex ratios could have reached different equilibrium states in the main wild sea bass populations (Vandeputte et al., 2012). Similar pattern has been observed in the Atlantic silverside, *Menidia menidia*, where the relative influence of genetics and temperature on sex ratios varies along a latitudinal gradient (Lagomarsino and Conover, 1993; Vandeputte et al., 2012).

The fact that variation in natural temperature may induce variations in sex ratios could explain the abundance of females in North Wales if the fish come from local spawning ground and thus the source of the higher female ratio would be related to local environmental conditions.

Regional variation in reproductive strategies of sea bass should be further investigated and fishery independent data should also been included in data collection to better assess the potential influence of fishery in the sex ratio. In the meantime if the protection of female bass (e.g. old female spawners) is a management target, a precautionary approach could be applied in North Wales with some fishing restrictions during winter and spring, when the proportion of females caught is higher.

5. RECRUITMENT PATTERNS

5.1 Introduction

Analysis of bass recruitment in ICES stock assessment indicates very weak 2008 and 2009 year classes (ICES, 2013). These year classes are now recruiting to the fishery at age 7 and 6 and the combination of declining recruitment and increasing fishing mortality is causing a rapid decline in the stock biomass and ICES has called for an 80% reduction in catches to turn the situation around.

Temperature is an essential parameter in determining abundance of recruits. An increase in temperatures from 1988–1990 coincided with strong 1989 year class, and several above-average year classes were formed from then until the mid-2000s whilst sea temperatures remained relatively high (ICES, 2013). Sea temperatures have declined in the last few years, and recruitment has also declined. In general, cold winters are considered to cause elevated mortality in 0-group and 1-group sea bass in UK estuaries.

The presence of 0-group bass has been confirmed in seven Welsh estuarine areas (Kelley, 1986) and other coastal areas in South Wales (Lancaster et al., 1998). After hatching, bass larvae tend to occur in the upper part of the water column, and the arrival of post-larval bass into sheltered bays, harbours and estuaries along the South Wales coast usually occurs during spring tides in late June (Jennings, 1990; Jennings and Pawson, 1992).

A recruitment index is an essential indicator to assess the state of the stock and is needed covering the main nursery areas over the full geographic range of the stock. Currently, recruitment indices of 0-group bass are not available and the recent assessment has been based on data of 1-group bass with the last samples collected in 2011 (ICES, 2013).

In this last chapter we provide the recruitment index of 0-group bass around Welsh waters, the length frequency distribution of the recruits over summer-early autumn and the species composition of the estuarine areas sampled.

5.2 Materials and methods

Data on 0-group bass were collected during the period of July-October 2013 and 2014 around nine Welsh coastal areas (Table 5.1 and Figure 5.1). To collect bass recruits a seine net with a 4 mm mesh size and 10 m long was used in 2013 and a seine net with a 4 mm mesh size and 6 m long was used in 2014 (the reduction of the net was necessary for a better handling of the net in the estuaries). The selected areas corresponded to those identified in Kelley (1986) and Lancaster et al. (1998). Only Conwy and Malltraeth were areas without historical data on bass recruits, but they were identified as suitable locations to support early life stages (Kelley, 1986). Netting operations were conducted according to the guidelines for beach-seine surveys of 0-group bass (Armstrong, 2010).

Sampling was undertaken once a month, from July to October 2013 and 2014. A recruitment index was estimated for each location, in terms of number of bass/100 m^2. Area was calculated by measuring the distance covered with the net and then multiplying it by 2/3 the length of the net (considering the curve described by the net during the tow).

During each sampling, catch species composition (in weight) was first recorded and then bass were measured and weighed. A total of 759 bass recruits were measured, 55 during 2013 and 704 during 2014.

To study the size frequency distribution, we applied the Kernel Density Estimation (KDE) approach, using the Gaussian weight function. This technique overcomes the discreteness of the histogram approaches by centring a smooth kernel function at each data point then summing to obtain a density estimate. Kernel density estimates provide a data-driven method for approximating length-frequency data with probability density functions (Sheather and Jones, 1991). Sanvicente-Añorve et al. (2003) first presented the use of KDEs to identify modes in length-frequency distributions and to examine their change over time. Moreover, KDEs are valuable tools in length frequency analysis and related methods such as modal progression analysis. Finally, bass growth rate (mm $month^{-1}$) was calculated by area.

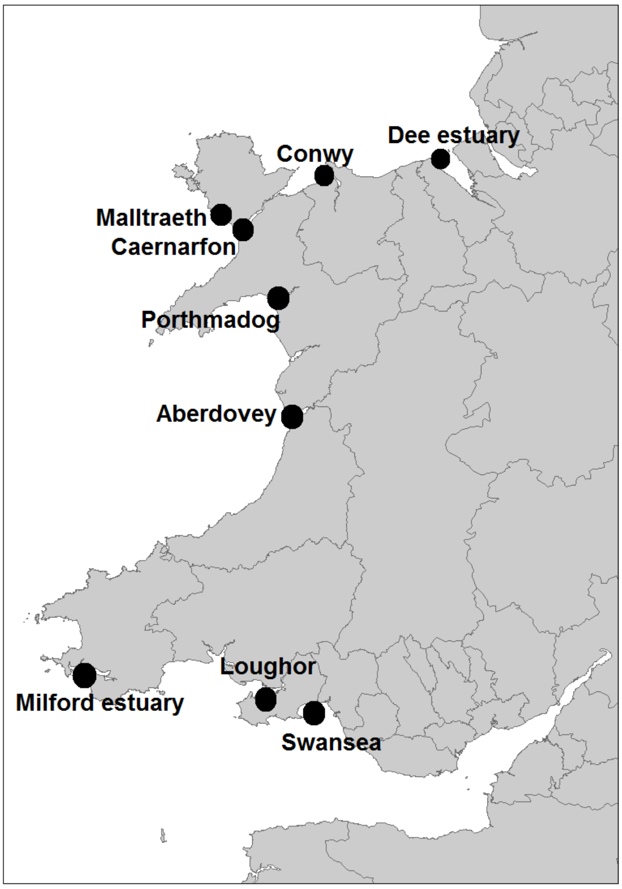


Figure 5.1. Locations of the nine estuarine areas sampled to collect bass recruits during 2013 and 2014.

Table 5.1. Latitude and longitude of the sampling areas.

Location	Latitude	Longitude
Dee estuary	53.346230	-3.310177
Conwy	53.278216	-3.820759
Malltraeth	53.191510	-4.385533
Caernarfon	53.105439	-4.311485
Porthmadog	52.920903	-4.080825
Aberdovey	52.526344	-4.041289
Milford estuary	51.723197	-5.164621
Loughor	51.664593	-4.075932
Swansea	51.597183	-3.992055

5.3 Results

A total of 1113 0-group bass were caught during the two years survey, 52 during 2013 and 1061 during 2014. Catch species composition in terms of % in weight was estimated for both years for North (Figure 5.2), Mid (Figure 5.3) and South Wales (Figure 5.4).

Gobies (*Pomatoschistus microps*), sand eels (*Ammodytes tobianus*) and Clupeidae (herring and/or sprats) were the most representative species in North Wales (Figure 5.2). Bass was only present in the Dee estuary and Caernarfon in 2014.

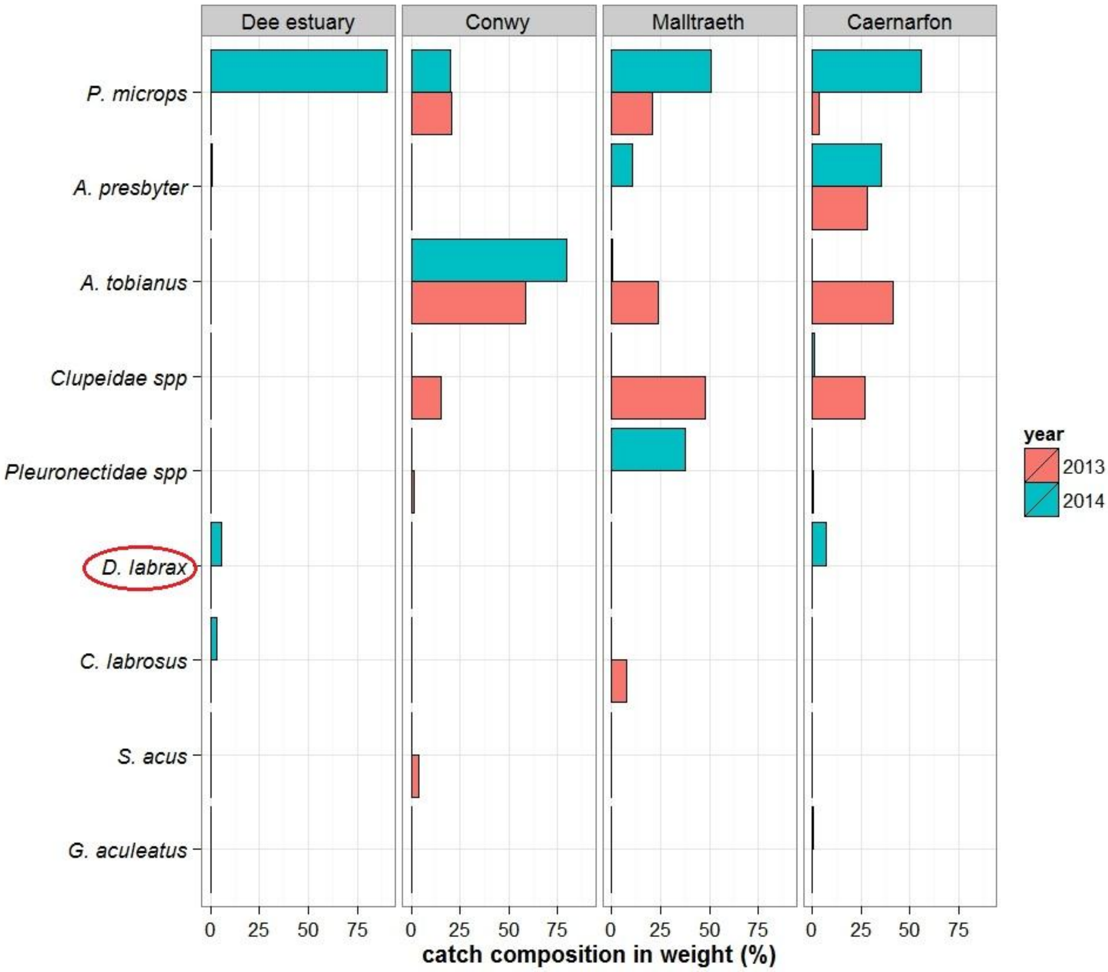


Figure 5.2. Catch species composition in weight obtained from seine netting in the Dee estuary, Conwy, Malltraeth and Caernarfon during July-October 2013 and 2014. Red circle: bass (*Dicentrarchus labrax*).

In Mid Wales, gobies and sand smelt (*Atherina presbyter*) were the most frequent species encountered in samples. Bass was present in Porthmadog only during 2014 and in Aberdovey in both years, but in very small quantities (Figure 5.3).

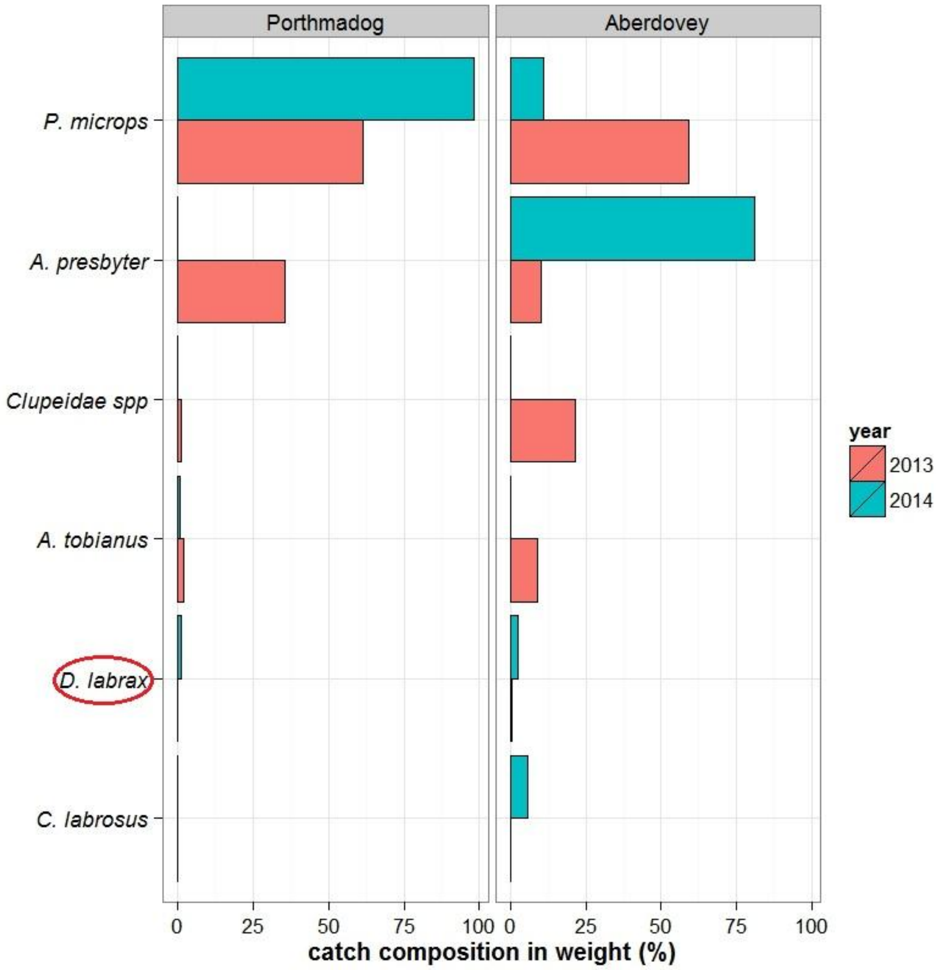


Figure 5.3. Catch species composition in weight obtained from seine netting in Porthmadog, and Aberdovey during July-October 2013 and 2014. Red circle: bass (*Dicentrarchus labrax*)

Finally in South Wales, gobies and sand eels were the most common species followed by bass, particularly during 2014 (Figure 5.4). South Wales thus appeared the area where bass recruits were more abundant (Table 5.1).

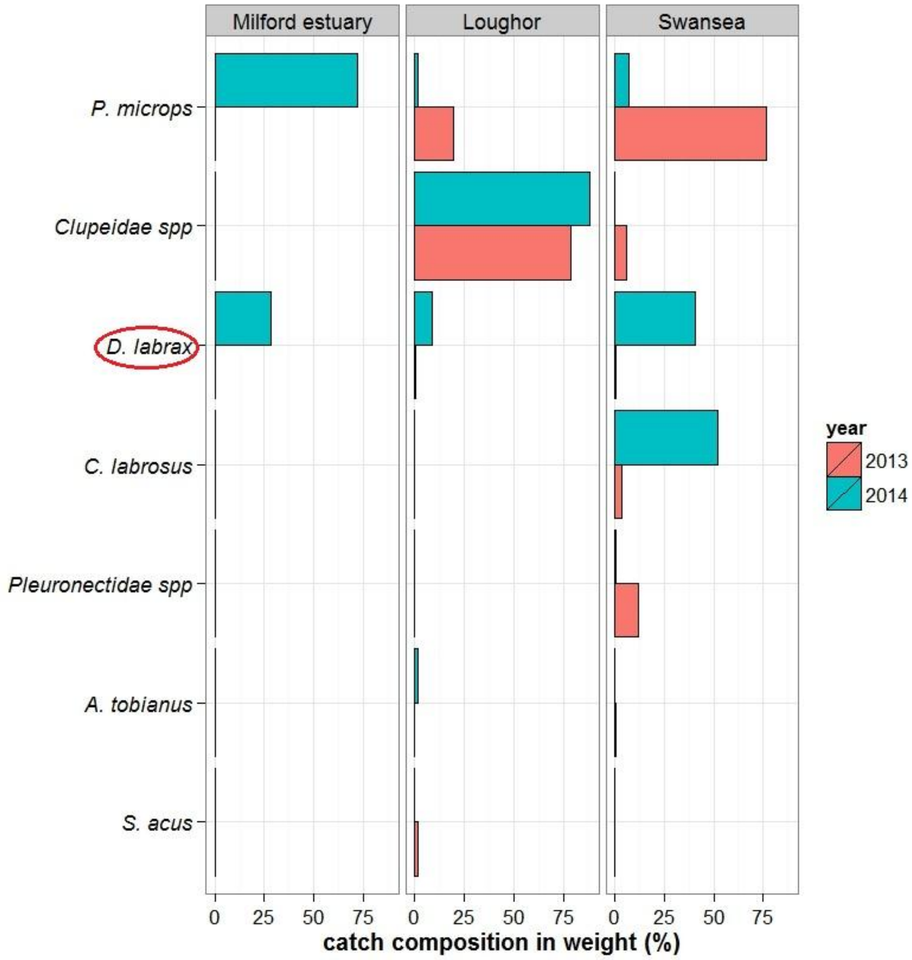


Figure 5.4. Catch species composition in weight obtained from seine netting in Milford estuary, Loughor and Swansea during July-October 2013 and 2014. Red circle: bass (*Dicentrarchus labrax*).

Table 5.1. Total number and relative abundance of bass recruits (0-group) caught with a micromesh seine net along nine coastal areas. Highest recruitment indices are in red.

Area	Sampling site	n. of netting operations		n. of 0-group bass		Recruitment index (0-group bass/100 m^2)	
		2013	2014	2013	2014	2013	2014
North	Dee estuary	0	9	-	79	-	12.09
	Conwy	3	6	0	0	0	0
	Malltraeth	2	12	0	1	0	0.11
	Caernarfon	4	15	0	36	0	3.37
Mid	Porthmadog	4	6	0	92	0	20.18
	Aberdovey	9	9	1	11	0.08	1.61
South	Milford estuary	1	9	0	223	0	31.84
	Loughor	11	12	9	303	0.27	27.40
	Swansea	14	14	42	316	2.43	31.27
total		48	92	52	1061		

A bimodal pulse of newly-settled recruits in South and North Wales was detected through the length frequency data (Figure 5.5). During 2014, South Wales was characterised by the widest size range, also due to higher number of bass recruits collected than the rest of Wales.

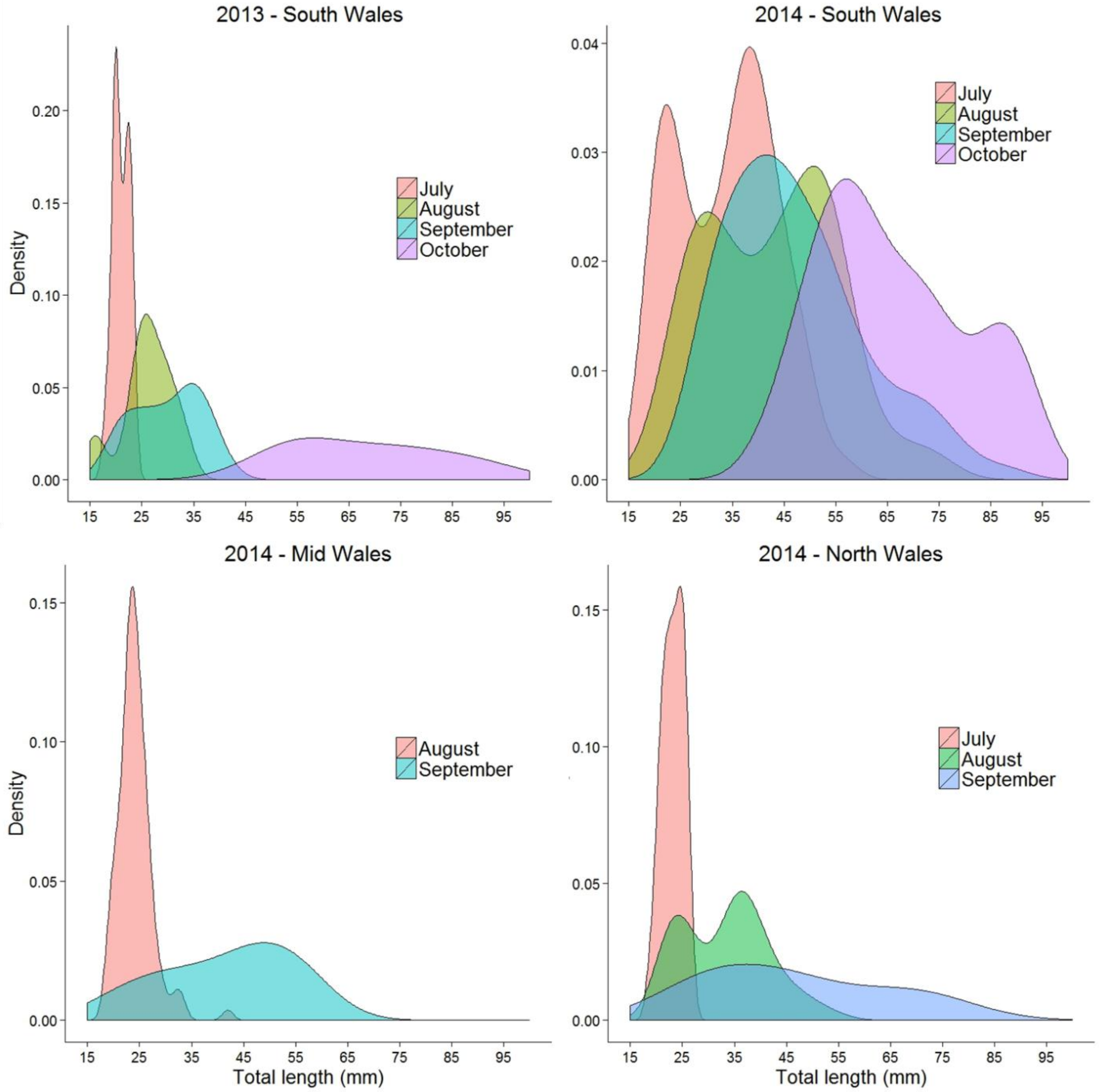


Figure 5.5. Kernel density estimates of the length frequency data of bass recruits (0-group) caught in North, Mid and South Wales during 2013 and 2014.

Bass growth rate (mm month^{-1}) was calculated by area and month (Figure 5.6). On average the size of recruits in South Wales was bigger than North and Mid Wales during July and August, while in September the sizes were similar between the three areas.

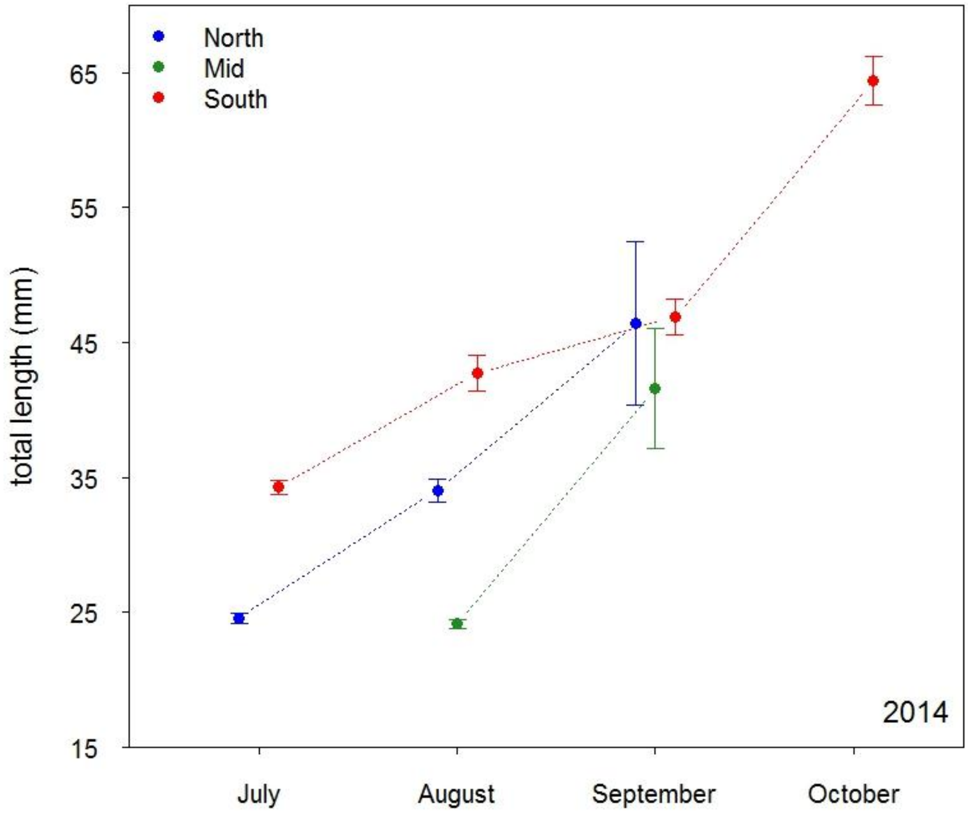


Figure 5.6. Average total length (± SE) of bass recruits by area and month during 2014.

Comparisons between the two consecutive years was possible only for South Wales (Figure 5.7). Bass recruits in 2014 were much bigger than 2013 during July, August and September. However in October sizes were similar between the two years.

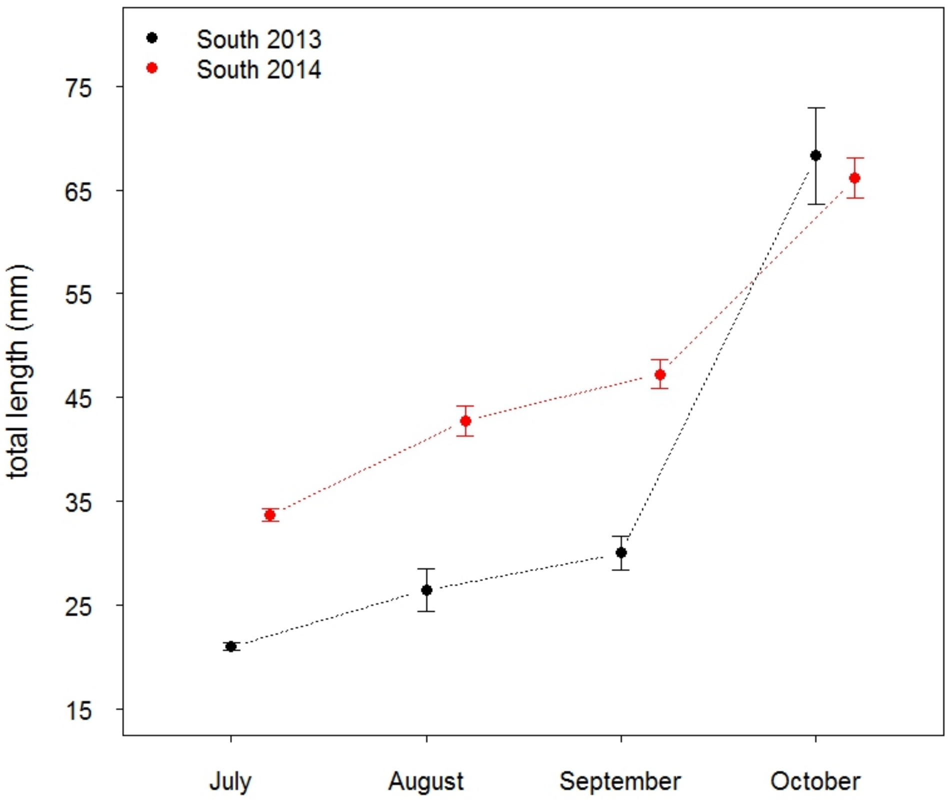


Figure 5.6. Average total length (± SE) of bass recruits by month during 2013 and 2014 in South Wales.

5.4 Discussion

The abundance of 0-group bass recruits (recruitment index) was calculated for 2013 and 2014 around the Welsh coastline. The abundance of recruits is highly dependent on the temperature, which may explain the poor recruitment after the cold spring of 2013. The higher temperature in 2014 allowed the main settlement areas around Wales to be identified with more confidence.

Kelley (1988) classified the strength of recruitment as “weak”, “moderate”, “strong” and “very strong” depending on the number of recruits per m^2. Considering this classification, the recruitment indices in 2013 should be classified as “weak” in all three areas where recruits were found (Swansea, Loughor and Aberdovey). The recruitments indices in 2014 would be classified as “moderate” for Swansea, Loughor, Milford estuary, Porthmadog and Dee estuary and “weak” for Aberdovey, Caernarfon and Malltraeth. Therefore, even if 2014 was a better year for recruitment than 2013, it cannot be defined as a “strong” or “very strong” year, at least compared with the classification used in the 1980s.

Temperature also influences the growth rate, which could explain the differences in length frequency between 2013 and 2014 in South Wales. However, besides the differences in the average length for July, August and September, the average length in October was similar between the two consecutive years, due to the higher growth rate of recruits between September and October of 2014 with respect to the previous year and, possibly, to the death of the smallest recruits at the beginning of autumn 2013.

Growth rate can be highly different not only between years but also between regions, depending on local conditions of temperature, food availability and bass density. The initial differences in length frequency during July 2014 between the three Welsh areas may be related not only to local differences in temperature and food availability, but above all, to different times in recruits settlement and, ultimately, to the proximity with the spawning grounds, to the spawning time and to the local oceanographic conditions.

A bimodal pulse of newly-settled recruits in South and North Wales was detected through the length distribution of the recruits during the summer. This shows the presence of protracted spawning and possibly late season pulses in spawning.

South Wales and in particular the Milford estuary, Swansea Bay (Blackpill), and Loughor appeared to be the most important areas for 0-group settlement. However, data shows the presence of bass recruits in Mid (e.g. Porthmadog) and North Wales (e.g. Dee estuary). This finding could be related to the presence of local spawning grounds in Mid and North Wales, a finding that should be further investigated due to the important management implications that could result.

GENERAL DISCUSSION

The present study represents the most comprehensive data collection and analysis of bass population in Wales and offers insights on local characteristics of the stock and possible management measures.

Whilst most of the life history parameters are consistent with those estimated for the general stock unit of ICES Divisions VIIafg (ICES, 2013), the size at maturity of female bass appeared significantly lower than the ICES estimate. The decline in the current size at maturity compared to previously published studies (e.g. Pawson and Pickett, 1996) could indicate potential compensatory effects in this life history parameter in response to over-exploitation (Jennings & Kaiser, 1998) or it could be an environmentally driven difference confined to Welsh waters c.f. the much wider ICES statistical areas. On the other hand, if an increase in MLS is a management objective aimed to ensure mature females spawn at least once, a 40 cm MLS could be a first target, as it would allow 82% of the females to spawn at least once before capture.

With a 40 cm MLS, in the short term fishers using gillnets will lose 11.6% of their catches, with peaks in summer and autumn (19.8% and 14.5%, respectively). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 14.8% of their catches with peaks in summer and autumn (19.9% and 18.5%, respectively). If MLS would increase to 42 cm, the short-term losses of fishers will be much higher. In this case the annual loss for fishers using gillnets will be 22.3% of the catches in terms of number of fish. However, their losses will be different by season, with peaks in summer (40.7%) and autumn (30.9%). Fishers using line (rod and line and/or longline) will lose, on a yearly basis, 28.1% of their catches. Also, in this case, their losses will be different by season, with peaks in summer (37.1%) and autumn (35.8%). Regional differences in catch losses will also occur (47.2% in North and Mid Wales and 29% in South Wales).

All estimated catch losses will occur in the short-term after implementation of a new MLS and loss of catches should decrease over time. In particular, we estimated that the increase of the MLS to 40 cm could result in a decrease of 17% of the total number of bass caught one year after implementation (the time required for fish to grow from 36 to 40 cm), whilst no difference is expected in terms of biomass. The increase of the MLS from 36 to 42 cm would cause a decrease of 25% of the total number of bass one year and half after the implementation (the time required for fish to grow from 36 to 42 cm), whilst no difference is expected in terms of biomass. However, the model used for these estimates could be biased and the figure presented should be considered only as a general trend.

Specific features of the bass stock and fisheries have been detected for Wales and could be taken into account for management purposes. In North Wales, sex ratio was highly skewed in favour of females during all seasons. As fishery independent data on bass >25 cm were not collected, we are not able to assess if the skewed sex ratios found in the commercial capture of North Wales reflect the natural sex ratio of the stock in the area or if it is the result of fisheries with harvesting biased towards females. Protection of bass females could be focused on the big old fat fecund female fish (hereafter, "BOFFFFs"), which contribute disproportionally to stock productivity, as they invest larger proportion of their energy in reproduction. Moreover it has been demonstrated that, for many species, large old females fish not only produce more eggs than smaller females but also produce higher quality eggs and larvae grow faster and can resist to starvation (e.g. Hixon et al., 2013).

The fact that variation in natural temperature may induce variations in sex ratio could explain the abundance of females in North Wales if the fish come from local spawning ground and thus the source of the higher female ratio would be linked to local environmental conditions.

Regional variation in reproductive strategies of sea bass should be further investigated and fishery independent data should also been included in data collection to better assess the potential influence of the fishery in the sex ratio. In the meantime, if the protection of female bass (e.g. old female spawners) is a management target, a precautionary approach could be applied in North Wales with some fishing restrictions during winter and spring, when the proportion of females caught is higher.

The spawning season of bass around Welsh waters has been estimated to be between January and May. All five months should therefore be considered if the aim is to protect bass during the entire spawning period. However, in the long term, the reduction of the fishing mortality (F) could be a better target than the spawning closures.

In terms of recruitment, even if 2014 was a better year for recruitment than 2013, it cannot be defined as a strong or very strong year, at least compared with the classification used in the 80's. In the future, a time series of recruitment of 0-group bass should be built and a prediction model of recruitment strength in relation with temperature should be provided.

Bass recruits (0-group) have been found not only in South Wales, but also in Mid and North Wales. This finding could be related to the presence of local spawning grounds in Mid and North Wales, a finding that should be further investigated for the important management implications that could result.

The analysis of the $\delta^{13}C$ and $\delta^{15}N$ signatures in adult bass collected around Welsh waters showed the presence of connectivity between North and Mid Wales for feeding behaviour of adult bass whilst fish from South Wales appeared more isolated and characterised by a very distinctive isotopic signature. This finding suggests the possible presence of two separated sub-populations of bass in Welsh waters with little mixing between bass in the south with those in mid and north Wales. This aspect could also be translated into two possible different management units.

Stable isotopes analysis also suggested that a portion of the largest bass adopt estuaries as preferential feeding areas, which could therefore be characterised by higher protection levels, if protecting large bass (e.g. large spawners) is a management target. Large bass spawners produce large numbers of eggs, as suggested by the analysis of the gonad somatic index. This result highlights the desirability to protect large spawners, not only by increasing the protection levels in the estuaries during the feeding season, but also by implementing a possible maximum landing size.

Acknowledgement

This study would not have been possible without the support of many people. A special thanks to the fishers involved in data collection for investing their time and for their essential feedback. Many thanks to all the staff of the fish processors involved, particularly Mermaid Seafoods in Llandudno and Welsh Seafoods in Milford Haven, for being so kind and so helpful with our data collection. Thanks to Andrew Marriott for sharing the methodology of preparing and trimming scales and to the British Geological Survey, particularly Sarah Bennet and Melanie Leng, for rapidly running all our samples. Thanks to Hilmar Hinz for his help during the initial phase of this work. Special thanks to John Lancaster for teaching us everything related to bass recruits and for sharing his experience and his inspirational point of view. Thanks to Phil Coates for the support during the initial phases of this work and to Phil Marshall and Phil Wensley for their help in data collection of bass recruits. Thanks to the staff in Nuffield Lab and to all the research assistants, internship students and volunteers that helped during the last two and half year, and in particular: Jennifer Fox, Thomas Busbridge, Thomas Overy, Abigail Carrol, Anna Selbmann, Charlie Key, Aymeric Richard and Jordan McDermott.

References

Armstrong M. 2010. Guidelines for beach-seine surveys of 0-gp and 1-gp bass *(Dicentrarchus labrax*) in UK nursery grounds. Cefas document. 11p

Baroiller J.F., D'Cotta H., Saillant E. 2009. Environmental effects on fish sex determination and differentiation. Sexual Development 3: 118–135.

Block B. A., Jonsen I. D., Jorgensen S. J., Winship A. J., Shaffer S. A., Bograd S. J., Hazen E. L., Foley,D. G., Breed G. A., Harrison A. L., Ganong J. E., Swithenbank A., Castleton M., Dewar H., Mate B. R., Shillinger G. L., Schaefer K. M., Benson S. R., Weise M. J., Henry R. W., Costa D. P. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature 475: 86–90.

Dando P.R., Demir N. (1985) On the spawning grounds and nursery grounds of bass, *Dicentrarchus labrax*, in the Plymouth area. Journal of the Marine Biological Association of the United Kingdom 65:159–168.

Doucett R.R., Hooper W., Power G. 1999. Identification of anadromous and nonanadromous adult brook trout and their progeny in the Tabusintac River, New Brunswick, by means of multiple-stable-isotope analysis. Transactions of the American Fisheries Society 128: 278–288.

Fritsch M. 2005. Traits biologiques et exploitation du bar commun *Dicentrarchus labrax* (L.) dans les pêcheries françaises de la Manche et du Golfe de Gascogne. Mémoire de thèse, Ifremer, 314pp.

Fritsch M., Morizur Y., Lambert E., Bonhomme F., Guinand B. 2007. Assessment of sea bass (*Dicentrarchus labrax*, L.) stock delimitation in the Bay. Fisheries Research 83: 123-132.

Hixon M.A., Johnson D.W., Sogard S.M. 2014. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES Journal of Marine Science 71:2171-2185

Hosmer D.W., Hosmer T., Le Cessie S., Lemeshow S. 1997. A comparison of goodness-of-fit tests for the logistic regression model. Statistics in Medicine 16: 965–980.

Hosmer D.W., Lemeshow S. 2000. Applied Logistic Regression. 2nd edn. John Wiley & Sons: New York.

Hothorn T., Hornik K., Zeileis A. 2006. Unbiased Recursive Partitioning: A Conditional Inference Framework. Journal of Computational and Graphical Statistics 15: 651–674.

Hutchinson J. J., Trueman C.N. 2006. Stable isotope analyses of collagen in fish scales: limitations set by scale architecture. Journal of Fish Biology 69: 1874–1880.

ICES. 2012. Report of the Working Group on Assessment of New MoU Species (WGNEW), 5–9 March 2012, ICES CM 2012/ACOM:20. 258 pp.

ICES. 2013. Report of the Working Group for Celtic Seas Ecoregion (WGCSE), 8–17 May 2013, Copenhagen, Denmark. ICES CM 2013/ACOM.

Jennings, S. 1990. Population dynamics of larval and juvenile bass *Dicentrarchus labrax* (L.). Ph.D. thesis, University of Wales, 266 pp.

Jennings S., Kaiser M.J. 1998. The effects of fishing on marine ecosystems. Advances in Marine Biology 34: 201-352.

Jennings S., Pawson M. G. 1992. The origin and recruitment of bass, *Dicentrarchus labrax*, larvae to nursery areas. Journal of the Marine Biological Association of the United Kingdom 72: 199-212.

Jennings S., Warr K.J. 2003. Environmental correlates of large-scale spatial variation in the $\delta^{15}N$ of marine animals. Marine Biology 142: 1131–1140.

Jímenez-Valverde A., Lobo J.M. 2006. The ghost of unbalanced species distribution data in geographical model predictions. Diversity and Distributions 12: 521–524.

Kelley D.F. 1986. Bass nurseries on the west coast of the U.K. Journal of the Marine Biological Association of the United Kingdom 66: 439-464.

Kelley D.F. 1988. The importance of estuaries for sea-bass *Dicentrarchus Labrax* (L.). Journal of Fish Biology 33 (Suppl. A): 25–33.

Kendall N.W., Quinn T.P. 2013. Size-selective fishing affects sex ratios and the opportunity for sexual selection in Alaskan sockeye salmon *Oncorhynchus nerka*. Oikos122: 411–420.

Kennedy M., Fitzmaurice P. 1972. The biology of the bass, *Dicentrarchus labrax*, in Irish waters. Journal of the Marine Biological Association of the United Kingdom 52: 557–597.

Lagomarsino I.V., Conover D.O. 1993. Variation in environmental and genotypic sex-determining mechanisms across a latitudinal gradient in the fish, *Menidia menidia*. Evolution 47: 487–494.

Lancaster J.E., Pawson M.G., Pickett G.D., Jennings S. 1998. The Impact of the "Sea Empress" oil spill on seabass recruitment. Marine Pollution Bulletin 36: 677-688.

Mayr E. 1963. Animal Species and Evolution. Belknap Press of Harvard University Press, Cambridge, MA, pp797.

Navarro-Martin L., Blazquez M., Vinas J., Joly S., Piferrer F. 2009. Balancing the effects of rearing at low temperature during early development on sex ratios, growth and maturation in the European sea bass (*Dicentrarchus labrax*): Limitations and opportunities for the production of highly female-biased stocks. Aquaculture 296: 347–358.

Ogle D.H. 2009. Data to support Fish Stock Assessment package: Package FSA. GPL version 2 or newer URL (www.rforge.net/FSA, www.ncfaculty.net/dogle).

Pawson M.G., Brown M., Leballeur J., Pickett G.D. 2008. Will philopatry in sea bass, *Dicentrarchus labrax,* facilitate the use of catch-restricted areas for management of recreational fisheries? Fisheries Research 93: 240–243.

Pawson M.G., Pickett G.D. 1987. The bass (*Dicentrarchus labrax*) and management of its fishery in England and Wales. MAFF Direct Fish Res, Lowestoft (59), 37pp.

Pawson M.G., Pickett G.D. 1996. The annual pattern of condition and maturity in bass (*Dicentrarchus labrax* L) in waters around the UK. Journal of the Marine Biological Association of the United Kingdom 76: 107-126.

Pawson M.G., Pickett G.D., Leballeur J., Brown M., Fritsch M., 2007. Migrations, fishery interactions and management units of sea bass (*Dicentrarchus labrax*) in Northwest Europe. ICES Journal of Marine Science 64: 332–345.

Piferrer F., Blazquez M., Navarro L., Gonzalez A. 2005. Genetic, endocrine, and environmental components of sex determination and differentiation in the European sea bass (*Dicentrarchus labrax* L.). General and Comparative Endocrinology 142: 102–110.

Sanvicente-Añorve L., Salgado-Ugarte I.H., Castillo-Rivera M. 2003. The use of kernel density estimators to analyze length-frequency distributions of fish larvae. Institute of Marine Research, Postboks 1870 Nordnes, Bergen, Norway. pp. 419–430.

Sheather S.J., Jones M.C. 1991. A reliable data-based bandwidth selection method for kernel density-estimation. Journal of the Royal Statistical Society: Series B (Statistical Methodology) 53: 683–690.

Sing T., Sander O., Beerenwinkel N., Lengauer T. 2005. ROCR: visualizing classifier performance in R. Bioinformatics 21: 3940–3941.

Strobl C., Boulesteix A.L., Zeileis A., Hothorn T. 2007. Bias in random forest variable importance measures: illustrations, sources and a solution. BMC Bioinformatics 8: 25.

Strobl C., Malley J., Tutz, G. 2009. An introduction to recursive partitioning: rationale, application, and characteristics of classification and regression trees, bagging, and random forests. Psychological Methods 14: 323–348.

Svedäng H., Hornborg S. 2014. Selective fishing induces density-dependent growth. Nature Communications 5: 4152.

Trueman C. N., MacKenzie K. M., Palmer M. R. 2012. Identifying migrations in marine fishes through stable-isotope analysis. Journal of Fish Biology 81: 826–847.

Vandeputte M., Quillet E., Chatain B. 2012. Are sex ratios in wild European sea bass (*Dicentrarchus labrax*) populations biased? Aquatic Living Resources, 25: 77–81

Wilson K., Hardy I.C.W. 2002. Statistical analysis of sex ratios: an introduction. In ICW Hardy (ed.), Sex ratios: concepts and research methods. Cambridge University Press, Cambridge, pp. 48-92.

Zweig M.H., Campbell G. 1993. Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. Clinical Chemistry 39: 561–577.

ANNEX I

Pictures of gonads inside and outside the ventral cavity by sex for maturity stages II-VII

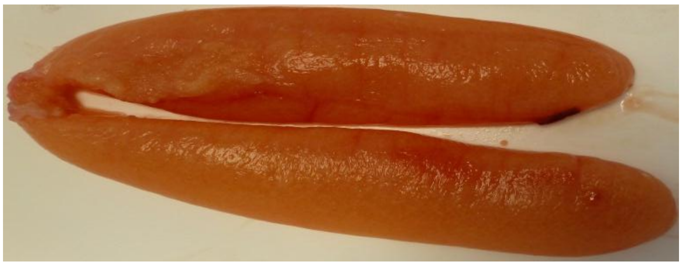
<u>**Females**</u>

Stage 2


Stage 3


Stage 4


Stage 5



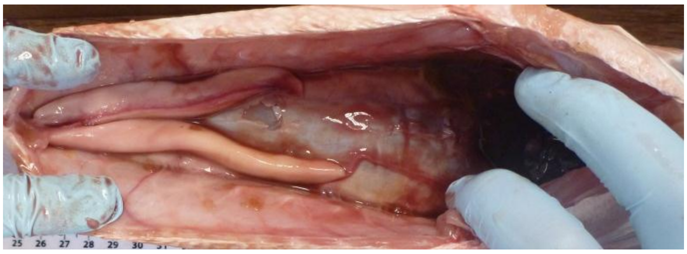

Stage 6


Stage 7


Males

Stage 2

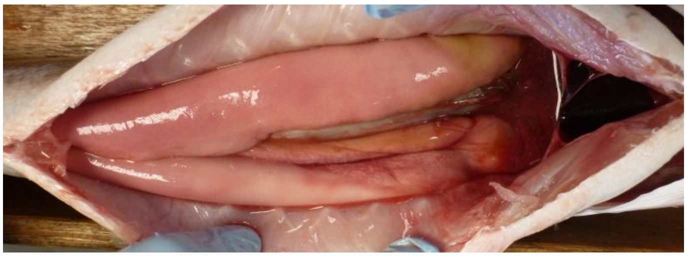
Stage 3



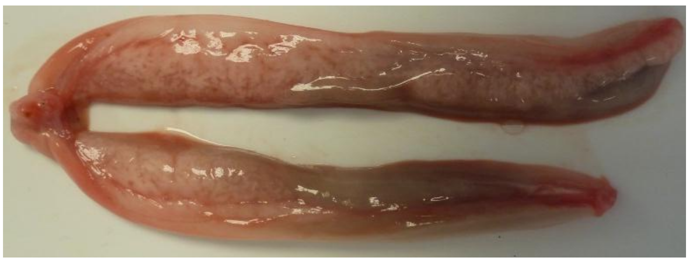
Stage 4

Stage 5

Stage 6



Stage 7



ANNEX II

Catch at age matrices of bass caught with gillnet and line around Welsh waters during the period 2013-2014

Table A2.1. Age-length matrix of bass caught with gillnet around Welsh waters during the period 2013-2014

Length/Age	4	5	6	7	8	9	10	11	12	12+	TOTAL
35	1										**1**
36	2	2	1								**5**
37	1	6	13	1							**21**
38	2	15	18	8							**43**
39	1	16	28	10							**55**
40	1	13	41	15	1						**71**
41		7	40	23							**70**
42		12	51	20	1						**84**
43		5	51	25	6	1	1				**89**
44		3	38	34	7						**82**
45		1	36	22	5						**64**
46		1	22	20	5	3					**51**
47			14	16	10	3	1				**44**
48			3	19	15	2	2				**41**
49			3	16	3	3	2				**27**
50			2	3	10	1	4	1			**21**
51			1	5	5	4	1	1	1		**18**
52				3	2	5	4	2			**16**
53					1	5	6	1		1	**14**
54				1		5	2	1		1	**10**
55					1	5	1	1	3		**11**
56					1		4	4			**9**
57					2	1	4	1	1	1	**10**
58						1					**1**
59							1	1	1		**3**
60							2		2	1	**5**
61							1			2	**3**
62						1			1		**2**
63											**0**
64										2	**2**
65										1	**1**
>65										6	**6**
TOTAL	**8**	**81**	**362**	**241**	**75**	**40**	**36**	**13**	**9**	**15**	**880**

Table A2.2. Age-length matrix of bass caught with line around Welsh waters during the period 2013-2014

Length/Age	4	5	6	7	8	9	10	11	12	12+	TOTAL
35			1								**1**
36	1	3	1								**5**
37	1	10	4								**15**
38	7	15	19	7							**48**
39		8	38	8							**54**
40	2	7	31	8							**48**
41		4	34	18							**56**
42		3	28	20	11						**62**
43		4	19	18	8						**49**
44			9	24	5						**38**
45			7	16	7						**30**
46			4	9	10	1					**24**
47		1	5	12	10	7	2				**37**
48			1	3	7	5	3				**19**
49				4	3	11	2	1			**21**
50			1	4	4	5	5	2	1		**22**
51				2	6	6	3	1	1		**19**
52				1	9	4	5		2	1	**22**
53					3	3	3	2	2	1	**14**
54						5	2	3	1		**11**
55					1	1	3		2	1	**8**
56					1	1	7	1	2	2	**14**
57							1	1			**2**
58						1	1	2	1	2	**7**
59						1			2		**3**
60							2	1	1		**4**
61									1	1	**2**
62									1		**1**
63										2	**2**
64								2			**2**
65									1	1	**2**
>65										7	**7**
TOTAL	**11**	**55**	**202**	**154**	**85**	**51**	**39**	**16**	**18**	**18**	**649**