Key biological information for the management of Black Bream in the Vasse-Wonnerup

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Cover photos: A family fishing for Black Bream in Wonnerup Inlet and James Keleher from Murdoch University holding a 43 cm Black Bream caught (and released) in the Deadwater. Photographs by James Tweedley.

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Non-technical summary

The Vasse-Wonnerup is a shallow intermittently-open system located near the town of Busselton, Western Australia and is listed under the Ramsar Convention. Despite its ecological importance, the Vasse-Wonnerup is highly modified and suffers from excess nutrients, low oxygen levels, which can lead to fish kills. A major component of the fish that die during these kills is the iconic recreational species Black Bream (*Acanthopagrus butcheri*). Because Black Bream are a solely estuarine species, *i.e.* individuals complete their life cycle within the estuary and do not leave, depleted populations of this species cannot be replenished from stocks in the marine environment or from other estuaries.

Results from previous studies in the Vasse-Wonnerup demonstrated that, following a major fish kill in April 2013 there was no evidence of recruitment (an increase in juveniles following the birth of new fish) of Black Bream from that year. It was not known, however, whether this was due to the environment at the time of spawning not being conducive for survival or to a lack of sufficient numbers of brood stock (sexually mature fish) and thus whether recruitment would continue to fail in the future. It also became apparent that the good, thorough information required for management of this fish in the Vasse-Wonnerup was lacking. There was thus an urgent need to acquire information on the key biological characteristics of Black Bream and assess the health of this stock in the Vasse-Wonnerup.

Samples of Black Bream were collected from the Wonnerup Inlet and Deadwater between February 2014 and September 2015 and the resultant data combined with those obtained previously between February 2012 and November 2013. The combined data indicated that the catches of juvenile Black Bream in the nearshore waters declined significantly following the fish kill in April 2013. Although catch rates in the offshore waters did not decline over that period, there were very few Black Bream belonging to the 2013 or 2014 year classes, thus confirming that recruitment had also failed in 2014.

In terms of the health of individual fish, their body condition and growth in the Vasse-Wonnerup were relatively poor compared to other estuaries. Thus, for example, at the Minimum Legal Length (MLL) for retention by recreational fishers of 250 mm, the average weight of females was 262 g, and they took, on average, 6.2 years to reach that size. These values were very different from the corresponding values recorded in the nearby Swan River Estuary in 1993-95, in which females in the upper reaches were ~20 g (8 %) heavier and grew much faster, taking only 2.7 years to reach the MLL (3.5 year less). The condition and growth of Black Bream in the Vasse-Wonnerup, however, did parallel those recorded for Black Bream in the Swan River Estuary in 2007-11, following a period during which the aquatic environment in that estuary had become degraded through increases in nutrient levels and a decrease in oxygen levels.

The poor condition and growth of Black Bream in the Vasse-Wonnerup is presumably related to the large amounts of macroalge present in their diets (82 % by volume). As this food source is of low nutritional value, it largely reflects the poor feeding conditions in this system, perhaps due to a lack of large invertebrates (*e.g.* bivalves) as a result of the excess nutrients. Thus, the condition, growth and dietary composition of Black Bream in the Vasse-Wonnerup were indicative of a population living in a stressed environment.

The peak in spawning of Black Bream in the Vasse-Wonnerup occurred in August/September, which is different from that found elsewhere in south-western Australia, where spawning typically peaks in November, likely due to the unique hydrological characteristics of the Vasse-Wonnerup. The estimates of length and age at maturity of 163 mm and 2.6 years, respectively, for females of Black Bream in the Vasse-Wonnerup did not differ significantly from those recorded in the Swan River Estuary in 2007-11. However, precise estimates of these maturity parameters could not be attained as few fish belonging to the 2+ and 3+ age classes were present in the samples during the spawning season as a result of the fish from these years being affected by the large fish kill in April 2013.

In summary, the population of Black Bream in the Vasse-Wonnerup Estuary is under extreme pressure and it is not known whether recruitment will continue to fail in the future. As Black Bream is largely confined to the Wonnerup Inlet and Deadwater where they spawn, to reduce sustainability of this population in the future, there is a need for a refuge area for Black Bream to be created to protect its spawning stock. This could include introducing structure/habitat in the Deadwater to attract Black Bream and provide structure for potential food sources (*e.g.* bivalves). The establishment of an artificial oxygenation plant to ensure their survival during hypoxic events would also be of value. While surveys of the invertebrate communities have been conducted in areas upstream of the surge barriers (*i.e.* Vasse and Wonnerup estuaries), no work has been done in the downstream areas. Thus, surveys should be conducted in Wonnerup Inlet and the Deadwater to assess the level of prey availability for fish, including Black Bream. This could include calorific work to assess the nutrient content of the various prey items.

In the long term, to re-establish a productive Black Bream recreational fishery, water quality in the Deadwater must be improved to reduce macroalgae growth, which would promote a more diverse macroinvertebrate community and thus providing more nutritional prey for Black Bream. As the stock of Black Bream in the Vasse-Wonnerup could be on the edge of collapse if recruitment failure continues, ongoing monitoring is also necessary to inform management and protect this valuable species.

1.0 Introduction

The Vasse-Wonnerup is a shallow, intermittently-open, nutrient-enriched system located near the town of Busselton, Western Australia (Brearley, 2005). The wetland provides habitat for over 37,500 water birds comprising ~90 species, a function that is recognised by its designation in 1990 as a Wetland of International Importance under the Ramsar Convention (Lane *et al*., 2007). However, although the importance of the system is well recognised, the catchment of the Vasse-Wonnerup has undergone substantial anthropogenic modification (Tweedley *et al*., 2015a). For example, much of the catchment has been cleared, primarily for cattle grazing, extensive drainage networks have been constructed, several rivers that used to flow into the system have been diverted to the sea and surge barriers have been installed in the exit channels of the estuaries to prevent seawater intrusion (Lane *et al*., 1997). Furthermore, the large amounts of fertilizer applied to crops, combined with animal waste discharged from pastures into the estuaries, resulted in the Vasse-Wonnerup becoming "*the most grossly enriched major wetland system known in Western Australia*" (McAlpine *et al*., 1989). Moreover, without management intervention, nutrient loads are expected to increase over the next 20 years due to increased urbanisation and more intensive agriculture (Department of Water, 2010). These factors have led to a multiplicity of detrimental effects, including increases in the prevalence of eutrophication, algal blooms, hypoxia and anoxia, fish kills, undesirable odours, mosquito problems and the death of fringing vegetation (Lane *et al*., 1997; Brearley, 2005; Tweedley *et al*. 2014a).

Despite the well-publicised environmental problems present in the Vasse-Wonnerup, the system is fished by substantial numbers of recreational fishers and there are also several commercial licence holders. While mullet species (*i.e.* the Sea Mullet *Mugil cephalus* and Yelloweye Mullet *Aldrichetta forsteri*) are the target of the commercial sector, the vast majority of recreational fishers target Black Bream *Acanthopagrus butcheri*, the iconic recreational fish species present in south-western Australian estuaries. In order to manage the populations of any fish species, fishery and environmental managers require a suite of key information including growth rates, age (population) structure, the timing, duration and location of spawning and the size and age at which sexual maturity occurs. Information on the biology of different Black Bream stocks is becoming increasingly important as some stocks in south-western Australia have become depleted through overfishing and/or environmental degradation (Lenanton *et al*., 1999; Cottingham *et al*., 2015).

Robust information on the key biological traits of Black Bream in the Vasse-Wonnerup is currently lacking. Given that fish kills occur regularly in this system, with such events dating back to 1905 (Lane *et al*. 1997; Hart 2014), and that a particularly large fish kill occurred in April 2013; resulting in the death of >30,000 fish primarily adult Black Bream, Sea Mullet and Yelloweye Mullet (Kath Lynch, Department of Water, pers. com.), there is an urgent need to determine the key biological characteristics of Black Bream listed above. Furthermore, samples of Black Bream collected in the year following the 2013 fish kill indicated that there were no young juvenile Black Bream (*i.e.* those in the 0+ age class), although it was not known whether this was due to environmental factors at the time of spawning or insufficient numbers of sexually mature adults (Tweedley *et al.,* 2014a).

Black Bream are regarded as a solely estuarine species *sensu* Potter *et al.* (2015a,b) and thus individuals complete their life cycle within estuaries and this life history strategy has resulted in populations in different estuaries being genetically distinct from one another (Chaplin *et al*., 1998). While temperate estuaries are considered the most degraded of all aquatic ecosystems (Jackson *et al.,* 2001) due to a range of anthropogenic activities (Kennish *et al.* 2002; Rabalais *et al.,* 2009; Tweedley *et al.,* 2015b), the microtidal estuaries of south-western Australia, due to their geomorphological and hydrological characteristics, are regarded as being predisposed to 'natural' environmental degradation

(Tweedley *et al.*, 2014b, 2015c). As a result species that are confined to these latter estuaries must adapt to such perturbations. Recent studies in the Swan River Estuary have demonstrated that the biological characteristics Black Bream are plastic (*i.e.* highly variable) and that following detrimental changes to the environment, the body condition, *i.e.* length-weight relationship (a measure of the health of individuals) was shown to have declined by ~5%, growth by ~30% and length at maturity ~10%, whereas the age at maturity increased by ~30% (Cottingham *et al.*, 2014). This thus demonstrated that environmental condition of an estuary can have detrimental effects on the biology of Black Bream. Therefore, as well as providing crucial information for fishery and environmental managers, the calculation of biological characteristics of Black Bream would also provide a baseline to monitor how fish respond to long-term changes in the environment in which they reside.

In light of the above, the aims of this proposed study are to:

1) Continue to sample the nearshore and offshore waters of Wonnerup Inlet and the Deadwater seasonally from February 2014 until May 2015 using the same sites and methods as in Tweedley *et al.* (2014a) to determine the abundance of Black Bream and elucidate whether populations have increased since the April 2013 fish kill.

2) Collect a small number of Black Bream each month (n = 30) to calculate a suite of biological parameters for Black Bream in the Vasse-Wonnerup, namely body condition, growth, timing of spawning, the length and age at which Black Bream reach sexual maturity and the contribution of major categories to the diets of Black Bream in this system.

3) Where available, compare the results obtained in aim 2, with those for corresponding Black Bream populations from the nearby Swan River Estuary in 1993-95 and, more recently, in 2007-11.

4) Synthesise the results with data from the recently completed acoustic tracking program to provide a suite of recommendations to aid in the management of Black Bream in the Vasse-Wonnerup.

2.0 Materials and methods

2.1 Sampling regime

A total of eight sites in the nearshore and offshore waters of Wonnerup Inlet and the Deadwater were sampled seasonally over six consecutive seasons from February 2014 to May 2015 (Fig. 1). The nearshore waters were sampled using a 21.5 m long seine net that consisted of two 10 m long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m long bunt made of 3 mm mesh. The seine net, which was laid parallel to the shore in a depth of 1.5 m and then hauled onto the beach, swept an area of 116 m^2. Two replicate samples were collected at each site, on each sampling occasion. Adjacent offshore waters were sampled using sunken composite multifilament gillnets comprising eight 20 m long panels, each with a height of 2 m, containing a different stretched mesh size, *i.e.* 35, 51, 63, 76, 89, 102, 115 or 127 mm. Gillnets were set for one hour, to minimise any fish deaths and allow the release of fish alive to the water.

To determine the spawning period of Black Bream, additional samples were collected monthly from the offshore waters of the upper reaches of the Deadwater between October 2014 and September 2015 using the same gill net as described above. This site was chosen as previous research showed that Black Bream remained relatively abundant in this area throughout the year (Tweedley, unpublished data) and, although it lacks riverine input, this site is located furthest 'upstream' from the entrance channel and thus, to some extent, parallels the region in a typical estuary where Black Bream would spawn. The data collected during the current study were combined with those recorded by Tweedley *et al.* (2014a) previously in this system.

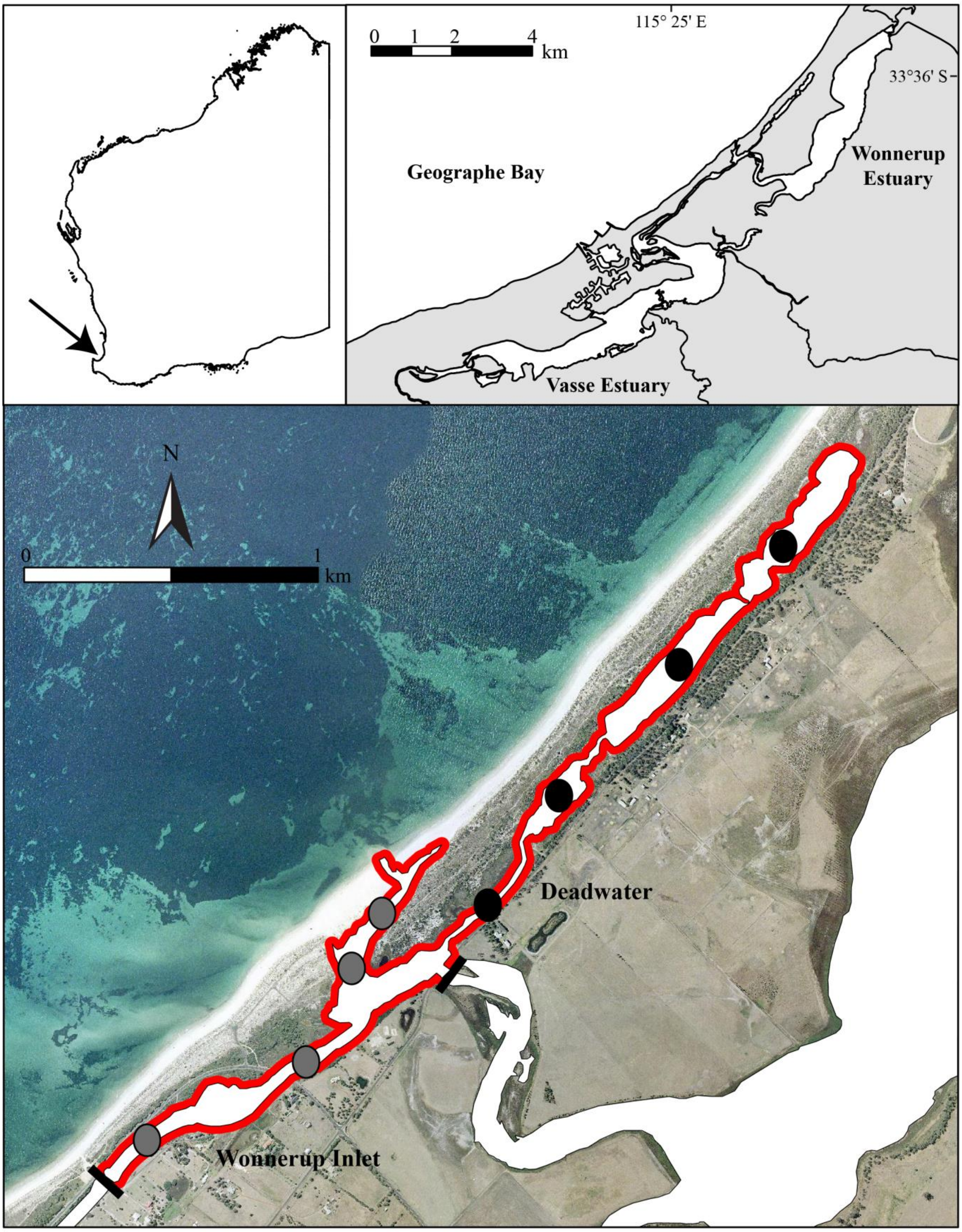

Figure 1. Map showing location of the sites in Wonnerup Inlet and the Deadwater at which fish were sampled in the shallow, nearshore (< 2 m) and deeper, offshore waters (> 2 m) seasonally between February 2014 and May 2015 and monthly between October 2014 and September 2015. Insets show the location of the Vasse-Wonnerup in Western Australia and the location of Wonnerup Inlet and the Deadwater within the Vasse-Wonnerup.

2.2 Laboratory procedures

Each retained Black Bream was measured to the nearest 1 mm (total length), weighed to the nearest 1 g and sexed on the basis of macroscopic examination of its gonads. The smallest fish, which could not be sexed, were designated randomly (and in equal numbers) as females and males. The sagittal otoliths (ear bones) of each fish were removed, cleaned and stored. All otoliths were initially examined using a dissecting microscope under reflected light. Previous studies had shown that the opaque zones in all otoliths could be clearly identified without sectioning when there were up to six such zones, but this was not always the case with otoliths containing a greater number of such zones (Sarre & Potter, 2000). Thus, when otoliths contained ≤6 opaque zones, the numbers of their zones were counted using whole otoliths, but, when there were >6 such zones, the numbers were counted in sectioned otoliths (Fig. 2).

Figure 2. Sagittal otoliths viewed under reflected light of Black Bream. Left: Whole otolith from 2 year old fish. Right: Sectioned otolith form 15 year old fish.

For sectioning, otoliths were embedded in clear epoxy resin, sectioned transversely (*ca* 400 μm) through their primordia and mounted on glass microscope slides using DePX mounting adhesive and the number of zones likewise counted using a dissecting microscope under reflected light. The age of individual Black Bream, estimated from the number of opaque zones in their otoliths, took into account that i) newly-formed opaque zones typically become delineated from the otolith periphery by the beginning of November (Sarre & Potter, 2000), ii) a birth date, which corresponded to the approximate peak in the mean standardised gonad weight and iii) the date of collection.

2.3 Analysis of temporal changes in Black Bream abundance

The mean density of Black Bream (*i.e.* fish 100 m^{-2}) from 21.5 m seine net samples collected from the nearshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup seasonally between February 2014 and May 2015 were calculated and combined with those collected by Tweedley *et al.* (2014a) using identical methods and at the same sites between February 2012 and November 2013. Note that only those two regions were included in the analyses as 1,605 of the 1,608 (*i.e.* 99.8%) Black Bream recorded during the earlier study were found from those regions. These univariate data were then square-root transformed and used to construct a Euclidean distance matrix, which was, in turn, subjected to a two-way PERMANOVA (Anderson *et al.*, 2008) to identify whether the density of Black Bream differed among sampling occasions (14 levels) and regions (2 levels). Both main effects were considered fixed and the null hypothesis of no significant differences was rejected when the *P*-value was <5%. Where a significant difference in any main effect or interaction term was detected, a pairwise PERMANOVA was conducted to identify the particular pairwise comparisons that were responsible for the difference. This was supplemented by examining back transformed plots of the marginal means. In this analysis, particular focus was placed on determining how the abundance of Black Bream had changed since the fish kill in April 2013.

While the characteristics of the fish communities of the shallow, nearshore waters of the Vasse-Wonnerup have been described recently and in considerable detail (see Tweedley *et al.*, 2012, 2014a, 2014c; Beatty *et al.*, 2014), little is known about the fish communities present in deeper, offshore waters. Thus, to place the population of Black Bream in the offshore areas of the system in context with other species residing in those waters, a table was compiled using the average catch rates of all 18 species recorded from the gill nets. A shade plot (Clarke *et al*., 2014) was then constructed from the square-root transformed fish faunal composition data to visually display any differences in the relative abundance (reflected in catch rates per hour) of Black Bream and the other 17 fish species in the two regions in each of the four seasons over two years. The shade plot is a simple visualization of the frequency matrix, where a white space for a species demonstrates that the species was never collected, while the depth of shading from grey to black is linearly proportional to the abundance of that species (Clarke *et al.,* 2014; Valesini *et al.,* 2014). Fish species (*x* axis) were ordered by a hierarchical cluster analysis of their mutual associations across seasons and regions, while the samples (*y* axis) were separated into the two regions and arranged in chronological order from August 2013 to May 2015.

As with the nearshore data, PERMANOVA was employed to identify whether the density of Black Bream differed spatially or temporally. Only, in this case, as samples were obtained in an equal number of seasons in each year the analysis had three main effects, year (two levels), season (four levels) and region (two levels). As above, where necessary, pairwise PERMANOVA test(s) were run and back transformed plots of the marginal means graphed. Note that unlike the data from the nearshore waters, sampling in the offshore waters was only undertaken after the fish kill in April 2013 had occurred.

2.4 Assessment of body condition

For each sex, the parameters a and b of length-weight relationship, $W = aL^b$, were estimated by fitting linear equations of the form: $\ln(W_j) = \ln(a) + b \ln L_j$, to the weight (g) and total length (mm), where ln refers to the natural logarithm, W_j and L_j are the observed masses and length, respectively of the j'th fish. The above parameters were then used to estimate the average weight of each sex at 250 mm, the minimum legal length (MLL) for retention of this species. To account for bias associated with the logarithmic transformations, the correction factor $\exp(\hat{\sigma}^2/2)$ was employed (Beauchamp & Olson, 1973).

2.5 Growth

Using non-linear regression, the von Bertalanffy growth model (VBGM) was fitted separately to the lengths at age of females and males of Black Bream in the Vasse-Wonnerup. The von Bertalanffy growth equation is $\hat{L}_t = L_\infty[1 - \exp(-k(t - t_0))]$, where $\hat{L}_t$ is the expected total length at age t (years), L_∞ is the asymptotic length (mm), k is the growth coefficient (year^{-1}) and t_0 is the hypothetical age (years) at which fish would have zero length. The von Bertalanffy growth parameters were then used to estimate the average age at 250 mm.

2.6 Maturity

The gonads of each Black Bream were weighed to the nearest 0.01 g and assigned to one of the following stages on the basis of their macroscopic appearance: I/II = virgin or resting, III = developing, IV = maturing, V = pre-spawning, VI = spawning, VII = spent and VIII = recovering spent (Laevastu, 1965). The trends exhibited by the prevalence of the different stages in ovarian development in sequential months, allied with those of gonad weights were used to determine the spawning period and the approximate time of peak spawning; the latter being used as the birth date of Black Bream. Note that, as gonad weight is highly dependent on fish size, with larger fish generally having proportionately larger gonads than smaller individuals, the monthly trends in gonad weight of female and male Black Bream were compared by standardising for length (Gonor, 1973). In this analysis only fish $\geq L_{50}$

(length at which 50% of fish are mature) were used. This was achieved using Analysis of Covariance (ANCOVA).

Logistic regression analysis was used to determine the probability P that a female or male of a given length possessed gonads at stages III-VIII during the spawning season. The logistic equation is $P = 1/\{1 + \exp[-\ln(19)\,(L - L_{50})/(L_{95} - L_{50})]\}$, where L is the total length of the fish in mm and L_{50} and L_{95} are the lengths at which 50% and 95% of fish attain maturity, respectively. The values of L_{50} and L_{95} were estimated by minimising the negative log-likelihood (NLL), determined as $NLL = \sum_j \{M_j \ln(P_j/(1-P_j)) + \ln(1-P_j)\}$ where M_j is the maturity class of the j'th fish, *i.e.* 0 = immature and 1 = mature, and P_j is the probability of the j'th fish being mature. The analysis was undertaken using OpenBUGS (Surhone *et al*., 2010) to obtain median and approximate 95% credible intervals for the L_{50}s and L_{95}s and the expected proportion of mature fish at each of a range of total lengths. The prior distribution for each parameter was represented by a non-informative normal distribution. The above approach was also used to relate the probability that a female or male possessed mature gonads to the age of the fish.

2.6 Dietary analyses

The entire gut was removed from each retained Black Bream and the percentage stomach fullness of each Black Bream was estimated visually. Stomach contents were then extracted and examined under a dissecting microscope and the percentage volumetric contribution of each major category of prey recorded. Each dietary item was assigned to a major prey category, *i.e.* macroalgae, detritus, polychaete, mollusca, crustacea or teleost and the total contribution of each of those categories calculated (*e.g.* Chuwen *et al*., 2007; Lek *et al*., 2011).

3.0 Results

3.1 Temporal changes in Black Bream abundance

3.1.1 Nearshore waters

Densities of Black Bream recorded in the shallow, nearshore waters of Wonnerup Inlet and the Deadwater were shown by PERMANOVA to differ significantly among sampling occasions, but neither among regions nor for the interaction between these two main effects (Table 1). A pairwise PERMANOVA test comparing the density in each pair of sampling occasions demonstrated that they generally fell into one of two groups (Table 2). The first group contained sampling occasions in February, May and November 2012, February 2013 and November 2014 where densities ranged from 7 to 37 Black Bream 100 m^{-2}. In contrast the other group comprised the remaining nine sampling occasions, where densities were consistently lower, *i.e.* ≤1 Black Bream 100 m^{-2} (Fig. 3).

The mean density of Black Bream underwent a conspicuous seasonal trend in the sampling occasions before the fish kill, *i.e.* February 2012 to 2013. Densities were highest in February 2012 (37.4 Black Bream 100 m^{-2}), then progressively declining through May to a minimum in August (0.3 Black Bream 100 m^{-2}), before increasing through November to a second peak in February 2013 (28.8 Black Bream 100 m^{-2}; Fig. 3). In the sampling occasion immediately after the fish kill, densities of Black Bream 100 m^{-2} had declined to <0.2 and remained at very low levels (*i.e.* <1 Black Bream 100 m^{-2}) or were not recorded for the next six sampling occasions, over an 18 month period. Relatively substantial numbers of Black Bream were recorded in November 2014 and individuals were also recorded, albeit in lower densities in February and May 2015 (Fig. 3)

Table 1. Mean squares (MS), *pseudo-F* ratios, components of variation (COV) and significance levels (*P*) from a two-way PERMANOVA test on the data for the density of Black Bream (fish 100 m^{-2}) recorded in the shallow, nearshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup seasonally between February 2012 and May 2015. df = degrees of freedom. Significant results are highlighted in bold.

Main effects	df	MS	*Pseudo-F*	COV	*P*
Sampling occasion	13	**33.97**	**9.38**	**1.90**	**0.1%**
Region	1	9.81	2.71	0.05	11.5%
Interactions					
Sampling occasion x Region	13	3.72	1.09	0.01	43.5%
Residual	196	3.62		3.62	

Table 2. Pairwise *t*-statistic values and significance levels (*P*) for a pairwise PERMANOVA test on the data for the density of Black Bream (fish 100 m^{-2}) recorded in the shallow, nearshore waters of the Vasse-Wonnerup among the 14 consecutive sampling occasions between February 2012 and May 2015. Insignificant pairwise comparisons are highlighted in grey.

		2012				**2013**				**2014**				**2015**
		Feb	**May**	**Aug**	**Nov**	**Feb**	**May**	**Aug**	**Nov**	**Feb**	**May**	**Aug**	**Nov**	**Feb**
2012	**May**	0.88												
	Aug	2.79	3.83											
	Nov	1.51	1.07	2.55										
2013	**Feb**	0.33	1.78	5.26	2.75									
	May	2.85	4.00	0.41	2.72	5.39								
	Aug	2.64	3.48	0.71	2.20	4.97	1.11							
	Nov	3.00	4.34	1.77	3.06	5.66	2.04	2.14						
2014	**Feb**	2.93	4.16	1.00	2.88	5.52	0.78	1.56	1.00					
	May	3.00	4.34	1.77	3.06	5.66	2.05	2.13	0.00	1.00				
	Aug	3.00	4.34	1.77	3.06	5.66	2.05	2.13	0.00	1.00	0.00			
	Nov	2.21	2.47	1.82	1.24	4.10	2.10	1.27	2.69	2.37	2.69	2.69		
2015	**Feb**	2.47	3.09	1.32	1.81	4.64	1.70	0.65	2.54	2.07	2.54	2.54	0.71	
	May	2.58	3.27	0.67	2.30	4.77	0.95	0.12	1.63	1.20	1.63	1.63	1.04	0.43

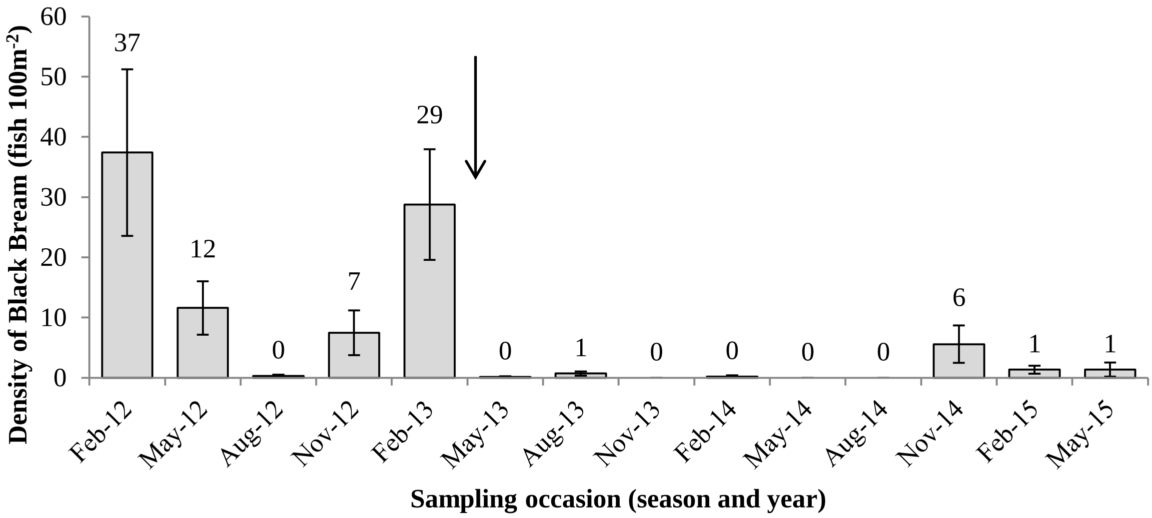

Figure 3. Mean density of Black Bream (fish 100 m^{-2}) recorded from 21.5 m seine nets in the shallow, nearshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup in each season between the February 2012 and May 2015. Error bars represent ±1 standard error and the black arrow denotes the approximate time at which the large fish kill occurred.

3.1.2 Offshore waters

A total of 3,960 fish, comprising 18 species from 13 families, were recorded during the two years of seasonal sampling in the deeper, offshore waters of the Vasse-Wonnerup (Table 3). Fourteen of these species were classified as marine estuarine-opportunists, which spawn in marine waters, but whose juveniles enter estuaries, often in large numbers, and use these systems as a nursery area. Only two solely estuarine species were recorded, *i.e.* Black Bream and Yellowtail Grunter, which complete their life cycles within the estuary and the two remaining species belonged to the estuarine & marine and marine straggler guilds, *i.e.* Cobbler and Southern Fiddler Ray, respectively. Among the 18 fish species, three were particularly abundant, *i.e.* Sea Mullet, Yelloweye Mullet and Black Bream, which together comprised ~60% of the total number of fish recorded.

Table 3. Mean catch rates per hour ($\bar{X}$) of species and percentage contribution to the overall catch (%) and ranking by catch rate (R) of each of the 18 fish species recorded in the deeper, offshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup in each season between the August 2013 and May 2015. The data for Black Bream are highlighted in grey. Life-cycle guilds (LCG) are abbreviated as follows: E, solely estuarine; E&M, estuarine & marine; MEO, marine estuarine opportunist and MS, marine straggler (see Potter *et al.*, 2015a,b).

Common Name	Species Name	LCG	$\bar{X}$	%	R
Sea Mullet	*Mugil cephalus*	MEO	3.41	21.57	1
Yelloweye Mullet	*Aldrichetta forsteri*	MEO	3.03	19.12	2
Black Bream	*Acanthopagrus butcheri*	E	2.95	18.63	3
Yellowtail Grunter	*Amniataba caudavittata*	E	1.46	9.25	4
Western Striped Grunter	*Pelates octolineatus*	MEO	0.98	6.21	5
Common Silverbiddy	*Gerres subfasciatus*	MEO	0.98	6.20	6
Tarwhine	*Rhabdosargus sarba*	MEO	0.91	5.78	7
Yellowfin Whiting	*Sillago schomburgkii*	MEO	0.87	5.48	8
Mulloway	*Argyrosomus japonicus*	MEO	0.42	2.67	9
Western Australian Salmon	*Arripis truttaceus*	MEO	0.30	1.87	10
Tailor	*Pomatomus saltatrix*	MEO	0.21	1.31	11
Skipjack Trevally	*Pseudocaranx wrighti*	MEO	0.09	0.58	12
Australian Giant Herring	*Elops machnata*	MEO	0.06	0.39	13
Smalltooth Flounder	*Pseudorhombus jenynsii*	MEO	0.05	0.30	14
Southern School Whiting	*Sillago bassensis*	MEO	0.03	0.22	15
Estuary Cobbler	*Cnidoglanis macrocephalus*	E&M	0.03	0.20	16
Western School Whiting	*Sillago vittata*	MEO	0.02	0.14	17
Southern Fiddler Ray	*Trygonorrhina fasciata*	MS	0.02	0.10	18
	Total		**15.83**	**100.00**	

The shade plot with the associated cluster dendrogram demonstrates that fish utilising the offshore waters of the Vase-Wonnerup fall into one of three categories. 1) Species that were most abundant and found in each season/region combination, *i.e.* Sea Mullett, Yelloweye Mullet and Black Bream (Fig. 4). 2) Species found in most seasons and regions, but generally in low numbers (*e.g.* Western Striped Grunter, Yellowfin Whiting, Common Silverbiddy and Tailor) and 3) species that were sporadic in their occurance and, even then, only occurred in low numbers (*e.g.* Australian Giant Herring, Southern School Whiting and Cobbler).

This analysis confirms that Black Bream represent a key component of the fish fauna of the offshore waters of the Vasse-Wonnerup (Wonnerup Inlet and the Deadwater). Moreover, their densities of this resident species remained more consistent than those of two abundant mullet species, which use estuaries as a nursey and feeding area. There was also no indication of Black Bream catch rates being greater in one of the regions.

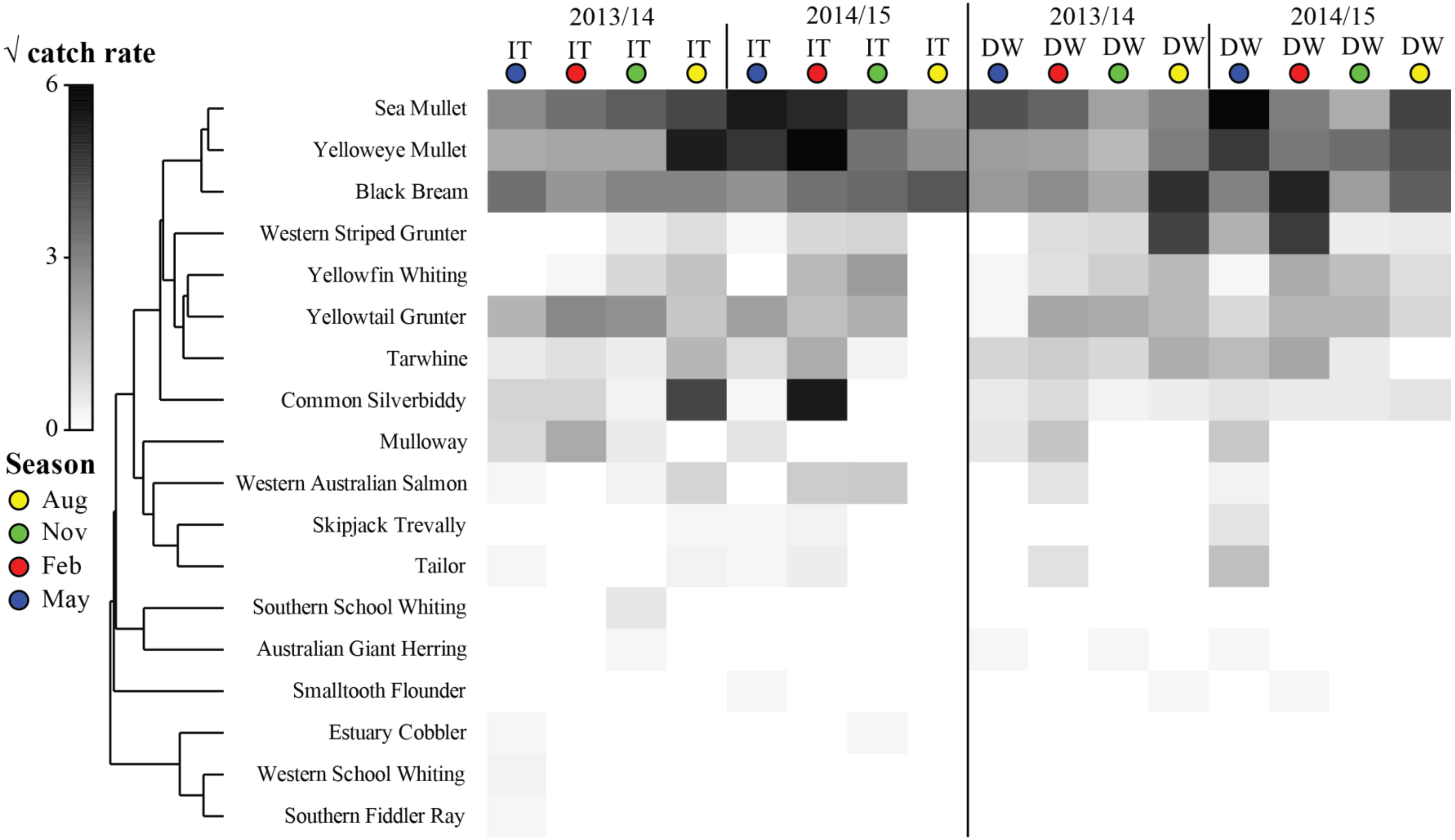

Figure 4. Shade plot of square-root transformed of average catch rate (fish hour^{-1}) data for each species recorded in the offshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup in each season between the August 2013 and May 2015. Shading intensity is proportional to catch rate. Fish species were ordered by a hierarchical cluster analysis of their mutual associations across seasons and regions. Seasons are ordered consecutively within a region (IT = Wonnerup Inlet and DW = Deadwater). Full species names and life cycle guilds are given in Table 3.

Catch rates of Black Bream in the deeper, offshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup were shown by three-way PERMANOVA not to differ significantly among years (2013/14 and 2014/15), seasons or regions, nor among any of the two- or three-way interaction terms. The trend in catch rates among sampling occasions, *i.e.* season and year combinations, is shown in Fig. 5. This demonstrates that there is no clear trend in catch rate of Black Bream since the fish kill, with average catch rates ranging from 8-18 Black Bream hour^{-1}, but with the variability being relatively high.

Table 4. Mean squares (MS), *pseudo-F* ratios, components of variation (COV) and significance levels (P) from a three-way PERMANOVA test on the data for the catch rate of Black Bream (fish hour^{-1}) recorded in the offshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup in each season between the August 2013 and May 2015. df = degrees of freedom.

Main effects	**df**	**MS**	***Pseudo-F***	**COV**	***P***
Year	1	3.19	1.25	0.02	24.5%
Season	3	4.04	1.59	0.09	21.7%
Region	1	0.29	0.11	-0.07	75.0%
Interactions					
Year x Season	3	6.56	0.86	-0.04	45.9%
Year x Region	1	0.04	0.01	-0.16	91.2%
Season x Region	3	3.29	1.29	0.09	31.7%
Year x Season x Region	3	2.55	1.00	0.00	42.5%
Residual	48	2.54		2.54	

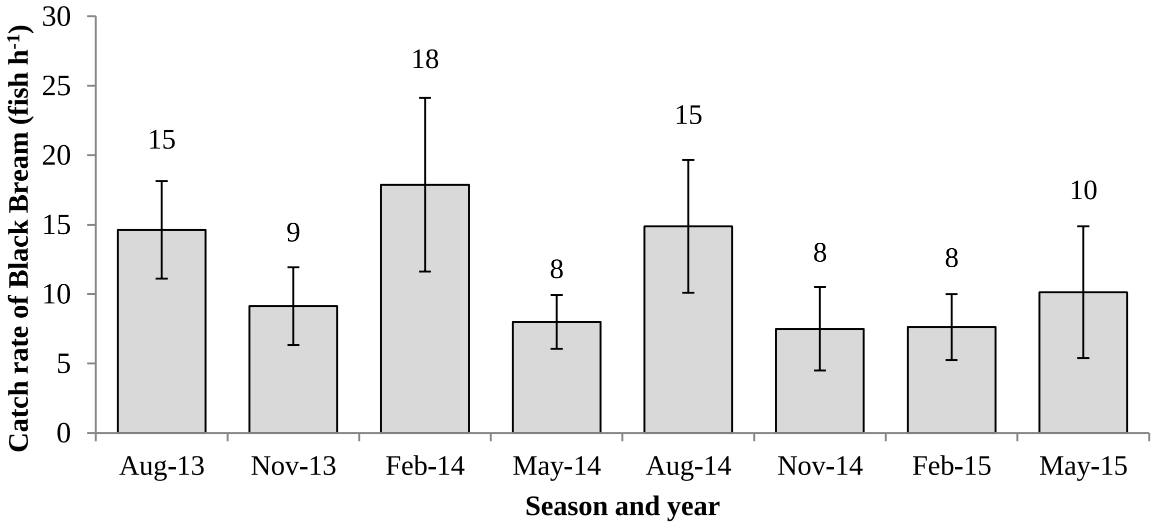

Figure 5. Mean catch rate of Black Bream (fish hour^{-1}) recorded from gill nets in the deeper, offshore waters of the Wonnerup Inlet and Deadwater regions of the Vasse-Wonnerup in each season between the August 2013 and May 2015. Error bars represent ±1 standard error.

3.2 Year class strengths

The 2010, 2011 and 2012 year classes were by far the most abundant year classes of Black Bream taken between February 2012 and September 2015 in the Vasse-Wonnerup (Fig. 6). The year class strengths also demonstrate that recruitment of Black Bream occurs, to some extent, each year. However, although, as shown above, catch rates in the offshore waters did not undergo a noticeable declined following the fish kill in April 2013 (Fig. 5), very few representatives of the 2013 and 2014 year classes were present in this system, which presumably reflects recruitment failure in those recent years (Fig. 6).

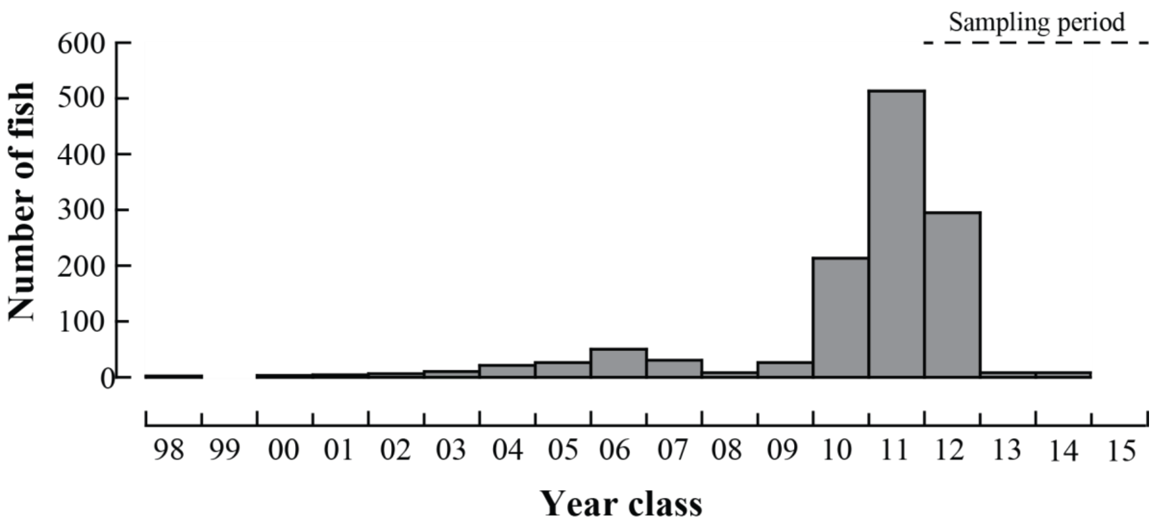

Figure 6. Number of Black Bream representing different year classes collected using seine and gill nets in the Vasse-Wonnerup between February 2012 and September 2015. Note fish spawned in 2015 would be too small to be recorded in any of the sampling occasions. Dashed line denotes the time as which sampling occurred.

3.2 Body condition

The body condition (length-weight relationship) of Black Bream from collected from the Vasse-Wonnerup was markedly less than that of the Swan River Estuary in 1993-95 and slightly less than that recorded in that same latter estuary in 2007-11 (Fig. 7). Thus, for example, the modelled weight of a 250 mm Black Bream was 262 g in the Vasse-Wonnerup compared to 267 g and 283 g in the Swan River Estuary in 2007-11 and 1993-95, respectively. The Black Bream in the Vasse-Wonnerup are thus ~8% lighter than those recorded in the Swan River Estuary in 1993-95.

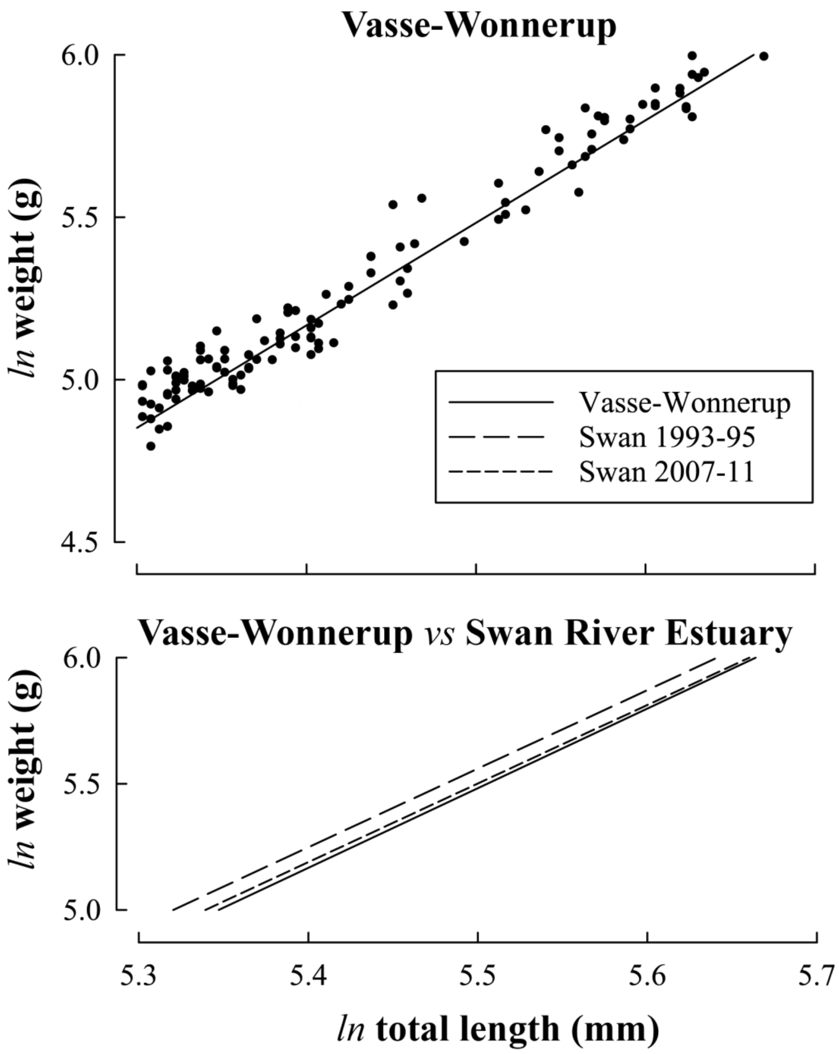

Figure 7. Log_e-log_e relationship between weight (g) and total length (mm) for Black Bream collected in the Vasse-Wonnerup (top) and a comparison with those collected from the Swan River Estuary in 1993-95 and 2007-11 (bottom).

3.3 Growth

The growth rates of Black Bream in the Vasse-Wonnerup paralleled that recorded in the Swan River Estuary in 2007-11, however, both of these rates were far less than that recorded in the Swan River Estuary in 1993-95 (Fig. 8). Thus, for example, the age at the MLL in the Vasse-Wonnerup for females and males were 6.2 and 6.8 years, respectively, were similar to those recorded in the Swan River Estuary in 2007-11, 6.2 and 7.3 years, respectively, both of which were far greater those recorded in the Swan River Estuary in 1993-95 of 2.7 and 2.9 years. Female and male Black Bream in the Vasse-Wonnerup thus take 3.5 and 3.9 years longer to reach 250 mm than in the Swan River Estuary in 1993-95.

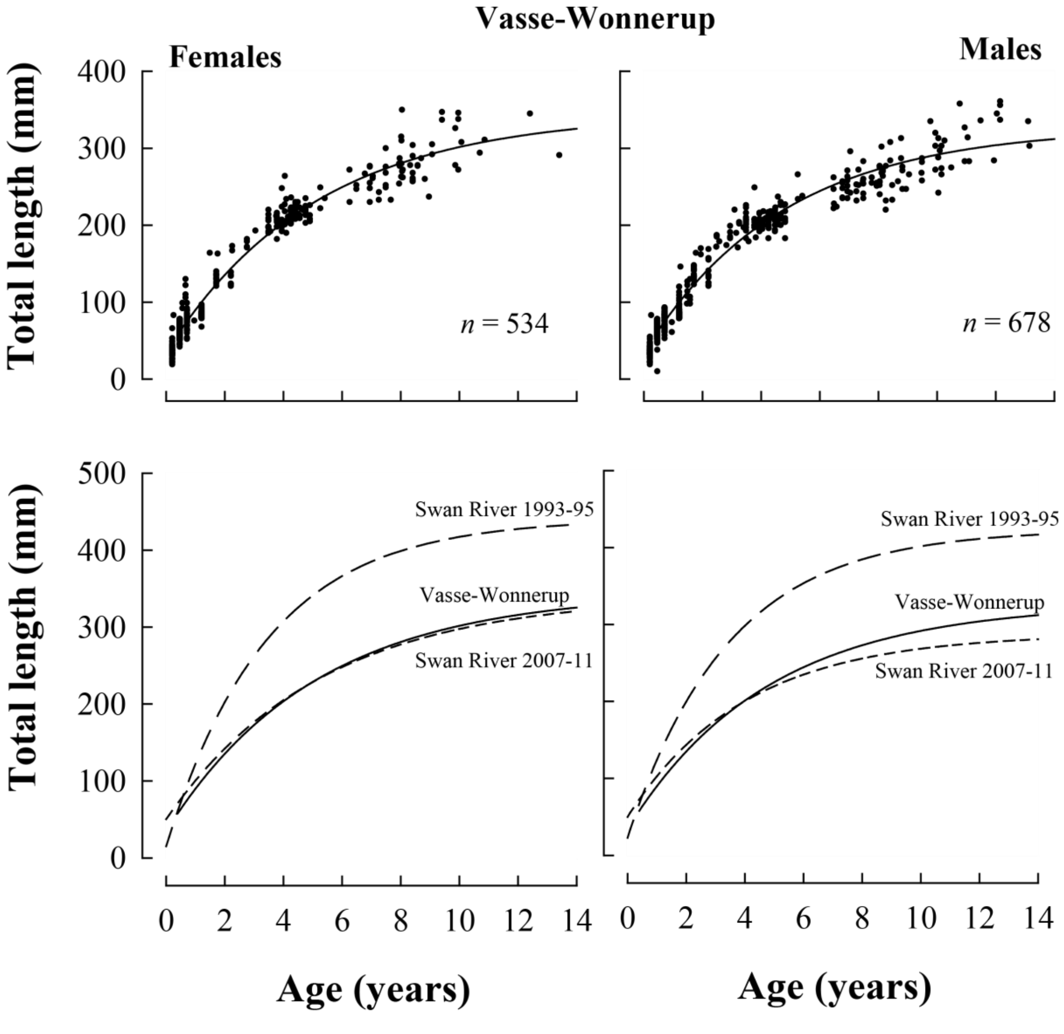

Figure 8. von Bertalanffy growth curves for female and male Black Bream from the Vasse-Wonnerup (top) and a comparison with those from the Swan River Estuary in 1993-95 and 2007-11 (bottom).

3.4 Spawning period

The mean gonad weights (standardised for a fish with a total length of 230 mm) of female Black Bream, increased from <1.8 g between January and April and from 2.1 g in June to ~10 g between July and September then declined to 2.3 g in December (Fig. 9). The mean gonad weights of male Black Bream followed a similar trend, rising from 2.8 g in June to between 6.3 and 13.3 g July and September then declined to 2.2 g in December. The peak in spawning of Black Bream in the Vasse-Wonnerup occurred earlier than that in the Swan River Estuary where the prevalence of fish with stage V/VI gonads, and their respective gonad weights peaks in November (Fig. 9).

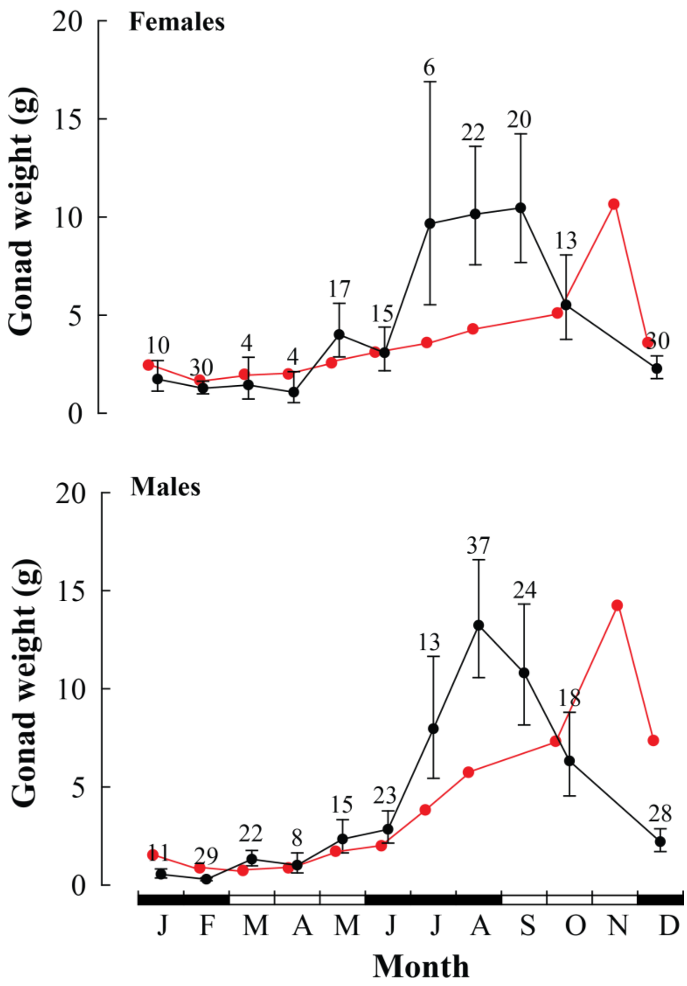

Figure 9. Monthly mean gonad weights and 95% confidence intervals for Black Bream caught in the Vasse-Wonnerup with lengths ≥L_{50} at maturity (●) and mean gonad weights for Black Bream in the Swan River Estuary in 2007-11 (●). The gonad weights have been standardised for fish of a common length (230 mm) using ANCOVA. Sample size of fish from the Vasse-Wonnerup is shown for each month.

Between January and April, almost all female Black Bream with lengths ≥L_{50} at maturity possessed virgin or resting ovaries (stage I/II; Fig. 10). The percentage frequency of occurrence of females with mature/spawning gonads (stage V/VI) increased from 0% in June to between 33 and 46% in July to October, before declining to 7% in December. The percentage frequency of occurrence of sequential stages in testis development followed a similar trend to that of ovaries, with the mature/spawning testes (stage V/VI) of males likewise being greatest between July and October (Fig. 10).

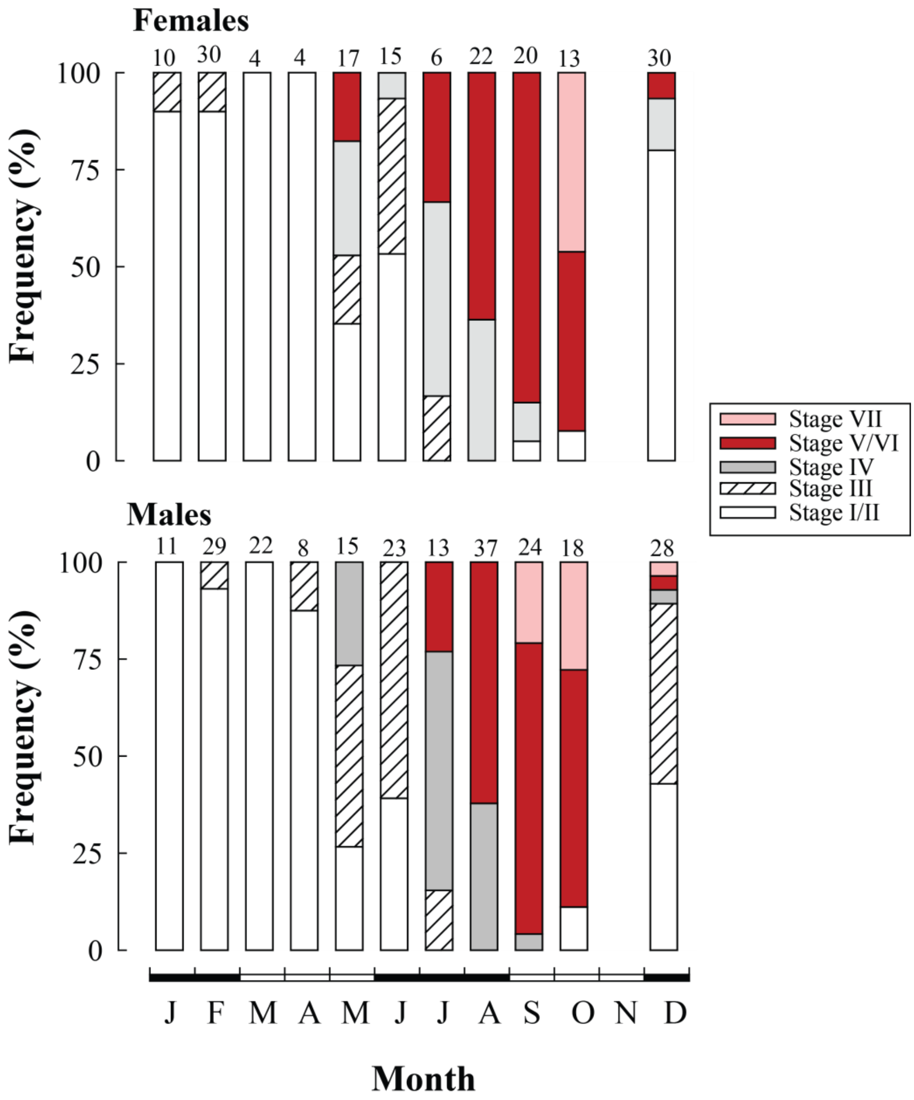

Figure 10. Percentage frequency of occurrence in successive calendar months of sequential stages in gonadal development stages in females and males of Black Bream with lengths ≥ L_{50} at maturity in the Vasse-Wonnerup. Sample size for each month is shown.

3.5 Length and age at maturity

During the spawning season (July to October) all females <140 mm in total length were immature (*i.e.* possessed gonad stages I/II) and all >180 mm were mature (*i.e.* possessed gonad stages III-VIII; Fig. 11). There were no females belonging to the 140-159 and 160-179 length classes present in the samples. Similar trends were exhibited by males, with all males <140 mm being immature and 75% of individuals of this sex in the 140-159 mm length class being mature and all males ≥160 mm in length being mature (Fig. 11).

The ogives describing the relationship between the proportion of mature females and males and total length in the Vasse-Wonnerup did not differ significantly ($P > 0.05$) from the corresponding sex in the Swan River Estuary in 2007-11. Thus, the L_{50} at maturity for females in the Vasse-Wonnerup of 163 mm (Table 5) was only slightly greater than the 156 mm recorded in the Swan River Estuary in 2007-11. The L_{50} at maturity for males in the Vasse-Wonnerup of 147 mm (Table 4) was slightly less than the 155 mm recorded in Swan River Estuary. However, care must be taken when drawing conclusions from these results as few fish <180 mm were represented in the samples. However, we are 95% confident that the length at maturity of females of Black Bream was between 142 and 186 mm (Table 6).

Table 6. Estimates of the total lengths (mm) and ages (years), and associated credible limits, at which 50% (L_{50} and A_{50}) and 95% (L_{95} and A_{95}) of female and male Black Beam were mature in the Vasse-Wonnerup Estuary and Swan River Estuary in 2007-11.

Estuary	Sex	Statistic	L_{50} (mm)	L_{95} (mm)	A_{50} (y)	A_{95} (y)	n_{length}	n_{age}
Vasse	**Female**	**Median**	**163**	**177**	**2.6**	**3.0**	**139**	**134**
		Lower	142	147	2.1	2.2		
		Upper	186	204	3.2	3.9		
	Male	**Median**	**147**	**155**	**2.1**	**2.5**	**201**	**194**
		Lower	138	144	1.9	2.1		
		Upper	155	173	2.3	3.1		
Swan	**Female**	**Median**	**156**	**188**	**2.5**	**3.7**	**422**	**422**
		Lower	151	181	2.4	3.4		
		Upper	161	198	2.7	4.1		
	Male	**Median**	**155**	**182**	**2.5**	**3.5**	**329**	**329**
		Lower	150	176	2.3	3.2		
		Upper	160	192	2.7	3.9		

All female Black Bream <3 years old were immature and all females that were ≥3 years old were mature. In the case of males, all 1 year olds were immature, whereas, 43% of 2 year old males and all of the male fish ≥3 years old were mature (Fig. 11).

The ogives describing the relationships between the proportion of mature females and age in the Vasse-Wonnerup and Swan River Estuary in 2007-11 did not differ significantly ($P > 0.05$) and the same was true for males. Thus, the A_{50} at maturity of 2.6 years for females and 2.1 years for males of Black Bream in the Vasse-Wonnerup were similar to those of the corresponding sex in the Swan River Estuary. However, as with the length at maturity, the very low numbers of 2 and 3 year old fish in samples resulted in relatively large credible intervals surrounding those median values. Thus, in the case of females, we are 95% confident that the age at maturity (A_{50}) was between 2.1 and 3.2 years. It is relevant, however, that in the Swan River Estuary, 56% of females had attained maturity by the end of their second year of life compared with 0% at that age in the Vasse-Wonnerup, indicating that spawning is typically delayed until the females are 3 years of age (Table 5, Fig. 11).

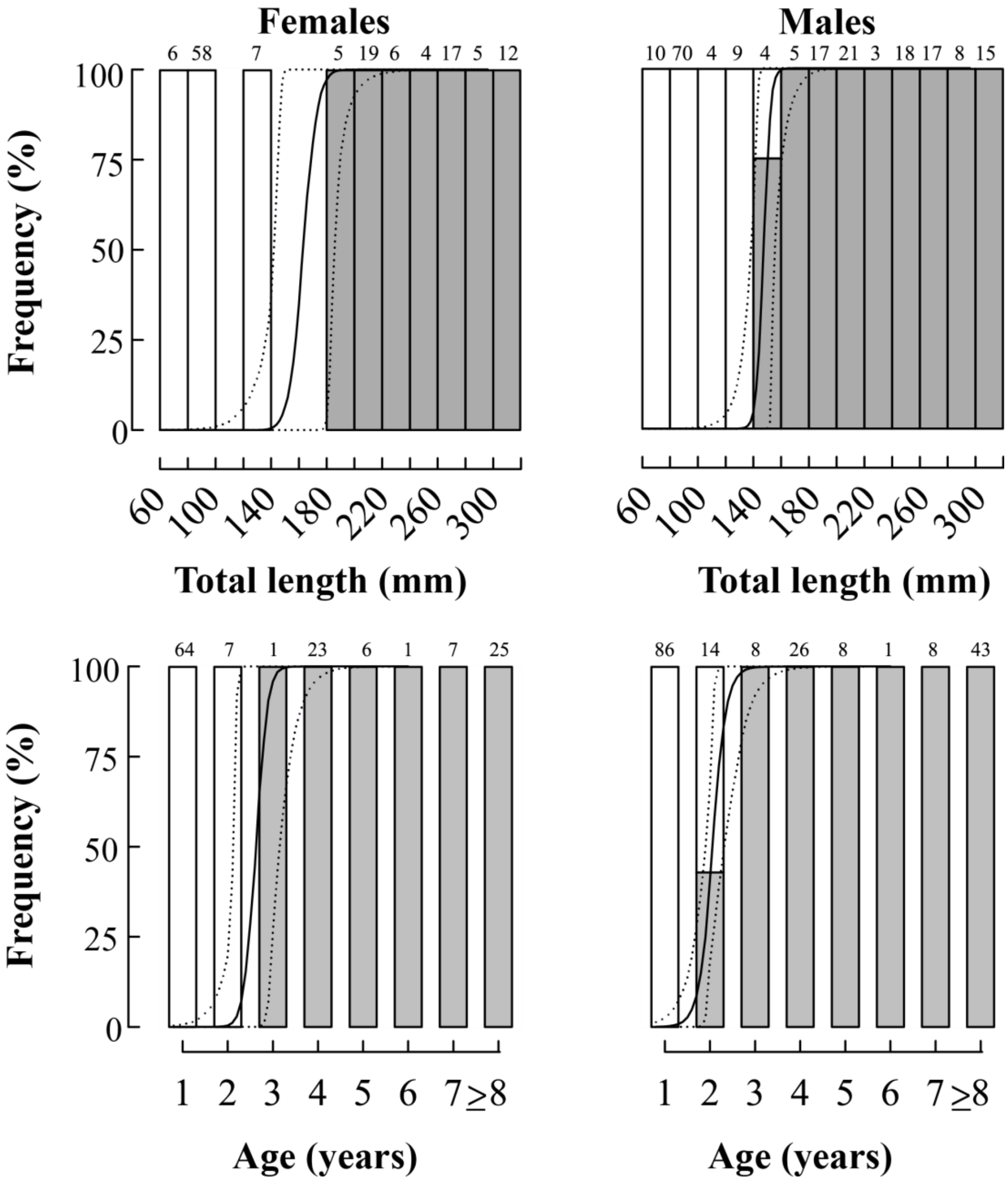

Figure 11. Percentage frequency of occurrence of female and male Black Bream with immature (white bars) and mature gonads (grey bars) in sequential 20 mm total length classes and in sequential ages during their spawning season in the Vasse-Wonnerup. Logistic curves (solid lines) and their 95% credible intervals (dotted lines) for the probability that a fish at a given length is mature were estimated using OpenBUGS. Sample size for each length class is shown.

3.6. Dietary composition

Although the major taxa present in the diets of Black Bream in the Vasse-Wonnerup were similar to those recorded in Black Bream from the Swan River Estuary, the frequency of occurrence and percentage volumetric contribution of each of the categories differed markedly. Thus, for example, while macroalgae occurred in 95% of the diets of Black Bream in the Vasse-Wonnerup, this category only occurred in 24% of diets in the Swan River Estuary (Table 7). The frequency of occurrence of detritus in the diets of Black Beam in the Vasse-Wonnerup was also substantially greater (48%) than in the Swan River Estuary (30%). In contrast to macroalgae and detritus, which are of low nutritional value, polychaetes, crustaceans and molluscs all occurred far less frequently in the Vasse-Wonnerup than in the Swan River Estuary. Teleosts did not occur frequently in the diets of Black Bream in either estuary (Table 7). The percentage volumetric contribution of macroalgae to the diets of Black Bream was 82% in the Vasse-Wonnerup compared with only 10% in the Swan River Estuary. While the contribution to the diets by polychaetes, crustaceans and molluscs were only 9% in the Vasse-Wonnerup, these prey categories accounted for 66% of the contribution to diets in the Swan River Estuary. On average, the guts of Black Bream in the Vasse-Wonnerup were ~36% full.

Table 7. Percentage frequency of occurrence (% F) and mean percentage volumetric contribution (% V) of the major dietary categories to the diets of Black Bream in the Vasse-Wonnerup and the Swan River Estuary in 2007. Data from the Swan River Estuary taken from Linke (2011).

Major	**Vasse-Wonnerup**		**Swan**	
Dietary Category	**% F**	**% V**	**% F**	**% V**
Macroalgae	95	82	24	10
Detritus	48	3	30	3
Polychaeta	30	6	61	25
Crustacea	3	2	69	22
Teleostei	3	2	5	1
Mollusca	1	1	59	19

4.0 Discussion

4.1 Temporal changes in Black Bream abundance

The density of predominantly juvenile Black Bream collected using a 21.5m seine net in the nearshore waters of Wonnerup Inlet and the Deadwater were found to change dramatically in the 14 consecutive seasons between February 2012 and May 2015. The greatest densities occurred in February 2012 and 2013 (both prior to the large fish kill), which is likely due to i) the movement of fish downstream from the markedly hypersaline Vasse and Wonnerup estuaries as occurs hypersaline reaches of other estuaries (*e.g.* Hoeksema *et al.,* 2006; Veale *et al.,* 2014) and ii) the presence of 0+ Black Bream, *i.e.* those fish spawned during winter and spring the year before (Sarre & Potter, 2000; Tweedley *et al.,* 2014a). The subsequent dramatic decline in abundance in August 2012, may reflect the upstream movement of fish following a decline in salinity levels and the restoration of a typical salinity gradient and/or the movement of those 0+ fish into deeper waters now they are larger and thus less susceptible to predation.

Following the large fish kill in April 2013, to which Black Bream contributed a very substantial proportion of the fish that died (Kath Lynch, Department of Water, pers. com.), there was an immediate and dramatic decrease in the abundance of Black Bream in the nearshore waters of Wonnerup Inlet and the Deadwater to almost zero. This situation continued for 18 months (including two spawning seasons) before low densities of 0+ Black Bream were recorded in November 2014. This provides strong evidence that the fish kill markedly reduced the abundance of 0+ fish and although some larger Black Bream were still present (see later), it might be possible that the spawning stock biomass, *i.e.* number of mature fish in this system, has become reduced to the extent where any natural recruitment is low. However, the presence of 0+ fish in November 2014 and in February and May 2015 is encouraging and suggests that some of the progeny of the spawning in July and August 2014 may have survived, although the extent of recruitment was still low.

In contrast to the nearshore waters where the density of Black Bream changed markedly over time, densities in the offshore waters did not change statistically over the two years. This was partly due to the fact that, unlike the nearshore waters, sampling was only initiated after the fish kill and so we are not able to comment on the population of large Black Bream prior to that event. The results of survey conducted seasonally for two years after the fish kill demonstrate that the population of larger Black Bream has not increased during this time. This is due to the fact the in order to be recorded in the gill nets fish need to be at least 100 mm total length and so the loss of the 0+ fish in the fish kill and the subsequent failure of the recruits since that event would have prevented 'new' fish reaching that size. Thus, these findings back up those data recorded from the nearshore waters and the analysis of year class strength. The lack of an increase in large Black Bream also indicates that there has not been substantial recruitment from Black Bream from the Port Geographe Marina where Black Bream are known to occur (Tweedley, unpublished data). Nevertheless, Black Bream are still one of the most numerous fish species in the deeper, offshore waters of the Vasse-Wonnerup and all efforts should be made to prevent future fish kills to maintain this population.

4.2 Condition, growth and maturity schedules

Although the recruitment success of Black Bream can be highly variable (*e.g.* Morison *et al.*, 1998; Jenkins *et al.*, 2010), the year class strength of fish collected from the Vasse-Wonnerup indicate that some recruitment occurred in each year up until 2012. These same data also demonstrate that, as hypothesised by Tweedley *et al.*, (2014a), there was limited recruitment success in both 2013 and 2014. As a result, the vast majority of the Black Bream in the estuary are representatives of the 2010 to 2012 year classes.

Body condition (*i.e.* the relationship between length and weight) is a well-used indicator of an animal's health and fitness (Peig & Green, 2009). At 250 mm total length (*i.e.* the length at which a Black Bream can be retained by a recreational fisher) a Black Bream from the Vasse-Wonnerup was 21 g (~8%) lighter than a Black Bream from the Swan Estuary in 1993-1995, despite the fish in the Vasse-Wonnerup being ~3.5 years older. This reduction in body condition is comparable to the decline in the Swan Estuary between 1993-1995 and 2007-2011, which Cottingham *et al*. (2014) attributed to the stress of decreasing freshwater discharge and a subsequent increase in the annual average extent of hypoxia

Comparisons of the growth rates of Black Bream in the Vasse-Wonnerup and Swan Estuary demonstrate that, in the Vasse-Wonnerup, females and males take 6.2 and 6.8 years, respectively, to reach 250 mm total length, which is around 3.5 years longer than in the Swan River Estuary, but similar to that recorded in that same estuary in 2007-11 following degradation of the estuarine environment. The slow growth rate of Black Bream in the Vasse-Wonnerup presumably dramatically increases susceptibility of Black Bream to fish kills and other environmental perturbations before being able to be retained by a recreational fisher.

The poor body condition and growth of Black Bream in the Vasse-Wonnerup suggests that these fish had low amounts of stored energy reserves. This hypothesis is supported by the fact that Black Bream in this system consumed a diet comprising predominantly macroalgae, which is of low nutritional value compared to invertebrates such as crustaceans, bivalve molluscs and polychaetes, which are consumed by Black Bream in other estuaries (Sarre *et al.*, 2000; Chuwen *et al*., 2007; Linke, 2011). Although the diets of Black Bream in the Vasse-Wonnerup Estuary comprised a greater amount of macroalgae than ingested by this species in the Swan River Estuary, the growth of Black Bream was almost identical. It may be relevant, however, that, in the Swan River Estuary in 2007-11, Black Bream were restricted to the shallow margins of the estuary as the deeper waters (>2 m) were often hypoxic (Cottingham *et al*., 2014; Tweedley & Hallett, 2014; Tweedley *et al*., 2015c) Thus, density-dependent effects were also implicated in the decline in growth in that estuary. In contrast, the density of Black Bream in the nearshore waters in the Vasse-Wonnerup was far lower.

It must also be considered that unlike in other estuaries in south-western Australia, Black Bream may occasionally exit the Vasse-Wonnerup into the reasonably sheltered waters of Geographe Bay and so feed and accrue some of their growth outside the estuary. This could be a life-history strategy to mitigate the limited food resources present within the estuary itself. Such a conclusion is supported by the results of a recently completed acoustic tracking study, which showed that the last detection of ~12% of tagged Black Bream occurred at the mouth of the entrance channel and that these fish not detected again inside the estuary (Beatty *et al*. in prep., see also 4.3 below).

An alternative or supporting contributor to the poor body condition of Black Bream could be the presence of infectious agents, such as fungi and parasites (Goede & Barton, 1990), which renders fish immunocompromised. This makes the fish more susceptible to disease and environmental stressors such as phytoplankton blooms and hypoxia (Lloret *et al*., 2013), and can thus potentially result in substantial mortality when the environment becomes degraded.

As there were few Black Bream of 2 and 3 years old in the samples, a likely consequence of recent fish kills, the length and age at maturity could not be estimated with a great degree of confidence. However, it is relevant that, unlike in the Swan River Estuary in 2007-11, where 56% of 2 year old female Black Bream were mature, maturity by females in the Vasse-Wonnerup Estuary was delayed until they were at least 3 years old. Although, this delayed maturation may also be due to the slightly poorer condition of Black Bream in the Vasse-Wonnerup it may also be related to the timing of spawning, which occurs immediately following winter, when body condition is typically poorest. Such poor condition can also decrease the reproductive potential of fish through a reduction in the number and quality of eggs and larvae (Lloret *et al*., 2013) and thus result in poor recruitment.

4.3 Implications for management and future directions

The population of Black Bream in the Vasse-Wonnerup Estuary appears under extreme stress, particularly from low dissolved oxygen concentrations, which has the potential to reduce the stock levels of Black Bream to below which it can recover. The along with ongoing efforts to reduce nutrient inputs into the system, both management and protection of specific fish habitats, and refinement of the operation of the surge barriers could benefit the fish communities. An acoustic tracking study on Black Bream has recently been completed (Beatty *et al*. in prep) that aimed to determine the spatial and temporal movement patterns of individuals throughout the system; including the passage through the Wonnerup and Vasse surge barriers and associated fish penstocks. This study confirmed that the population of Black Bream is largely restricted to Wonnerup Inlet, the Deadwater, and lower (~2 km) of the Vasse Estuary. The findings suggested that the Deadwater was the likely key spawning habitat for the species with all Bream at liberty being detected in that habitat for some time during the spawning period determined in the current study. While passage through the fish penstock on the Vasse fishgates was recorded during the study, it occurred when the water level below the gate was higher than above and that no fish passed back downstream through the penstock. This resulted in ~30% of Black Bream that were still being detected at the end of the study being present above the Vasse surge barrier. Given that the purpose of the penstock was to enable upstream and downstream passage of fishes and that the most severe fish kill events occur upstream of the gates during summer and autumn, the management of the penstocks are currently being reviewed along with possibly deploying oxygenation plants upstream of the Vasse surge barriers to help maintain adequate water quality during summer and autumn.

To ensure sustainability of this population in the future, there is a need for a refuge area for Black Bream to be created to protect the spawning stock. This could include introducing structure/habitat in the Deadwater to attract Black Bream and provide structure for potential food sources (*e.g.* bivalves). The establishment of an artificial oxygenation plant to ensure their survival during hypoxic events would also be of value. Surveys of the invertebrate communities are lacking and should be conducted in Wonnerup Inlet and the Deadwater to assess the level of prey availability for fish, including Black Bream. This could include calorific work to assess the nutrient content of the various prey items. While the invertebrate communities of the areas upstream of the surge barriers (*i.e.* Vasse and Wonnerup estuaries) has been surveyed recently (*e.g.* Chambers *et al.*, 2013; Tweedley *et al*., 2013) the invertebrate fauna in these waters are very different to that recorded in estuaries (Tweedley *et al*., 2011) and thus unlikely to reflect the communities in Wonnerup Inlet and the Deadwater, where the majority of Black Bream reside.

In the long term, to re-establish a productive Black Bream recreational fishery, water quality in the Deadwater must be improved to reduce macroalgae growth and promote a more diverse macroinvertebrate community, which, in turn, would provide more nutritional prey for Black Bream. As the stock of Black Bream in the Vasse-Wonnerup could be on the edge of collapse if recruitment failure continues, ongoing monitoring is also necessary to protect this iconic and valuable species. Although gill netting indicated that there had not been an increase in Black Bream numbers, this reinforced the fact that recruitment had not been successful. However, monitoring of these deeper, offshore waters is as valuable as looking for the 0+ fish as it enables the survival of the cohort to be tracked.

Furthermore, as Black Bream is confined to its natal estuary for the whole of its life cycle, the individuals of this species are exposed, throughout life, to any deleterious changes in environmental quality within that estuary. This feature, allied with its plastic biological characteristics, makes Black Bream an ideal candidate for exploring the ways and extent to which certain key biological characteristics of a fish species respond to detrimental and other changes in its environment. Consequently, Black Bream has the potential to act as a valuable indicator of the health of the estuary.

Acknowledgements

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