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THE RELATIONSHIP BETWEEN FISH LENGTH AND OTOLITH SIZE AND WEIGHT OF THE AUSTRALIAN ANCHOVY, *ENGRAULIS AUSTRALIS* (CLUPEIFORMES, ENGRAULIDAE), RETRIEVED FROM THE FOOD OF THE AUSTRALASIAN GANNET, *MORUS SERRATOR* (SULIFORMES, SULIDAE), HAURAKI GULF, NEW ZEALAND

L. A. Jawad*, N. J. Adams

School of Environmental and Animal Sciences,
Unitec Institute of Technology, Victoria Street West,
Auckland 1142, New Zealand
**Corresponding author*
E-mail: laith_jawad@hotmail.com

L. A. Jawad (https://orcid.org/0000-0002-8294-2944)

The Relationship Between Fish Length and Otolith Size and Weight of the Australian Ancnovy, *Engraulis australis* (Clupeiformes, Engraulidae), Retrieved from the Food of the Australasian Gannet, *Morus serrator* (Suliformes, Sulidae), Hauraki Gulf, New Zealand. Jawad, L. A., Adams, N. J. — Relationships between fish length and otolith length, width and mass were examined in the Australian anchovy *Engraulis australis* (White, 1790) recovered from the food of Gannet examined from colonies at islands of Horuhoru Rock and Mahuki Islands in the Hauraki Gulf, New Zealand. The relationships between otolith length- fish total length (TL), otolith-weight-TL, and otolith-width-TL were investigated by means of non-linear regression models ($TL = 0.54\ OL^{16.86}$, $TL = 4.39\ OW^{7.61}$ and $TL = 26.19\ OWe^{2.2}$). This study characterizes the first reference available on the relationship of fish size and otolith size and weight for *E. australis* obtained from bird's food in the Pacific Ocean region.
Key words: otolith, size, Hauraki Gulf, fish length, morphometrics, non-linear regression, Gannet.

Introduction

The Australian anchovy, *Engraulis australis* (White, 1790) is a marine species that sometimes enters brackish waters (Whitehead et al., 2019). Typically the species inhabits the pelagic-neritic region of the sea at a depth of 31–70 m (Stevenson, 2004). Mature individuals of this species reach maximum total length of 150 mm (Miskiewicz & Neira, 1998) with average total length of 120 mm (Munroe & Nizinski, 1999). *Engraulis australis* are distributed along the Australian East coast from Queensland to Northern Tasmania including Lord Howe Island and Norfolk Island and then along the Australian Southern coast but excluding the Great Australian Bight and then North along to coast of Western Australia to Shark Bay, Western Australia. The species is also found in the coastal waters of North and South Island in New Zealand excluding southeast coast of the South Island (Froese & Pauly, 2019). Individuals of this species form compact schools and are prey to larger fishes, marine mammals and birds (Majluf & Reyes, 1989; Bunce, 2001; Schuckard et al., 2012).

The predator-prey relationship is an important key ecological interaction in understanding the functioning of marine ecosystems. These can be explored, in part, by determining the diet of apex predators. A highly visible component of the suite of marine predators is seabirds and examination of feeding and foraging ecology has been an important thrust in seabird research. Obtaining direct and systematic observations of feeding seabirds is challenging. Approaches to identifying prey of seabirds have included killing of birds to inspecting their stomach contents through to analyses of faeces or regurgitated food remains, and tissue collection (Duffy & Jackson, 1986; Andersen et al., 2004). Identification of species in the diet relies on identification of prey at varying degrees of digestion.

Fish otoliths are resistant to digestion and are characterised by species-specific characters. Examination of otoliths has allowed identification of fish found in the stomachs of predatory, piscivorous fishes (Blackwell and Sinclair, 1995; Labeelund et al., 1996) and also for regurgitated food remains of piscivorous birds (Veldkamp, 1995; Kubetzki & Garthe, 2003; Liordos & Goutner, 2009) and in regurgitations and faeces of fur seals (Page et al., 2005). Therefore, several investigators have examined the morphology of otoliths (Smale et al., 1995; Campana, 2004; Lombarte et al., 2006; Sadigzadeh & Tuset, 2012; Jawad et al., 2018 a, b). Beside taxonomic purposes, otolith sizes and morphometric features such as length, width and weight are also imperative to evaluate the size and mass of the fish being preyed upon, as often in studies on feeding ecology the only item enduring in the stomach of a predator is the otolith (Jawad et al., 2011 a, b, c).

In addition, the size and mass of a fish can be predicted from otolith measurements since somatic growth is positively related to a range of otolith parameters. Accordingly it is possible to reconstruct prey size and biomass from otoliths obtained from stomach contents of these animals (Battaglia et al., 2010). This is only possible when the correlations between detailed morphological features of the prey (e.g. otolith length and weight) and actual prey size, and weight-length relationships of prey species are known (Granadeiro & Silva, 2000; Jawad & Al-Mamry, 2012; Jawad et al., 2011 a). In addition as consistent taxonomic tools, otolith length and width parameters, and their associations are generally used in keys and identification guides on fish otolith morphology (Lombarte et al., 2006).

This study is part of series of investigations on the fish found in the food of the Australian gannets, *Morus serrator*. These studies include examination of several fish body structures including otolith. In this perspective, this paper aims to make data available on morphometric parameters by means of analysing body size and otolith size and weight relationships in *E. australis* (Gray, 1843) a marine pelagic-neritic species in the eastern Pacific coast of New Zealand. Except for the work of Furlani et al. (2007), no more information is available on fishes of the South Pacific in general and those of New Zealand in particular and it will be valuable for future researchers investigating the biology of piscivorous fishes, birds and marine mammals to detect the size of fishes from the length of regained otoliths. In a novel approach we used fish recovered from Australasian gannets, *Morus serrator* at two breeding colonies in the Hauraki Gulf, New Zealand.

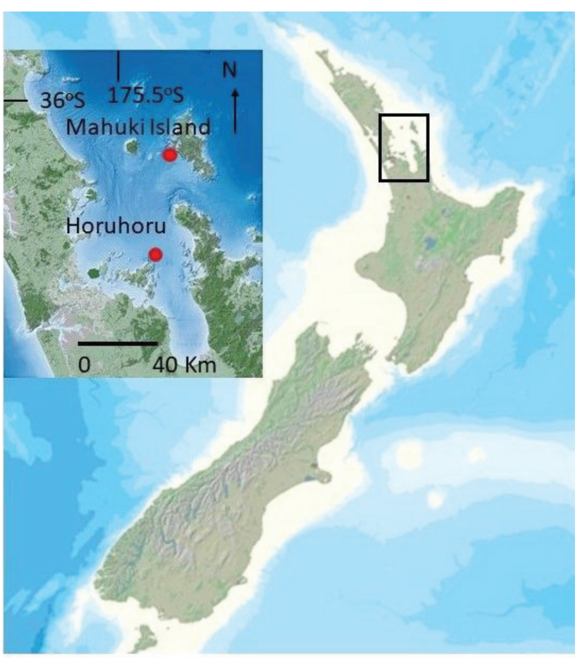

Fig. 1. Map showing the location of the gannet's colonies in the Hauraki Gulf, New Zealand.

Material and methods

Description of sampling area and stomach collection

Regurgitate samples were collected at two Australasian gannet colonies located on islands in the Hauraki Gulf namely Horuhoru in the inner Gulf and Mahuki Island, some 55 km to the North East in the outer gulf. As such the colony lies closer to deeper oceanic waters (fig. 1). Birds are present in substantial numbers at breeding colonies from July, when birds first return to the colonies, to March when the last of the chicks fledge. We sampled gannets in December and January across two consecutive breeding seasons (2017–2018 and 2018–2019) when adults were attending large chicks and making regular trips to coastal waters to collect food to feed chicks. Australasian gannets often feed in relatively close to their colonies and may return with relatively undigested fish. On capture and handling gannets may regurgitate spontaneously. All birds were released at their nest site after capture and collection of the regurgitation samples. The samples were collected as part of a study characterising the diet of gannets in the Hauraki Gulf foraging from neighbouring colonies.

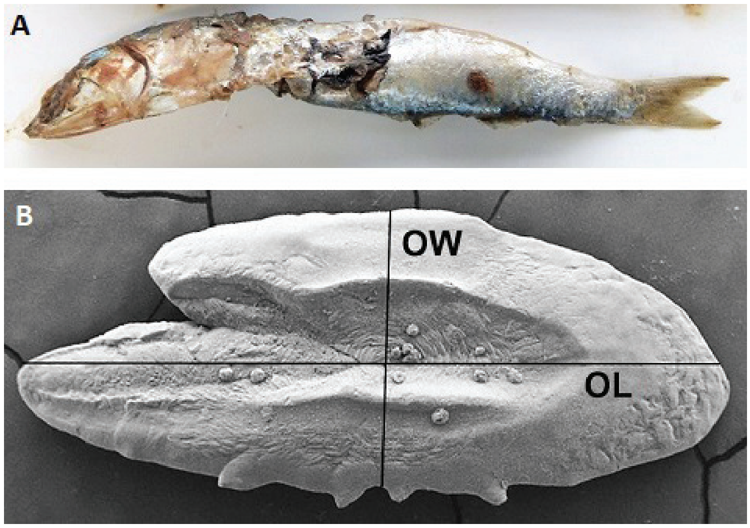

Fig. 2. A, *Engraulis australis*, 138 mm TL; B, Otolith of *Engraulis australis*, 135 mm TL showing otolith sizes, length (OL) and width (OW).

Adult gannets were caught at their breeding colony immediately on arrival to feed chicks using a modified shepherd's hook. Such birds frequently regurgitate food spontaneously on handling. To facilitate collection of contents, birds are held at angle with the bill and throat inclined downwards and where necessary accompanied by gentle massaging of the throat from the base to its junction with the mouth. Regurgitated samples were collected into buckets held in front of the bird's bill by a second individual. On collection food samples were placed in plastic bags and kept chilled in an insulated container with freezer blocks. At the end of the day samples were frozen for preservation. Once back at the laboratory samples were defrosted for analysis and removal of otoliths.

Collecting fish specimens from Gannet's food

Studies of otolith morphology and size recovered from predators must deal with the problem of otolith erosion by stomach acids, making them not suitable for species identification or size estimation (Barrett et al., 2007). In our study the problem of erosion was absent as whole, undigested fish were retrieved from the food of the gannet and the otoliths were still intact in the head of the fish where they were not expose to the acidic environment of the stomach of the bird. Chemical and mechanical aberrations can change the shape of the otolith and reduce their usefulness for size reconstruction of whole fish (Jobling & Breiby, 1986; Granadeiro & Silva, 2000).

The specimens were washed with water to remove any adhering food remains (fig. 2, A.) A total of 64 whole *E. australis* were obtained from the food samples of Australasian gannets *M. serrator*. Total length (TL) (± standard deviation) was measured to the nearest 1 mm from the tip of the snout to the posterior edge of the caudal fin. Otoliths (sagittae) were removed from both sides of the fish head by a cut in the cranium to uncover them and then cleaned and stored dry in glass vials. Each otolith was positioned under a dissecting microscope with the sulcus acusticus oriented towards the observer and its length was measured on the axis between the rostrum and post-rostrum axis (nomenclature of Smale et al., 1995) (fig. 2, B). Otolith weight was obtained to the nearest 0.001 g. The measurements used followed Jawad et al. (2017).

Statistical analysis

The relationship between otolith size (length, width, weight) and fish size (TL) was determined using non-linear regression for the following parameters: otolith length (OL) — total length (TL), otolith width (OW) — total length (TL) and otolith weight (OWe) — fish length (TL). These equations were first calculated for both left and right otoliths and ANCOVA test (Fowler and Cohen 1992) was used to check any differences between regressions.

Result

A total of 64 otoliths were extracted. Total length of the fish specimens used in this study ranged from 82–118 mm with an average value at 103.05 ± 3.6 mm. As the fish individuals were obtained in the food of gannet, *M. serrator*, the length range of our sample was limited. The data of fish total length, otolith length, width and weight are given in table 1. Ranges and means (± standard deviation) of otolith length, width and mass were shown in table 2.

Table 1. Data of fish total length, otolith length, otolith width and otolith weight obtained from *Engraulis australis* retrieved from the food of the Australasian gannet *Morus serrator*, Hauraki Gulf, New Zealand

Total length	Otolith length	Otolith width	Otolith weight
82	7.1	1.52	0.021
82.6	7.2	1.54	0.022
82.9	7.26	1.57	0.023
83	7.28	1.58	0.023
83.2	7.28	1.59	0.024
83.5	7.29	1.67	0.025
83.7	7.3	1.69	0.025
83.9	7.3	1.68	0.026
84	7.3	1.69	0.026
84.2	7.3	1.7	0.027
84.5	7.3	1.71	0.028
84.7	7.3	1.72	0.028
84.9	7.3	1.79	0.028
85	7.3	1.79	0.028
85.5	7.4	1.8	0.03
85.7	7.4	1.82	0.03
85.9	7.4	1.83	0.031
86	7.4	1.85	0.031
86.2	7.4	1.87	0.032
87	7.4	1.92	0.033
87.8	7.4	1.98	0.034
88	7.4	2	0.035
88.6	7.5	2.1	0.036
88.9	7.5	2.1	0.037
89	7.5	2.16	0.037
89.6	7.5	2.19	0.038
89.8	7.5	2.2	0.039
90	7.5	2.2	0.039
92.1	7.5	2.38	0.044
92.6	7.5	2.39	0.045
92.8	7.5	2.4	0.046
93	7.5	2.45	0.046
93.2	7.5	2.48	0.046
93.7	7.5	2.49	0.047
93.9	7.5	2.51	0.048
94	7.4	2.53	0.049
94.8	7.48	2.58	0.05
95	7.4	2.59	0.052
95.7	7.39	2.6	0.053
95.9	7.37	2.61	0.053
98	7.2	2.7	0.056
98.4	7.2	2.7	0.057
98.8	7.2	2.72	0.058
99	7.18	2.74	0.058
99.5	7.14	2.75	0.058
99.8	7.13	2.76	0.059
100	7.1	2.79	0.06
100.6	7.1	2.8	0.061
100.9	7.1	2.83	0.062
103	7.1	2.88	0.063

103.6	7	2.89	0.065
103.9	7	2.87	0.063
104	7	2.88	0.064
104.5	7	2.89	0.065
104.9	7	2.86	0.066
105.2	7	2.87	0.067
106	7	2.89	0.067
110	6.7	2.85	0.07
115	6.4	2.75	0.074
116	6.3	2.7	0.075
117	6.23	2.65	0.076
117.8	6.1	2.6	0.077
118	6.2	2.57	0.078

Table 2. Data analysis of *Engraulis australis* collected from the food of gannet inhabiting colonies at Hauraki Gulf, New Zealand

Parameter	Range	Mean (± SD)	Equation	R^2
Otolith length, mm	6.2–7.5	6.83 ± 5.5	$Y = -0.0017x^2 + 0.3081x - 6.4963$	0.9446
Otolith width, mm	1.68–2.89	2.26 ± 3.3	$Y = -0.0023x^2 + 0.4939x - 23.5140$	0.9970
Otolith weight, gms	0.021–0.078	0.048 ± 1.14	$Y = 3E\text{-}05x^2 + 0.0080x - 0.4188$	0.9979

Note. OL, otolith length; OW, otolith width; Owe, otolith weight. R^2, coefficient of determination.

The various relationships between fish length and otolith length, width and weight are shown in table 2 and fig. 3. In the examination of morphometric parameters (otolith length and width) and mass against fish total length, no substantial differences ($P = 0.2$) between right and left otoliths were detected by ANCOVA test. Consequently, single linear regression was plotted for each parameter. The otolith size parameters were significantly and highly correlated with the size of the fish (table 2).

Discussion

The significant relationship obtained in the present study between the fish total length and each of the morphometric characters of the otoliths the *E. australis* is in accordance with the other studies (Jawad & Al-Mamry, 2012; Jawad et al., 2011 a).

Although the taxonomic value of the otolith of *E. australis* is not an issue in the present study, but it is worth mentioning that the development of the relationship between fish and otolith sizes might be considered another taxonomic benefit that can be added to those previously set for fish otolith (Battaglia et al., 2010).

The relationships can be back-calculated to gain fish size from otoliths retrieved from the stomachs of predator bird. The biology and ecology of *E. australis* have been investigated in both the Australian and the New Zealand waters (Blackburn, 1967; Francis et al., 2005; Ward et al., 2006). On the other hand, the relationship of fish size-otolith measurements of this species were previously studied only in the Australian waters (e. g. Furlani et al., 2007). Accordingly, this research complements information for this species and for the region, which will be valuable exploring marine trophodynamics in the area (Zan et al., 2015).

The absence of statistical differences between left and right sagittae indicates that otoliths on either body side be used indiscriminately for fish-size estimations (Battaglia et al., 2010; Jawad et al., 2011 a, b; Mehanna et al., 2016; Park et al., 2017; Yilmaz et al., 2015; Qasim et al., 2019).

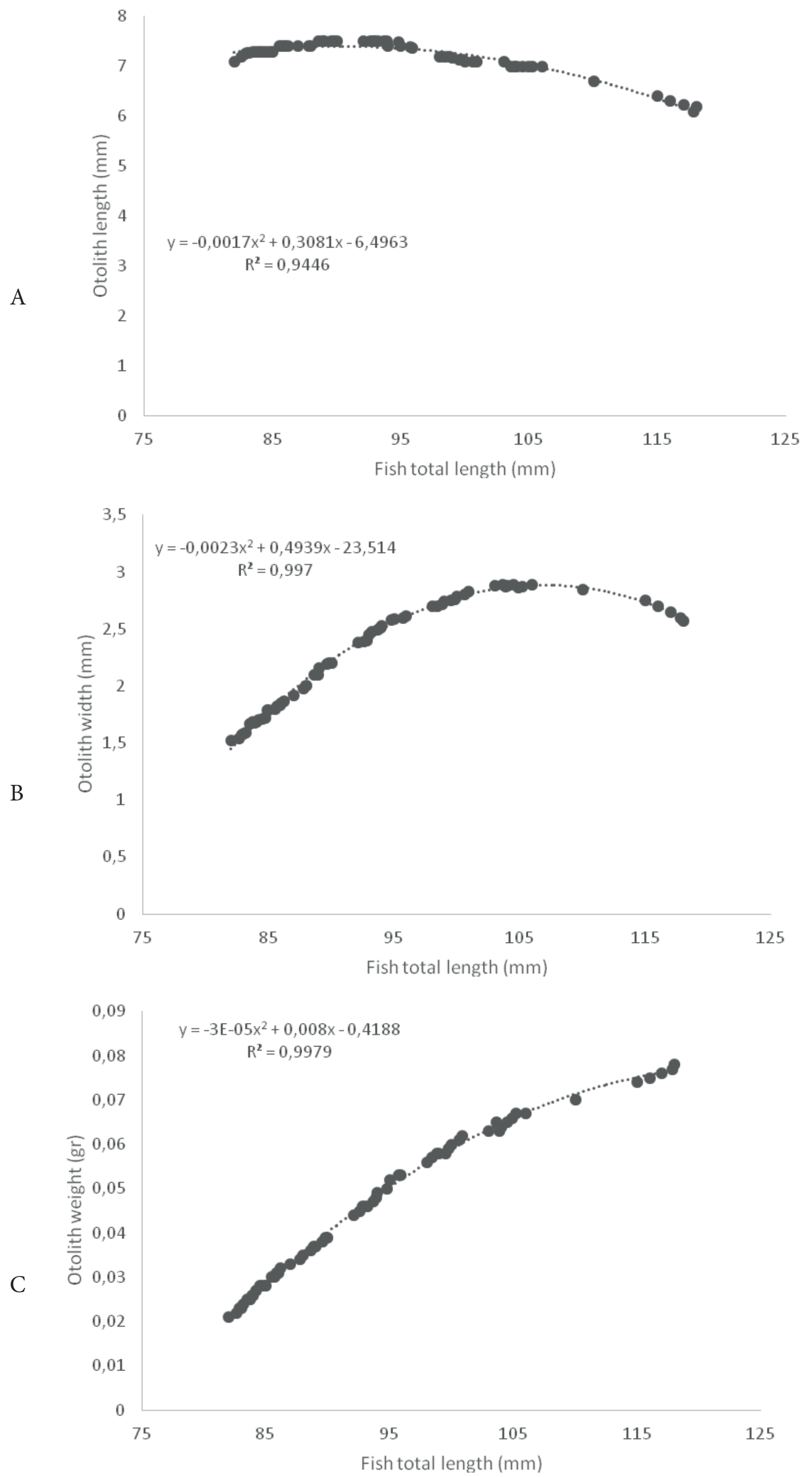

Fig. 3. Fish total length relationship with: A — otolith length; B — otolith width; C — otolith weight.

Determination of fish size from otolith measurements should be used cautiously because of differences in the growth of individuals belonging to the same species but of different stocks or that live in different areas (Campana et al., 1993; Reichenbacher et al., 2009) or because of variations between sexes (Echeveria, 1987).

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Conflicts of interest
The authors declare that they have no conflicts of interest.

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