

Figure 15. Contribution to dietary carbon (grey bars; %CC) and size frequency distributions (white bars; %F) by size class of identifiable prey items examined from the stomachs of (a) combined ( $n = 140$ ), (b) summer ( $n = 27$ ), (c) autumn ( $n = 52$ ) and (d) winter ( $n = 61$ ) of *E. wongratanai* caught off the coast of Scottburgh, KZN in 2014 and 2015.

Table 9. Diet items found in stomachs of *E. wongratanai* ( $n = 140$ ) caught off the coast of Scottburgh, KZN in 2014 and 2015. %N = percentage of total prey items; %V = percentage volume of prey items; %F = percentage frequency of occurrence of prey items; %IRI = index of relative importance of prey items.

Prey items	All seasons			
	%N	%V	%F	%IRI
Acartiidae	0.02	0.02	0.71	0.00
Calanidae	16.85	14.27	65.71	17.77
Candaciidae	5.45	5.92	47.14	4.66
Centropagidae	1.25	1.08	28.57	0.58
Clausocalanidae	0.21	0.18	4.29	0.01
Corycaeidae	0.41	0.23	6.43	0.04
Decapod	2.12	0.38	26.43	0.58
Decapod larvae	1.28	0.04	22.14	0.25
Eucalanidae	42.48	55.82	68.57	58.58
Euchaetidae	2.07	2.41	32.86	1.28
Euphausiacea	0.05	0.00	1.43	0.00
Fish eggs	0.10	0.02	3.57	0.00
Fish larvae	3.55	10.63	27.14	3.35
Heterorhabdidae	0.05	0.06	2.14	0.00
Hyperiid amphipods	2.53	0.03	33.57	0.75
Mecynoceridae	0.09	0.12	2.14	0.00
Metridinidae	0.62	0.83	13.57	0.17
Mysid	0.03	0.09	1.43	0.00
Oncaeidae	16.23	4.65	60.00	10.89
Ostracoda	0.19	0.17	7.86	0.02
Paracalanidae	0.91	0.70	6.43	0.09
Pontellidae	0.02	0.03	0.71	0.00
Pseudodiaptomidae	0.51	0.51	10.00	0.09
Sapphrinidae	1.16	0.83	22.14	0.38
Temoriidae	1.30	0.86	26.43	0.50

Table 10. Diet items found in stomachs of *E. wongratanai* ( $n = 27$ ) caught off the coast of Scottburgh, KZN in summer 2014 and 2015. %N = percentage of total prey items; V = percentage volume of prey items; %F = percentage frequency of occurrence of prey items; %IRI = index of relative importance of prey items.

Prey items	Summer			
	%N	%V	%F	%IRI
Acartiidae	0.00	0.00	0.00	0.00
Calanidae	14.39	8.68	38.24	13.33
Candaciidae	3.60	2.66	11.76	1.11
Centropagidae	0.00	0.00	0.00	0.00
Clausocalanidae	0.38	0.23	2.94	0.03
Corycaeidae	1.89	0.84	14.71	0.61
Decapod	2.27	0.08	8.82	0.31
Decapod larvae	0.19	0.00	2.94	0.01
Eucalanidae	19.13	17.68	38.24	21.27
Euchaetidae	3.03	3.01	8.82	0.81
Euphausiacea	0.38	0.02	2.94	0.02
Fish eggs	0.00	0.00	0.00	0.00
Fish larvae	22.92	58.66	38.24	47.15
Heterorhabdidae	0.00	0.00	0.00	0.00
Hyperiid amphipods	4.55	0.05	29.41	2.04
Mecynoceridae	0.19	0.22	2.94	0.02
Metridinidae	0.57	0.53	5.88	0.10
Mysid	0.00	0.00	0.00	0.00
Oncaeidae	19.32	3.43	32.35	11.13
Ostracoda	0.38	0.29	5.88	0.06
Paracalanidae	0.00	0.00	0.00	0.00
Pontellidae	0.19	0.21	2.94	0.02
Pseudodiaptomidae	2.27	1.71	11.76	0.71
Sapphrinidae	0.95	0.54	14.71	0.33
Temoriidae	1.89	1.16	20.59	0.95

Table 11. Diet items found in stomachs of *E. wongratanai* ( $n = 52$ ) that contained food caught off the coast of Scottburgh, KZN in autumn 2014 and 2015. %N = percentage of total prey items; %V = percentage volume of prey items; %F = percentage frequency of occurrence of prey items; %IRI = index of relative importance of prey items.

Prey items	Autumn			
	%N	%V	%F	%IRI
Acartiidae	0.00	0.00	0.00	0.00
Calanidae	16.64	16.60	45.90	16.31
Candaciidae	4.73	6.42	42.62	5.08
Centropagidae	2.59	2.75	36.07	2.06
Clausocalanidae	0.10	0.15	1.64	0.00
Corycaeidae	0.00	0.00	0.00	0.00
Decapod	1.94	0.88	24.59	0.74
Decapod larvae	2.44	0.10	34.43	0.93
Eucalanidae	29.90	47.35	54.10	44.67
Euchaetidae	1.64	2.41	26.23	1.14
Euphausiacea	0.05	0.00	1.64	0.00
Fish eggs	0.25	0.07	6.56	0.02
Fish larvae	1.99	6.62	24.59	2.26
Heterorhabdidae	0.00	0.00	0.00	0.00
Hyperiid amphipods	1.40	0.02	21.31	0.32
Mecynoceridae	0.00	0.00	0.00	0.00
Metridinidae	0.40	0.64	8.20	0.09
Mysid	0.05	0.34	1.64	0.01
Oncaeidae	29.15	10.08	57.38	24.06
Ostracoda	0.20	0.24	6.56	0.03
Paracalanidae	2.64	2.54	14.75	0.82
Pontellidae	0.00	0.00	0.00	0.00
Pseudodiaptomidae	0.90	1.10	16.39	0.35
Sapphrinidae	0.65	0.62	14.75	0.20
Temoriidae	1.59	1.42	27.87	0.90

Table 12. Diet items found in stomachs of *E. wongratanai* ( $n = 61$ ) that contained food caught off the coast of Scottburgh, KZN in winter 2014 and 2015 %N = percentage of total prey items; %V = percentage volume of prey items; %F = percentage frequency of occurrence of prey items; %IRI = index of relative importance of prey items.

Prey items	Winter			
	%N	%V	%F	%IRI
Acartiidae	0.03	0.03	1.52	0.00
Calanidae	17.35	14.34	77.27	18.12
Candaciidae	6.18	6.36	54.55	5.06
Centropagidae	0.63	0.55	27.27	0.24
Clausocalanidae	0.24	0.19	6.06	0.02
Corycaeidae	0.36	0.22	3.03	0.01
Decapod	2.20	0.22	28.79	0.52
Decapod larvae	0.75	0.02	13.64	0.08
Eucalanidae	53.78	67.38	75.76	67.90
Euchaetidae	2.17	2.28	40.91	1.35
Euphausiacea	0.00	0.00	0.00	0.00
Fish eggs	0.03	0.00	1.52	0.00
Fish larvae	1.42	2.72	15.15	0.46
Heterorhabdidae	0.09	0.11	4.55	0.01
Hyperiid amphipods	2.89	0.03	36.36	0.79
Mecynoceridae	0.12	0.16	3.03	0.01
Metridinidae	0.75	0.98	18.18	0.23
Mysid	0.03	0.00	1.52	0.00
Oncaeidae	7.98	2.44	57.58	4.44
Ostracoda	0.15	0.11	7.58	0.01
Paracalanidae	0.00	0.00	0.00	0.00
Pontellidae	0.00	0.00	0.00	0.00
Pseudodiaptomidae	0.00	0.00	0.00	0.00
Sapphrinidae	1.51	0.98	28.79	0.53
Temoriidae	1.02	0.54	19.70	0.23

Large calanoid copepods (eucalanids and calinids) dominated numerically and in the index of relative importance, followed by oncaeids and fish larvae for all stomachs examined. Fish larvae and eucalanids were indicated to be the most important food item in summer according to the index of relative importance whereas eucalanids were the most important prey item in autumn and winter followed by oncaeids and calanids respectively (Figure 16).

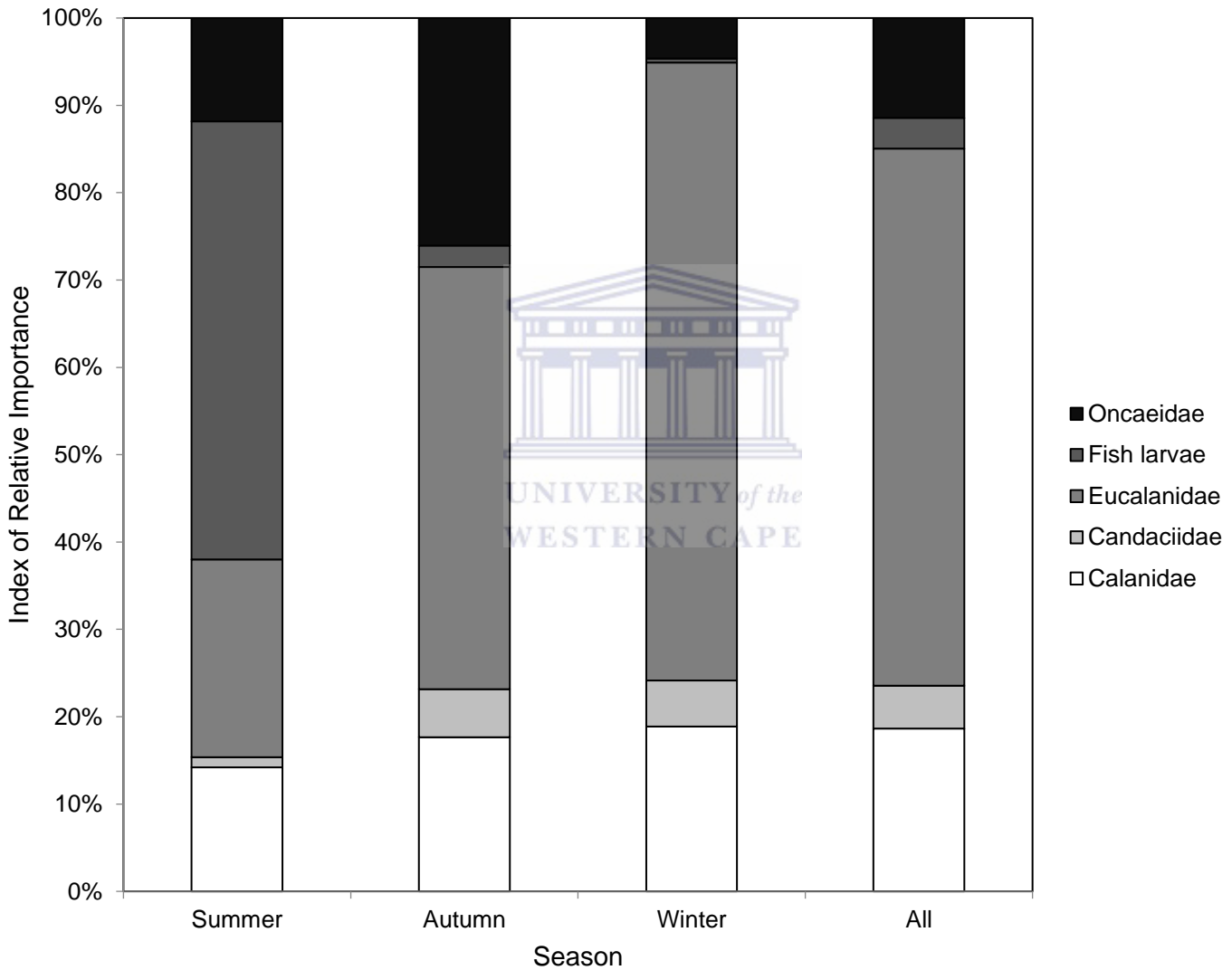


Figure 16. Index of relative importance (IRI %) of main prey items found in stomachs that contained food caught off the coast of Scottburgh, KZN in summer, autumn and winter 2014 and 2015.

### 3.5 Stable isotope analysis

Stable isotope ratios were calculated for 163 fish from May 2014 to April 2015. The overall mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  obtained for all fish were  $9.63 \pm 0.42$  ‰ and  $-17.84 \pm 0.57$  ‰, respectively. The mean  $\delta^{15}\text{N}$  for small, medium and large size classes were  $9.51 \pm 0.47$  ‰;  $9.54 \pm 0.43$  ‰ and  $9.8 \pm 0.30$  ‰, respectively (Table 13) whereas mean  $\delta^{13}\text{C}$  values were  $-18.01 \pm 0.55$  ‰,  $-17.69 \pm 0.43$  ‰ and  $-17.81 \pm 0.65$  ‰ for small, medium and large *E. wongratanai*, respectively (Table 13). The mean ratio of carbon-to-nitrogen (C:N) was greatest for large *E. wongratanai*, followed by small and medium sized fish (Table 13). Mean  $\delta^{15}\text{N}$  was greatest for fish caught in summer, followed by autumn, and then winter, while fish caught in winter were the most depleted in terms of  $\delta^{13}\text{C}$ , followed by caught in summer, then autumn (Table 14).

**Table 13.** Stable isotope measurements ‰ ( $\pm$  standard deviation) of *E. wongratanai* of different size classes; the number of samples ( $n$ ), mean caudal length (CL; mm), mean ( $\delta^{15}\text{N}$ ) values, mean ( $\delta^{13}\text{C}$ ) values and mean Carbon: Nitrogen ratios (C:N) are shown.

Size class	$n$	Mean ( $\pm$ std. dev.) CL (mm)	Mean ( $\pm$ std. dev.) $\delta^{15}\text{N}$	Mean ( $\pm$ std. dev.) $\delta^{13}\text{C}$	Mean ( $\pm$ std. dev.) C:N
Small (<131 mm)	53	118.77 $\pm$ 8.71	9.51 $\pm$ 0.47	-18.01 $\pm$ 0.55	4.22 $\pm$ 0.52
Medium (131-165 mm)	50	150.70 $\pm$ 10.32	9.54 $\pm$ 0.43	-17.69 $\pm$ 0.43	4.01 $\pm$ 0.52
Large (>165 mm)	60	178.35 $\pm$ 9.98	9.80 $\pm$ 0.30	-17.81 $\pm$ 0.65	4.49 $\pm$ 0.53

Table 14. Stable isotope measurements ‰ (± standard deviation) of *E. wongratanai* caught in different seasons; the number of samples (*n*), mean caudal length (CL; mm), mean (δ<sup>15</sup>N) values, mean (δ<sup>13</sup>C) values and mean Carbon: Nitrogen ratios (C:N) are shown.

Season	<i>n</i>	Mean (± std. dev.) CL (mm)	Mean (± std. dev.) δ <sup>15</sup> N	Mean (± std. dev.) δ <sup>13</sup> C	Mean (± std. dev.) C:N
Summer	40	170.37 ± 7.45	9.84 ± 0.33	-17.83 ± 0.64	4.61 ± 0.46
Autumn	10 1	142.66 ± 28.66	9.61 ± 0.43	-17.79 ± 0.41	4.05 ± 0.45
Winter	22	150.32 ± 20.28	9.3 ± 0.31	-18.08 ± 0.91	4.56 ± 0.70

All data were normally distributed except for δ<sup>13</sup>C values between seasons which failed Levene's test for normality and homogeneity of variances  $P < 0.05$ . There was a significant difference ( $F(2, 162) = 9.517, p < 0.001$ ) in δ<sup>15</sup>N between small, medium and large *E. wongratanai*. Large *E. wongratanai* were different in δ<sup>15</sup>N to medium ( $p = 0.02$ ) and small ( $p < 0.01$ ) sized fish, while there was no significant difference between medium and small *E. wongratanai* ( $p = 0.932$ ). There was a significant difference ( $F(2,162) = 4.326, p = 0.015$ ) in δ<sup>13</sup>C between size classes. Small and medium sized *E. wongratanai* were statistically different in terms of δ<sup>13</sup>C ( $p = 0.012$ ) while there was no difference between small and large ( $p = 0.152$ ), and large and medium sized *E. wongratanai* ( $p = 0.481$ ). There was a significant difference ( $F(2,162) = 13.745, p < 0.001$ ) in δ<sup>15</sup>N between fish caught in different seasons, while δ<sup>13</sup>C was not statistically different between fish caught in different seasons ( $F(2,162) = 2.320, p = 0.102$ ). In terms of δ<sup>15</sup>N fish caught in summer was different to autumn ( $p = 0.004$ ) and winter ( $p < 0.001$ ), and those caught in autumn were also different to fish caught in winter ( $p = 0.003$ ).

Regression analysis showed a weak but significant positive relationship of  $\delta^{15}\text{N}$  with fish size (Figure 217(a)) and of  $\delta^{13}\text{C}$  with fish size (Figure 17(b)). There was no significant relationship between  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  ( $\delta^{15}\text{N} = 0.078\delta^{13}\text{C} + 11.009$ ,  $R^2 = 0.011$ ,  $p = 0.187$ ) (Figure 18).

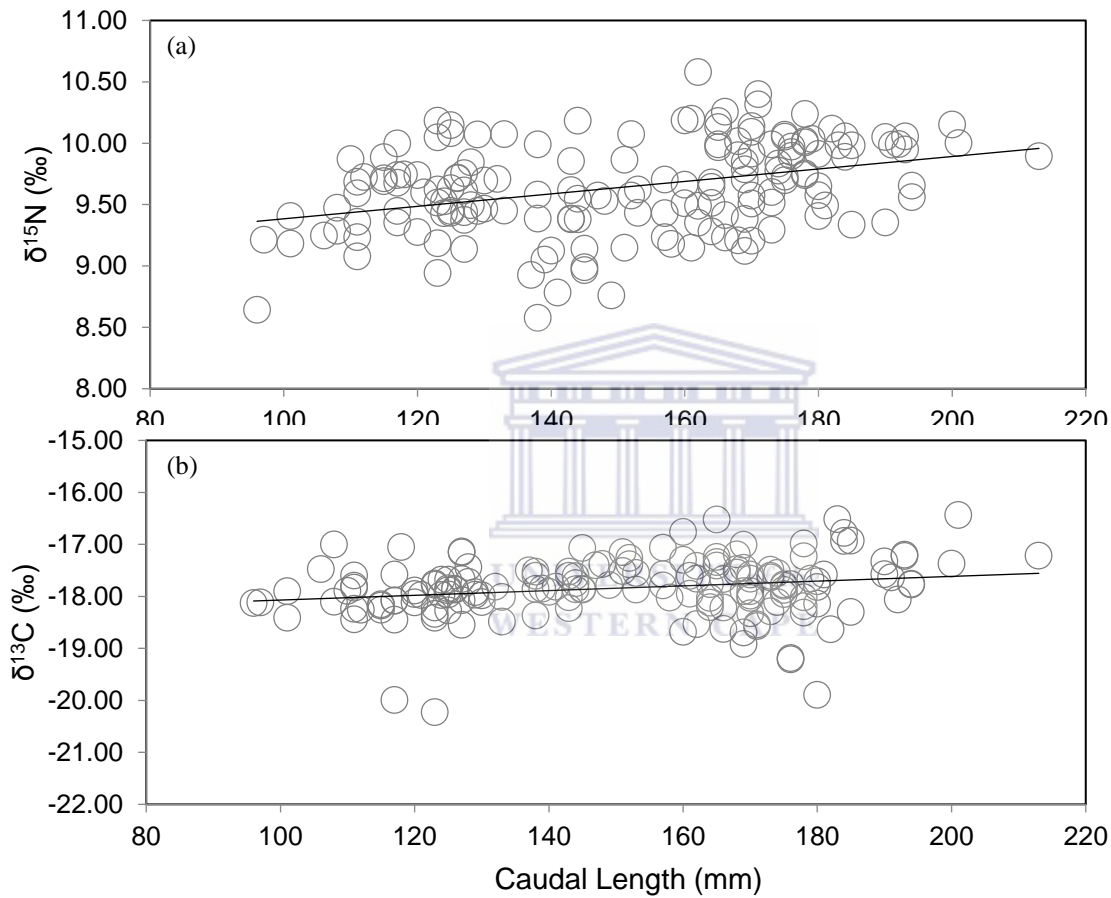


Figure 17. Changes in (a)  $\delta^{15}\text{N}$  ( $\delta^{15}\text{N} = 0.006\text{CL} + 8.7621$ ,  $R^2 = 0.131$ ,  $p < 0.001$ ,  $n = 163$ ) and (b)  $\delta^{13}\text{C}$  ( $\delta^{13}\text{C} = 0.005\text{CL} - 18.525$ ,  $R^2 = 0.046$ ,  $p = 0.006$ ,  $n = 163$ ) signatures with caudal length of *E. wongratanai* sampled off Scottburgh, KZN in 2014 and 2015 with fitted regression.

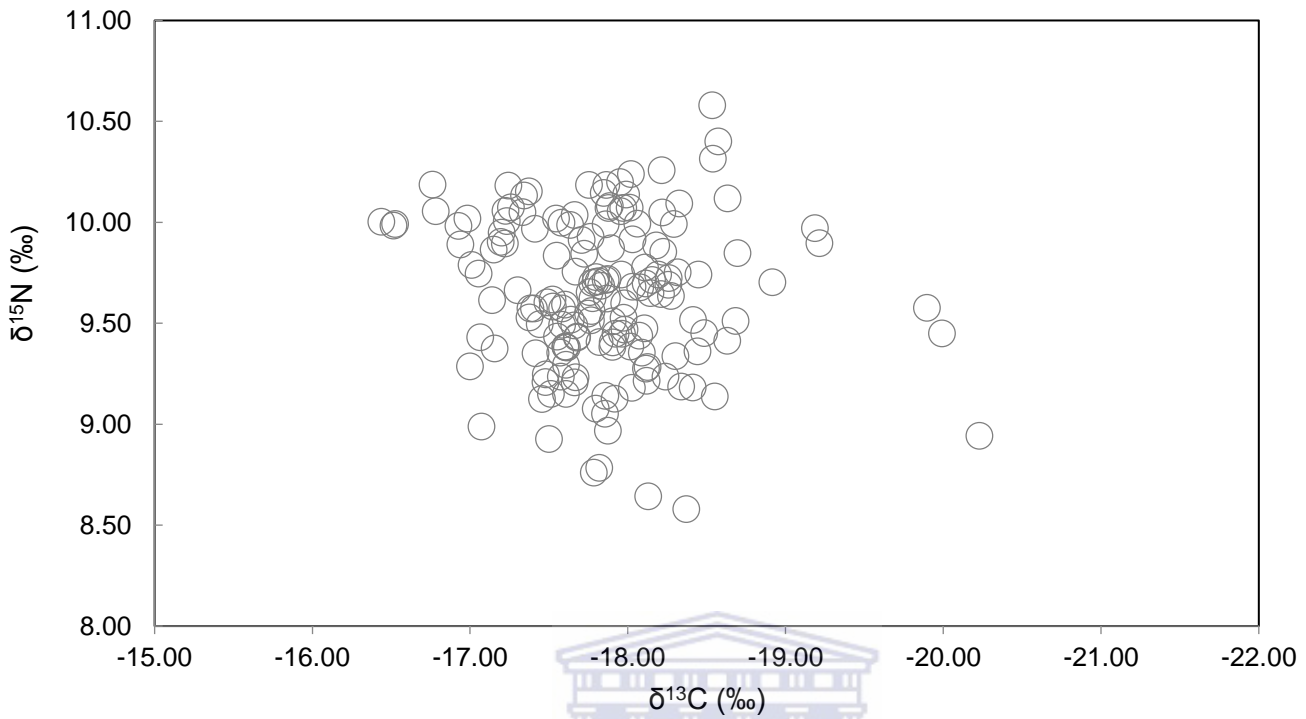
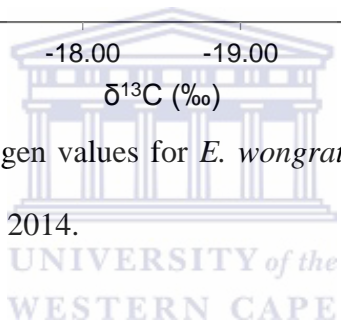


Figure 18. Stable carbon and nitrogen values for *E. wongratanai* white muscle tissue collected from Scottburgh, KZN in 2014 and 2014.



## Chapter 4: Discussion

### 4.1 Age and growth

There were significant, positive length-weight relationships which were best described with power curves for fish examined in this study (Table 3). These strong length-weight relationships observed in males, females and all individuals are in accordance with studies done on other *Etrumeus* species. As expected, the relationship between otolith-length with caudal length for *E. wongratanai* was best described by a linear relationship (Figure 7) (Araya *et al.* 2001). Geja *et al.* (in press) observed that the relationships between otolith-length and weight with caudal length for *E. whiteheadi* were best described by a power curve, which contradicts results observed in this study. However, the relationship between otolith-length and –weight with age was best described by a non-linear relationship, which is in accordance with the results obtained by both Geldenhuys (1978) and Francis and Campana (2004), who suggested that the relationship between otolith weight and age should be non-linear. Because as fish grow older, growth in total length, otolith length and otolith width slow down but otolith weight increases due to the continued deposition of material on otoliths (Blacker 1974; Boehlert 1985; Anderson *et al.* 1992; Francis and Campana 2004). There was no significant difference in the weight of left and right otoliths, suggesting that either side could be used for ageing, as Hunt (1979) observed that otolith pairs are mirror images of each other.

Information on the age of a species forms the basis of calculations of growth rate, productivity and mortality, which make it one of the most important biological variables (Campana 2001). These data on age of fish are especially useful when conducting stock assessments, since any estimated growth rate requires age data in their computation (Campana 2001). Although there are

several calcified structures that can be used for aging fish, otoliths have been applied over the broadest age range of species (Secor et al. 1995). As noted elsewhere, the aging of fish can be done at two scales; annual aging which is used in the harvesting calculations and population studies, and daily aging which is primarily used in the studies of young fish and recruitment (Casselman 1987). Age-bias plots of estimating age of *E. wongratanai* in this study (Figures 7, 8) indicated that there was no reader bias in the interpretation of annual growth zones to age estimates.

Precision estimates are given in Table 5. Precision can be defined as the reproducibility of repeated measures on any otolith, whether they are accurate or not (Campana *et al.* 1990). Consequently, precision cannot be used as a proxy for accuracy between readers, but rather the ease at which age can be determined from an otolith or an indication of the skill-level from one reader to another (Campana *et al.* 1990). When there is no obvious bias, CV and APE are similarly sensitive to differences in precision among readers, even though the CV is statistically more rigorous and flexible (Chang 1982). There are no designated target values for precision in ageing studies, due to the influence of life history traits. The CV in this study was calculated to be less than 5%, with a corresponding APE value of around 3% (Table 5). These values are a reflection of the ease at which annual growth zones of *E. wongratanai* were interpreted between readers. The general consensus in the literature is reporting CV values of less than 7.6%, which serves as a reference point for many fish of short to moderate longevity and reading complexity (Campana 2001).

No previous work has been conducted on the age and growth of *E. wongratanai*, and only a limited number of studies have been conducted on congeners elsewhere such as *E. whiteheadi* and *E. golanii* (Geldenhuys 1978; Waldron *et al.* 1991; Geja *et al.* in press; El-Sayed 1996; Yilmaz and Hossucu 2003; Mehanna and El-Gammal 2005; Farrag *et al.* 2014). *Etrumeus wongratanai* examined in this study ranged from 0 to 3 y. of age. Length-at-age for males in this study was 15.5 cm for 1 y. olds, 17.7 cm for 2 y. olds and 19.6 cm for 3 y. olds (Figure 10). In comparison, females were 16.2 cm at 1 y. old, 17.4 cm at 2 ys. old and 18.8 at 3 y. old (Figure 10).

*Etrumeus wongratanai* differs from its congener in South African waters, in this respect. In samples of *E. whiteheadi*, Geldenhuys (1978) and Waldron *et al.* (1991) reported individuals to range in age from 0 to 5 years old. Geja *et al.* (in press) observed *E. whiteheadi* to range between 0 to 4 years old for males and 0 to 8 year olds for females. These differences in age estimates could be attributed to differences in the environments occupied by the two species, with *E. whiteheadi* distributed primarily in the productive waters of the cold Benguela Current system off the west and southwest coasts whereas *E. wongratanai* is found in the warmer, oligotrophic waters of the east coast. Pauly (1998) noted that fishes from warmer waters tend to reach a lower maximum age and smaller maximum size than those fish of colder climes. Furthermore these differences in maximum ages could be a result of the sampling limitations in the fishery, as it is a spatially restricted area and may not have encompassed larger, older fish.

The values obtained for length-at-age of *Etrumeus wongratanai* in this study are also different to those reported for *E. whiteheadi* by Geldenhuys (1978), Waldron *et al.* (1991) and Geja *et al.* (in press). Geldenhuys (1978) reported length at age data to be 9.2 cm for 1 year olds and 16.3 cm for 2 year old fish. Waldron *et al.* (1991) reported mean length-at-age of fish aged 1.5 years old to be between 12.3 cm and 15.4 cm, 2.5 year olds to be 15.4 to 16.7 cm and 3.5 year olds to be 16.7 to 18.3 cm. Geja *et al.* (in press) observed mean length-at-age to be 11.6 cm at 1 year of age, 14.3 cm at 2 years of age, 16.3 at 3 years of age and 17.7 cm at 4 years of age. Parameter estimates in this study (Table 6) indicate a much faster growth rate when compared with that of Geja *et al.* (in press) for females, and this is even more pronounced in males. When all fish were combined and compared the two species appear to differ as well, with this study reporting a growth rate of 0.64 per year for *E. wongratanai* compared to 0.43 per year for *E. whiteheadi* reported by Geja *et al.* (in press). *Etrumeus wongratanai* appears to be a fast growing species in its first year of life, faster than has been reported for its congener *E. whiteheadi*. Although these differences in mean length-at-age could be attributed to errors in age estimation in the other studies (e.g. by mistaking the juvenile ring for an annual ring), that they are due to interspecific differences in the environment seems likely because fish tend to grow faster and mature quicker in warmer waters, than fishes that occur in cold or temperate waters (Pauly 1998). Identifying the first growth increment proves to be an important component of any age and growth study because with an incorrectly defined starting point, the age estimates will consistently be incorrect by a constant amount. Increased precision is imperative in age and growth studies because if a random error of one year is observed, it could introduce unacceptable error into all individual age estimates. Thus age validation or counts of daily rings are important for determining the precision of age estimations (Campana 2001).

Mean age-at-length of *Etrumeus wongratanai* in this study seems to be in accordance with previous studies conducted on *E. golanii* in the Gulf of Antalya in the Mediterranean Sea by Yilmaz and Hossucu (2003) and in the Egyptian sector of the Red Sea by Mehanna and El-Gammal (2005). Both studies noted that *E. golanii*, lived to a maximum age of 3 years. In contrast, Farrag *et al.* (2014) reported that *E. golanii* in the Egyptian Mediterranean Sea lived to a maximum age of 5 years. Growth rates of *E. wongratanai* were similar to those reported by Mehanna and El-Gammal (2005), but slightly higher than those reported by Yilmaz and Hossucu (2003) and Farrag *et al.* (2014) for *E. golanii*. The difference in maximum age groups between studies could be due to variation in habitats, length range and exploitation rate. Habitats could affect the maximum age to which fish survive due to shallow and deep habitats offering different amounts of food (Harvey and Nakamoto 1997). With a greater length range, fish are expected to be older at greater sizes and if fish are not overly exploited it gives an individual fish a chance to reach its maximum age. Similar to *E. wongratanai*, *E. golanii* has a high growth rate during its first year of life, which slows down as it increases in age, and this deceleration of the growth rate observed could associated with the onset of maturity.

#### 4.2 Length at maturity

Length-at-maturity is another important parameter in fisheries research as it indicates the “ideal” length to remove individuals from the population to ensure that a healthy spawning stock is maintained (Farrag 2010). The length at 50% maturity in this study was estimated to be 16.1 cm for females, which corresponds to an age of 1.1 y. The CL at which 50% of males attain sexual maturity was estimated to be 15.6 cm, which corresponds to a mean age of 1.5 y. All females

were deemed to be mature at a CL above 19 cm (3 y.) and all males were deemed to be mature at a CL above 18 cm (3 y.) (Figure 11). There was scatter with age-at-maturity data which could be a reflection of error in identifying gonad maturity stages accurately, and the absence of a properly conducted validation study which contributed to inaccuracy in age estimation, and these data should thus be treated with caution.

When compared to the length at maturity results published on *E. whiteheadi* by Roel and Melo (1990), *E. wongratanai* attains maturity at a greater caudal length than its South African congener which was found to attain first sexual maturity at 14.5 cm for both sexes, which is counter-intuitive given that fish mature faster and at smaller sizes when in warmer waters in comparison to cooler waters (Pauly 1998). The difference in length at sexual maturity could be due to the difference in assessing maturation stages between the two studies. Roel and Melo (1990) applied macroscopic and histological techniques, the former being more susceptible to subjectivity as maturity can only be recognized with confidence in a more advanced stage of the maturation cycle. The latter technique detects the first signs of the onset of maturation and is therefore more accurate, even though females used in that study were past the peak of the spawning season. Histological techniques were not used in this study.

*Etrumeus golanii* in Egyptian Mediterranean waters attained sexual maturity at a TL of 12.6 cm for males and 13.1 cm for females (Osman 2011), while in the Gulf of Suez maturity was attained at a TL of 12 and 12.2 cm for males and females, respectively (El-Sayed 1996). The present results of length at sexual maturity for *E. wongratanai* are not consistent with these previously mentioned studies, but are in accordance with Sanders *et al.* (1984) who reported

length at maturity for female at 16.36 cm (corresponding to an age of 1.73 years) and 16.17 cm (1.70 y.) for male *E. golanii*. Differences in age at maturity between studies on the same species likely depends on the environmental conditions under which maturation takes place and the nature of the population (density-dependent growth) when length-at-maturity was determined. This is because growth is inhibited by intraspecific competition for food if stock sizes are large and this has been reported for many marine fish (Overholtz 1989; Helser and Almeida 1997; Sinclair *et al.* 2002; Moyle and Cech 2004).

#### 4.3 Gonadosomatic index and condition factor

The gonadosomatic index (GSI) is a cost effective method to indicate changes in reproductive condition and time of spawning (Plaza 2007). *Etrumeus wongratanai* showed high GSI values from June to December for the pooled data (Figure 12), whereas females showed high GSI values from May to December and males from July to December (Figure 13). These values indicate that the breeding season lasts between 8 and 6 months for females and males respectively, and that spawning takes place from the onset of winter to early summer. These findings are consistent with the observations of Connell (2001), who observed that *E. wongratanai* eggs were seen in small numbers through summer, but that spawning peaked in June to December based on the density of eggs at Park Rynie along the Kwazulu-Natal coast. There was a significant difference in GSI values between sexes (Table 7), which can be attributed to the need of male pelagic fish to produce large amounts of sperm to ensure fertilization of eggs, which is counter-intuitive since females typically have higher GSI values than males (Cole 2010). Spawning behaviour is often associated with ecological factors that influence the timing of spawning activity. Food availability is an example of an important

ecological factor in determining the timing of spawning activity, as the number of food items with high nutritious value available in the environment should ensure that larval growth is optimal; other ecological factors that can potentially influence spawning include temperature, day length, latitude, photoperiod, salinity and exposure (Cole 2010). For most fish, temperature controls maturation and the onset of spawning, but the mechanism by which it is controlled is still uncertain (Cole 2010). The temperature range in which spawning occurs is quite narrow, which is a limiting factor for geographical distribution of species. In low latitudes there is little variation in day length and as such food selection could play a vital role in gonadal development (Cole 2010). The reproductive period of fishes tends to decrease with increasing latitude; therefore fish that occur at high latitudes tend to have a short reproductive period, whereas fish that occur in the tropics spawn almost continuously (Cole 2010).

The monthly fluctuations in GSI values suggest that *E. wongratanai* is a serial spawner. This hypothesis is consistent with the observations of Roel and Melo (1990), who showed that *E. whiteheadi* is a serial spawner with a prolonged spawning period and it shares the reproductive characteristics of other well studied pelagic species that occur in South African waters such as sardine and anchovy. However, older fish frequently spawn earlier than younger fish; therefore a prolonged spawning season might not be accurate for individual fish (Cole 2010). The prolonged spawning season suggested here could be due to differences in spawning time between age groups.

Osman (2011) reported that the highest GSI values for *E. golanii* were observed during December to May for females and December to July for males in the Mediterranean Sea, with

the start of the spawning season coinciding with the onset of winter. El-Sayed (1996) reported results for *E. golanii* sampled off the Gulf of Suez and Plaza (2007) observed *E. micropus* in southern Japan. These authors indicated that spawning occurs with the onset of winter towards the end of spring and concluded that their respective species are serial spawners, which are in agreement with the present study. Fahay (1983) and Shaw and Drollinger (1990) reported that *E. sadina* in the Gulf of Mexico spawns from winter to summer during late January to early June, which agree with the results of the present study. In the case of *E. sadina* off the Eastern Gulf of Mexico, Houde (1977) reported that they spawn offshore from mid-October to the end of May.

Average fish size varied between years. In 2013, fish were (on average) smaller in July and August, whereas in 2014 fish were largest from May onwards. In 2015, fish were smallest in May through to June. There seems to be inter-annual variability in average fish size but average length data reported do not reflect a full year of catches due to the opportunistic nature of the fishery and thus should be treated with caution.

Condition factor is an indicator of the health of fish, and provides information on the variation in physiological status (Kreiner *et al.* 2001): it can be used for comparing populations as condition factor varies with weight, length and season for the same species (Parrish and Mallicoate 1995). The highest average values for condition factor in the present study were recorded in 2013, and were lowest in 2016. Condition factor was lowest in May through to August and increased from September in 2013, 2014 and 2015. The low condition factor values from May through to August could be due to the physiological strain during the spawning season (Farrag 2010). It is also likely that the condition of fish could be influenced by temperature, day length, food

availability, maturity stage and density-dependent effects (Parrish and Mallicoate 1995; Samat *et al.*, 2008). Density-dependent effects have been reported for sardine from the southern Benguela where CF and standardized gonad mass were lower when fish were abundant and higher when abundance was low (van der Lingen *et al.* 2006).

In this study, week number explained 32% while year explained 4% of the variation in condition factor of *Etrumeus wongratanai* (Table 6); this suggested a seasonal pattern of condition factor with a more consistent seasonal signal from year to year. Due to a lack of data in the summer months when fish are scarce, the whole seasonal cycle in CF (or GSI) could not be well established.

The findings in this study are in accordance with Farrag *et al.* (2014) who indicated that *E. golanii* collected in the Egyptian Mediterranean Sea showed the highest condition factor during July (summer), while the lowest was recorded from December to May (winter to spring) for females and early July (winter) for males. By contrast, El-Sayed (1996) and Yilmaz and Hossucu (2003), all of whom reported peak condition in January (winter) and spring for *E. golanii* from the Gulf of Suez and the Gulf of Antalya in the Mediterranean. These differences could be attributed to change in temperature and photoperiod and its knock-on effects of food availability which contributes to somatic growth and wellbeing of fish (Samat *et al.* 2008).

#### 4.4 Seasonal variation in diet

Highest feeding intensity in *E. wongratanai* was observed during winter, followed by autumn and summer (Figure 16). The vacuity index (VI) was highest in summer, followed by autumn and winter. The vacuity index is an inverse indication of feeding intensity, which is influenced

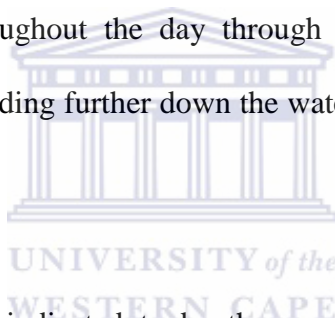
by fish abundance, spawning time, as well as seasonal changes in surface water temperature and available food items (Sakamoto *et al.* 1982). When fish are abundant density-dependent factors such as intraspecific competition for food affect the populations' feeding ability and this has been reported for many marine fish (Overholtz 1989; Helser and Almeida 1997; Sinclair *et al.* 2002; Moyle and Cech 2004). The vacuity index is expected to be low during the spawning season as fish need a greater energy input in the spawning season to meet the requirements of reproduction (Tsikliras *et al.* 2005). Surface water temperature, which is a good proxy for nutrient enrichment, influences the size and structure of plankton communities. When ocean water is cold and well mixed, sporadic nutrient enrichment of the euphotic zone occurs and this promotes the development of phytoplankton and in turn affect zooplankton communities and size structure. In cold water zooplankton communities are dominated by crustaceans such as large copepods and can support large numbers of fish (van der Lingen *et al.* 2006; Richardson 2008). Whereas, if surface waters are warm, stratified and stable they are nutrient deficient, and the phytoplankton community is dominated by small dinoflagellate and nanoflagellate populations, which results in the zooplankton community being dominated by gelatinous zooplankton and small crustaceans (van der Lingen *et al.* 2006; Richardson 2008). This is an indication of how water surface temperature influences the composition of zooplankton which becomes available to fish and thus affects their feeding intensity. That feeding intensity was highest during the spawning season (winter), and is in accordance with Farrag *et al.* (2010), who suggested that spawning fish need a higher energy input in order to meet the physiological demands of reproduction (Froese and Pauly 2000).

When data were pooled and considered by season, the diet of *E. wongratanai* was numerically dominated by prey items in the 1001-2000  $\mu\text{m}$  size class, though prey in the 2001-3000  $\mu\text{m}$  size class made the greatest contribution to dietary carbon (except during autumn, when prey  $>5000$   $\mu\text{m}$  were most important). Due to a lack of samples, the difference in prey size classes per season was more pronounced at prey size class extremes, but could be a reflection of the available food environment at the time of feeding (Lazarro 1987). Feeding on larger zooplankton increases the food consumption and net energetic gain, as feeding would be influenced by the increased handling time needed to ingest an equivalent biovolume when only small zooplankton are available for particulate feeders (van Deurs *et al.* 2014). The fish examined were caught during the day, most likely at different depths and this could have had an influence on our understanding of their diet, particularly if they also feed at night. This is because zooplankton and especially copepods are patchily distributed, occupy different layers of the water column and display different diel vertical migration behaviours (Daro 1988; James 1988; van Deurs *et al.* 2014).

The *Etrumeus wongratanai* collected here generally fed on large prey items, and this finding concurs with those of Mketsu (2008) and Vorsatz *et al.* (2015). In comparison to other local clupeoid species on the east coast, *E. wongratanai* tends to feed on the same size prey items as *E. whiteheadi*, but on larger prey items than do either anchovy and sardine (Vorsatz *et al.* 2015).

No phytoplankton was found in any of the stomachs examined, which is consistent with previous observations (Mketsu 2008; Vorsatz *et al.* 2015) and can perhaps be attributed to the low productivity of the environment and the minimum particle size *E. wongratanai* is able to

efficiently retain due to its gill-raker gap size (Vorsatz *et al.* 2015). The stomach contents documented in this study were dominated by zooplankton, which is in agreement with the findings of Blaxter and Hunter (1982) who noted that clupeoid fish from areas of low productivity tend to feed mainly on zooplankton. Fish larvae and large copepods were the most frequently occurring prey items in summer (Table 10), small (oncaeids) and large (eucalanids) copepods were the most frequently occurring prey items in autumn (Table 11), and large copepods (eucalanids and calanids) were the most frequently occurring prey items in winter (Table 12). The presence of copepods, fish larvae and hyperiid amphipods suggests that *E. wongratanai* feeds throughout the water column as zooplankton tend to concentrate at different depths of the water column throughout the day through diel vertical migrations to escape predators during the day by descending further down the water column and ascending at night to feed (Osman 2013).



Fish larvae and eucalanids were indicated to be the most important food item in summer according to the relative index of importance, whereas eucalanids were the most important prey item in autumn and winter followed by oncaeids and calanids respectively (Figure 21). Overall, large copepods were the dominant prey items in terms of frequency and relative importance. When primary productivity is similar in certain areas or seasons it is expected that different species of large and small copepods are abundant (van Deurs *et al.* 2014). Given this, it is not possible to exclude the fact that prey items found in the stomachs of *E. wongratanai* reflect what is available in its food environment at the time of feeding, rather than a mechanism of selective feeding on larger copepods and other zooplankton, because samples of the ambient environment at the time of fish sampling were unavailable. However, fish have the ability to adjust their diet

according to the seasonal abundance of prey items (Nieland 1982). The dominance of large copepods and other zooplankton suggests that there is some degree of selectivity in this species. If optimal foraging is employed by *E. wongratanai* it is highly unlikely that it would mainly focus on small prey items simply due their low contribution to ingested carbon, however, this needs to be corroborated with zooplankton data of the environment fish were caught in. The dominance of fish larvae in stomachs in summer months is indicative of spawning of clupeoid and other species along the east coast of South Africa, as *E. wongratanai*, *Sardinops sagax* and chub mackerel *Scomber japonicus* all display a peak spawning period between May to December off the coast of KwaZulu-Natal (Connell 2001). It is likely that these species spawn offshore; as this could partially explain the low frequency of fish eggs in the stomachs of *E. wongratanai* and only once they become larvae do they move inshore into an environment where they become vulnerable to predation by *E. wongratanai*. This is in accordance with Beckley and van Ballegooyen (1992), who observed that fish larval concentration decreased as you move further offshore in the Agulhas Current.

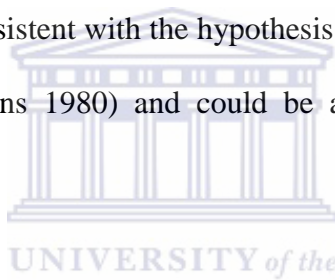
Species of *Etrumeus* across the globe tend to display similar zooplanktivorous feeding behaviours. Osman (2013) observed *E. golanii* in the Egyptian Mediterranean Sea to feed mainly on small crustaceans, fish larvae and mollusks. Small crustaceans were the major prey item in all seasons except for summer where fish larvae were preferred, which was proposed to be due to the increase in the abundance of fish larvae during the summer. Chen *et al.* (1992) reported that *E. sadina* from the Gulf of Mexico feeds primarily on euphausiids, fish larvae, copepods and gastropods, while Bianchi *et al.* (1993) reported that *E. whiteheadii* from Namibian waters feed mainly on copepods. In the East China Sea, Tanaka *et al.* (2006) reported that the stomach

contents of *E. micropus* were dominated by large calanoid copepods. These slight differences in prey items can be attributed to the food environment of each region in different habitats.

#### 4.5 Stable isotope analysis

The stable isotope data suggest that there are gradual changes in the diet of *E. wongratanai* as it increases with size. Large *E. wongratanai* had greater  $\delta^{15}\text{N}$  values than medium and small sized fish, although there were no significant differences in  $\delta^{15}\text{N}$  of medium and small size classes of *E. wongratanai*. There were also differences in  $\delta^{13}\text{C}$  values between size classes, however these results are inconclusive as the Tukey test was not powerful enough to recognise which group the large fish belonged to, and both  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of individual fish were significantly positively correlated with CL. These variations in isotopic signatures with size likely indicate that there is an increase in trophic level arising from dietary change and could also have been an effect of size-dependent metabolic turnover, or an accumulation of specific biochemical components (Rossi *et al.* 2004). The variations in isotopic signatures with size can further be attributed to shifts in metabolic demands (Levy 1990), prey availability, habitat, morphology or behaviour (Grossman *et al.* 1980). A consumer's growth rate can explain most of the variation observed in stable isotope ratios (Van der Zanden *et al.* 1998). Fish growth is a function of temperature, prey quality, and mass-specific consumption, as the respiration rates of fish decrease as fish size increases (Kitchell *et al.* 1977). Fish tend to grow faster in warmer waters and water temperature in turn affects the nutritional quality of prey items, as large prey items with high nutritious quality are found in cooler waters with high productivity and fish need to consume enough food in order to meet their metabolic demands (Pauly 1998).

Classical resource partitioning theory suggests that two competitors for the same resource can co-exist if that resource is partitioned differently amongst them (Schoener 1974). Fish generally grow in size during their ontogeny (Werner and Gilliam 1984) and this growth could lead to different resource use at different life stages. The most commonly mentioned explanation for ontogenetic dietary shifts in planktivorous fish is the development of the feeding apparatus (King and Macleod 1976, Gerking 1994). Therefore differences in the diet are associated with the size of the prey items that can be efficiently retained in the gill-rakers (Costalgo *et al.* 2012). Vorsatz *et al.* (2015) have shown that *E. wongratanai*'s gill raker gap increases with increasing fish size, thus affecting the prey size it could retain. The ontogenetic shift in the diet of *E. wongratanai* could then be considered to be consistent with the hypothesis that trophic relationships in pelagic food webs are size based (Cousins 1980) and could be an explanation for the increase in  $\delta^{15}\text{N}$  values of larger fish.



Stable isotope values for  $\delta^{15}\text{N}$  were significantly different between seasons, and were highest in summer, followed by autumn then winter. And while  $\delta^{13}\text{C}$  values were highest in autumn, followed by summer then winter, there was no significant difference between seasons. The differences in  $\delta^{15}\text{N}$  could be attributed to differences in the available prey environment in the different seasons, as observed in the gut content analysis (this study) where fish larvae were the most important food item in summer. Such prey would tend to have a higher  $\delta^{15}\text{N}$  than copepods, which were found to be more important in autumn and winter. Furthermore, seasonal variations in isotopic signatures could be due to seasonal differences at the base of the food chain and thus be caused by biogeochemical factors that affect stable isotope ratios of primary producers (Michener and Schell 1994). These factors, which affect  $\delta^{13}\text{C}$ , include the available forms of

dissolved oxygen (which is determined in part by temperature), the metabolic pathways used to fix carbon and phytoplankton growth rates, the latter of which are influenced by light and trace nutrient concentrations (Michener and Schell 1994). Nitrogen values ( $\delta^{15}\text{N}$ ) are similarly dependent on the composition of dissolved inorganic nitrogen which differs on the rate of nitrogen recycling in surface waters (Michener and Schell 1994).

Carbon-to-Nitrogen (C:N) ratios were all greater than 3.5, which suggests samples of *E. wongratanai* had a high lipid content, and this could introduce measurement error when interpreting  $\delta^{13}\text{C}$  in stable isotope analyses. It has been found that measurement error increases in  $\delta^{13}\text{C}$  analyses with an increase in lipid content (Post *et al.* 2007). Lipids are generally more depleted in  $\delta^{13}\text{C}$  than proteins and carbohydrates, meaning that a variation in lipid content between organisms can introduce bias in  $\delta^{13}\text{C}$  in stable isotope analyses (Post *et al.* 2007). Analyses of  $\delta^{13}\text{C}$  and C:N ratios can also be influenced by variations in the fractionation of  $\delta^{13}\text{C}$  during lipid synthesis, which results in differences between lipids, protein and carbohydrates by 6-8‰ (De Niro and Epstein 1977). Due to the heterogeneity of tissue types found in aquatic organisms, considerable bias could also be introduced by large differences in  $\delta^{13}\text{C}$  in lipids and other tissue types and the difference in lipid content between organisms (McConnaughey and McRoy 1979). Therefore in order to accurately estimate  $\delta^{13}\text{C}$  in aquatic animals it is necessary to account for lipid content when C:N ratios are consistently high (>3.5) (Post *et al.* 2007), either by chemical extraction of the lipid or by mathematical correction. Carbon-to-Nitrogen (C:N) ratios may also have an effect on  $\delta^{15}\text{N}$  values (Logan and Lutcavage 2008) but this is considerably smaller than for  $\delta^{13}\text{C}$ . Due to time and logistical constraints, fractionation was

precluded from this study and could be a reason for the depleted  $\delta^{13}\text{C}$  value observed in this study.

The mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  obtained here were  $9.63 \pm 0.42 \text{ ‰}$  and  $-17.84 \pm 0.57 \text{ ‰}$ , respectively. Nitrogen and carbon values were generally (substantially) lower than those reported for other *Etrumeus* species from around the world. In southern Africa, Sholto-Douglas *et al.* (1991) reported *E. whiteheadi* in the southern Benguela to have  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of  $13.7 \pm 0.8 \text{ ‰}$  and  $-16.2 \pm 0.9 \text{ ‰}$ , respectively, whilst van der Lingen and Miller (2011) reported a  $\delta^{15}\text{N}$  value of  $12.2 \pm 0.9 \text{ ‰}$ . Erasmus (2015) reported  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of  $11.09 \pm 1.77 \text{ ‰}$  and  $-16.86 \pm 1.15 \text{ ‰}$ , respectively for *E. whiteheadi* from the northern Benguela. Ahmad-Syazni *et al.* (2001) reported that *E. micropus* sampled in Hiroshima Bay, Japan had  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of  $16.41 \pm 1.0 \text{ ‰}$  and  $-15.6 \pm 0.4 \text{ ‰}$ , respectively. According to Gendron *et al.* (2001) *E. sadina* from Bahia de la Paz was shown to have  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of  $13.9 \text{ ‰}$  and  $-17.9 \text{ ‰}$  (no standard deviations reported). In comparison to these authors, *E. wongratanai* appear to sit at a lower trophic level. These differences could be due to regional baseline differences as these fish come from different ecosystems and are predisposed to different sources and types of nitrogen integrated into production (Waser *et al.* 2000, Montoya *et al.* 2002, Waite *et al.* 2007, van der Lingen and Miller 2014). In the Benguela Current ecosystem, upwelling plays a major role in making nitrogen available to organisms (van der Lingen and Miller 2014), in comparison to the Agulhas Current ecosystem where recycled and Nitrogen-fixed nitrogen are important (Montoya *et al.* 2002, Waite *et al.* 2007, van der Lingen and Miller *et al.* 2014). The hydrographic conditions of Hiroshima Bay, with its variable salinity and sea-surface temperature, results in a well-mixed water column year-round, which in turn, results in continued nutrient regeneration

and high levels of primary productivity (Ahmad-Syazni *et al.* 2001). These differences in oceanographic processes, thus make comparisons between ecosystems difficult.

*Etrumeus wongratanai* appear to have lower values of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  than reported for sardine sampled off the east coast in 2009 and 2010, with sardine there having a mean  $10.2 \pm 0.6$  ‰ and  $-13.3 \pm 1.0$  ‰ for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ , respectively (van der Lingen pers. comm.). This is counter-intuitive, considering that sardine are primarily filter-feeders that feed on small zooplankton (and phytoplankton) whereas east coast redeye feed on larger zooplankton (this study), but could be a reflection of inter-annual variation in trophic conditions on the east coast (van der Lingen and Miller 2014). de Lecea (2012) reported that isotopic signatures for pelagic zooplankton in the KZN Bight ranged from 4.38 ‰ to 9.66 ‰ during the summer and 5.29 ‰ to 9.41 ‰ during the winter for  $\delta^{15}\text{N}$ , while  $\delta^{13}\text{C}$  values ranged from -21.64 ‰ to -17.91 ‰ during summer and -20.61 ‰ to -18.70 ‰ during winter. The isotopic signatures reported in this study for *E. wongratanai* were higher in terms of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  than for majority of the zooplankton which included copepods and decapods reported by de Lecea (2012). This suggests that *E. wongratanai* likely feeds on this zooplankton. However, pelagic zooplankton with similar isotopic signatures to that of *E. wongratanai* can be attributed to nitrogen being recycled into ammonia which leads to an enrichment of  $\delta^{15}\text{N}$  values of plankton (de Lecea 2012).

## Chapter 5: Conclusions

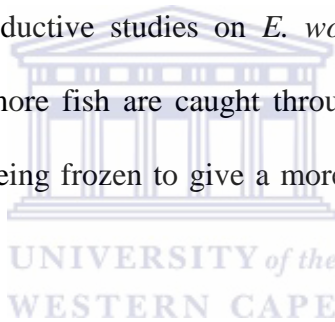
### 5.1 Age and growth

The present study provides the first set of data on the age and growth of *Etrumeus wongratanai* and indicates that annuli found on otoliths of *E. wongratanai* caught off Scottburgh, KwaZulu-Natal can be read with relative ease and with a small margin of imprecision between readers. It was observed that *E. wongratanai* appears to be a relatively short-lived species, not growing older than 4 years with a high growth rate during its 1<sup>st</sup> year of life. The results of other studies on *Etrumeus* species in South African waters and abroad tend to agree with the results attained in the present study as they indicated their respective species to be fast growing and short-lived with some attaining a maximum age of 8 years old. This study focused only on estimating age based on counts of annual growth zones and thus should be treated as preliminary and further work on the age and growth of *E. wongratanai* should incorporate counts of daily rings to validate the age of fish. This is important as determination of absolute age via daily ring analysis is required to determine the accuracy of the age estimate obtained from counts of annual growth zones and the counts of daily rings could provide strong corroboration with regard to the frequency of formation of these annual growth zones.

### 5.2 Length at maturity, gonadosomatic index and condition factor

It was observed that female *Etrumeus wongratanai* attained sexual maturity at a greater caudal length than males. *Etrumeus wongratanai* on the east coast of South Africa appears to attain sexual maturity at a greater length than that of its congeners found in South African waters and around the world. The scatter in the data with the fitted maturity ogives highlights the difficulty in using a macroscopic assessment of gonads to accurately determine whether a fish is sexually

mature. Microscopic examination of histological sections of gonads is suggested in future work to validate the macroscopic assessment of the size and age at which fish mature. The findings of the present study are consistent with that of reproductive work previously done on *Etrumeus* species from different regions. GSI data suggested that *E. wongratanai* is a multiple spawner and has a prolonged spawning season which lasts 6 months for males and 8 months for females. The spawning season extends from the onset of winter to summer, which has previously been observed in other *Etrumeus* species. There was a difference in GSI values between sexes which can be explained by the need for males to produce large amounts of sperm to ensure fertilization, although this is counter-intuitive since females typically have higher GSI values than males. A recommendation for further reproductive studies on *E. wongratanai* includes a more robust sampling procedure where a lot more fish are caught throughout the year and fish should be preserved in formalin instead of being frozen to give a more accurate estimates of gonad mass and hence GSI values.



Different seasonal patterns in condition factor from year to year were observed which could reflect inter-annual variability in environmental conditions. Condition factor was lowest from May to August in most years, before the onset of spawning, which suggests that the energy demands of reproduction seem to influence condition factor of fish within these months. Future research on condition factor should include data from all seasons to analyze the seasonal cycle for a full year.

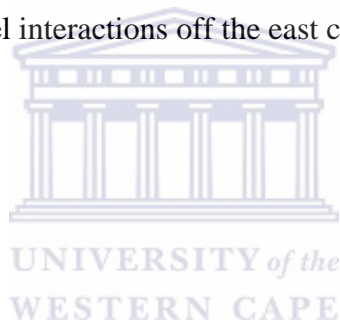
### 5.3 Seasonal variation in diet

The findings of the present study are in accordance with previous studies in terms of the diet composition of *E. wongratanai*. The present study indicates that *E. wongratanai* appear to display a seasonal variation in feeding intensity with a higher percentage of full stomachs being recorded in winter than any other season. There was a difference in the size class of prey items found in the stomachs of *E. wongratanai* by season as well as some degree of possible selectivity in prey items from season to season, with fish larvae being the most important prey in summer compared to large copepods in winter and autumn. This suggests a seasonal variation in diet. However, the assumption of selectivity could not be corroborated due to the lack of samples of the prey environment at the time of feeding, which emphasizes a need for sampling of the zooplankton environment at time of feeding in future research. Additionally, more robust sampling techniques are needed in order to get information on where exactly fish were caught, at which depth, and at what time of the day. Better representation of samples from each season is also required, as no data were collected in spring and data for summer are sparse in this study.

### 5.4 Stable isotope analysis

The present study provides the first set of isotope data for *E. wongratanai* off the east coast of South Africa. Stable isotope data suggest that there is an ontogenetic shift in diet of *E. wongratanai* in terms of  $\delta^{15}\text{N}$ . This likely reflects the increased prey size spectrum available to larger fish and could possibly serve to reduce the effects of intraspecific competition between small, medium and large fish. The data also suggest that there was a seasonal shift in  $\delta^{15}\text{N}$  signatures of fish which supports the findings of stomach content analysis and can be attributed to a different availability of prey items in the different seasons. When compared to *Etrumeus*

species in other parts of the world, *E. wongratanai* showed substantially lower  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values but different environmental properties of the different ecosystems where the other species of *Etrumeus* occur makes comparison difficult. When compared to  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of pelagic zooplankton from the east coast *E. wongratanai* tend to have higher  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values than the majority of pelagic zooplankton sampled in the KZN Bight, which suggests they feed on these organisms. Future research should include the removal of lipids from the muscle tissue of *E. wongratanai* for  $\delta^{13}\text{C}$  analysis given that the C:N ratios suggested high lipid content in muscle tissue which could introduce bias in interpretation of  $\delta^{13}\text{C}$ . Furthermore, the ambient environment where fish were caught needs to be sampled and isotope signatures analyzed to establish a baseline for trophic level interactions off the east coast of South Africa.



## Chapter 6: References

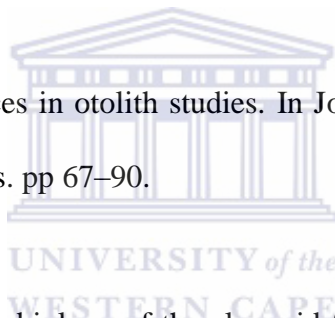
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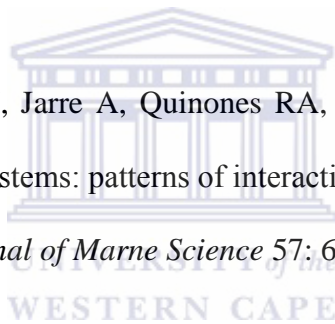
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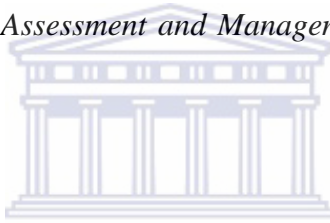
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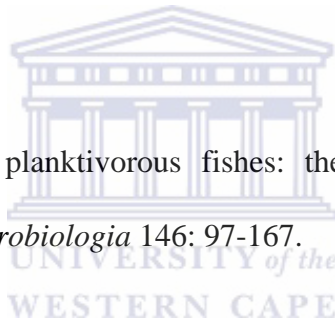
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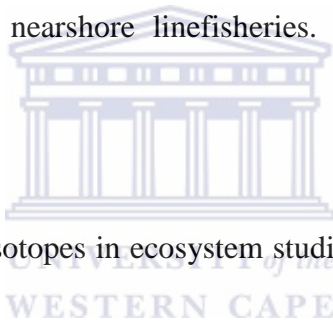
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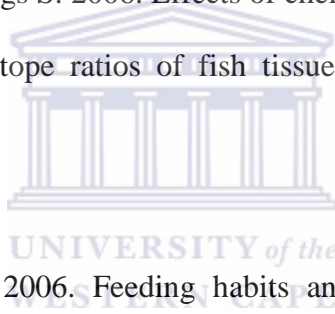
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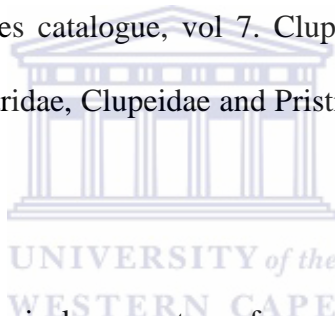
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