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SHORT COMMUNICATION

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New insights on feeding habits of the southern blue whiting *Micromesistius australis* Norman, 1937 in eastern South Pacific waters

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1 | INTRODUCTION

The southern blue whiting *Micromesistius australis* Norman, 1938 represents an important fishery resource for the South Pacific and Southern Atlantic oceans supporting seasonal landings in Chile, Argentina, Australia, New Zealand and Falkland Islands (UK) (Brickle, Arkhipkin, Laptikhovsky, Stocks, & Taylor, 2009; Niklitschek, Secor, Toledo, Lafon, & George-Nascimento, 2010). Trophic habits of southern blue whiting are well known in New Zealand and southwestern Atlantic waters, feeding mainly on hyperiid amphipods and euphausiids, highlighting *Themisto gaudichaudi* as the principal prey (Brickle et al., 2009). On the other hand, information for the southeast Pacific area are in technical reports from the Chilean Fisheries Grant Office confirming their carcinophagous feeding behavior. Although stomach content analysis is the most widely used method in tropho-dynamics, it could be biased by opportunistic feeding and differential digestion rates of the prey by the predator. The analysis of natural biological tracers, such as the stable isotope ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), is often employed for trophic ecology studies and constitutes a robust approach regularly used to trace energy flow pathways through food webs (Post, 2002). However, stable isotopes analyses alone are not sufficient, because the study is incomplete without stomach content analyses of prey. Thus, the purpose of this study was to describe the feeding habits of *M. australis* in South-Austral Pacific waters inferred from stomach-contents and stable isotopes.

2 | MATERIALS AND METHODS

A total of 900 blue whiting individuals were collected between 47–51° S from the fishery research cruise vessel "AGS-61 Cabo de Hornos" during winter 2014. Of these, 100 specimens were separated for stable isotope analyses in a size range of 15–71 cm total length (Figure 1). Tissue and stomachs was removed onboard and immediately frozen (−20°C). Each sample was weighed and its contents extracted. Prey items were identified to the lowest possible taxonomic level, weighed, counted, and their tissues frozen (−20°C). All tissue samples (~1 mg) were dissected and washed with mili-Q water. Due to the high lipid content in the fish tissues, they were removed using an ether petroleum solution in a soxhlet apparatus (Hussey, MacNeil, & Fisk, 2010). The tissues were then rinsed with mili-Q water and dried in an oven. The isotope composition was analysed at the "Laboratorio de Analisis Isotopico" of the Universidad Andres Bello, Viña del Mar Chile, using a

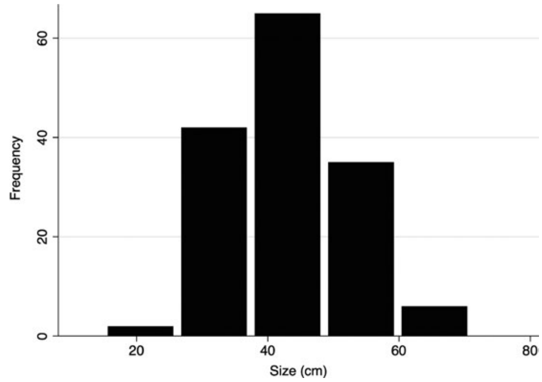

FIGURE 1 Size distribution frequency, *Micromesistius australis* (southern blue whiting) diet, South Pacific waters, winter 2014. $n = 100$

Eurovector elemental analyzer coupled to a "Nu-instruments" isotope ratio mass spectrometer.

2.1 | Data analysis

Common indices were used for stomach content analyses; number (N), weight (W) and frequency of occurrence (FO) were calculated for major prey categories. Prey were grouped into major categories (e.g., shrimps, mesopelagic fishes) for better estimation and comparison (Fry, 2013) (Table 1). Stomach content values were expressed as % Ø. Where, Ø was calculated with the equation:

$$\emptyset = \frac{wi}{Ni} + \frac{FOi}{Nsca}$$

Where, *W* is the total weight of *i* prey found in the stomachs (sca), Ni is total number of *i* prey and FO is the frequency of occurrence of the *i* prey. The analysis of isotope data was made using the package MixSIAR (Stock & Semmens, 2017). Dietary habits of blue whiting were fitted using a Bayesian mixing model based upon a Gaussian likehood with a mixture *dirichlet-distributeds*. For the Bayesian model the data was randomized with the 1000 bootstrapping method. The mean enrichment of δ^{15}N per trophic level (TDFs) was assumed to be 3.4 (Post, 2002). All mathematical analyses were performed with R Statistical software (R CoreTeam, 2017).

3 | RESULTS

Of 900 stomachs sampled (16%), 150 contained food with 145 identifiable prey (Table 1). Southern blue whiting showed 19 prey taxa, highlighting the fishes. Mostly composed of the myctophid family, of these the genus *Lampanyctus* was the most abundant in the whiting stomachs. In this context, mesopelagic fishes were the most important prey in the *M. australis* diet, with 78%. In second place were the

TABLE 1 Stable isotopic compositions of blue whiting *Micromesistius australis* and stomach contents from South Pacific waters, winter 2014

Major Group	Species	δ^{13}C	δ^{15}N	*n*
Predator studied	*Micromesistius australis*	−18.57 ± 0.9	16.4 ± 2.21	100
Prey groups studied				
Euphausiids	*Euphausia frigida*	−16.59 ± 0.63	13.69 ± 0.61	12
	Euphausia vallentini	−19.95 ± 1.45	9.24 ± 5.20	17
Shrimps	*Pasiphaea dofleini*	−16.66 ± 0.74	13.89 ± 1.87	5
	Pasiphaea acutifronz	−18.30 ± 0.55	15.81 ± 1.83	7
	Segestes articus	−17.31 ± 1.03	15.81 ± 1.29	12
Squids	*Todarodes filipovvae*	−16.56 ± 0.17	15.62 ± 1.78	3
Small Lobster	*Munida subrugosa*	−18.48 ± 1.02	9.03 ± 1.0	3
Mesopelagic Fishes	*Ceratoscopelus warmingii*	−17.23 ± 0.8	16.32 ± 1.79	2
	Diaphus sp	−17.36	14.15	1
	Electrona sp	−16.40 ± 0.22	17.85 ± 0.51	4
	Hygophum sp	−16.79	19.29	1
	Lampanyctodes hectoris	−17.92 ± 0.63	12.69 ± 4.14	2
	Lampanyctus australis	−17.03 ± 0.23	16.89 ± 0.86	5
	Lampanyctus sp	−17.36 ± 0.91	16.99 ± 1.18	41
	Maurolicus parvipinnis	−17.25 ± 0.53	15.76 ± 1.49	16
	Notophysis marginata	−16.51 ± 0.78	16.02 ± 2.94	3
	Stomia sp	−18.44 ± 0.47	16.44 ± 1.40	2
	Symbolophorus sp	−16.49	15.2	1
	Talismania aphos	−16.62 ± 0.42	17.55 ± 0.62	8

±standard deviations. *n*; number of specimens sampled (15–71 cm total length); δ^{13}C, Carbon; δ^{15}N, Nitrogen

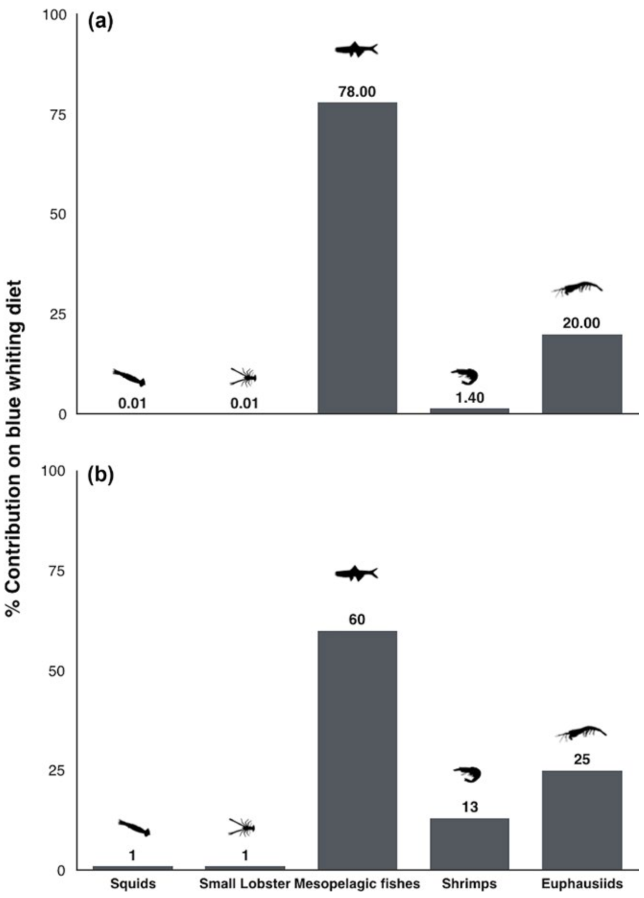

FIGURE 2 Percentage of contribution, southern blue whiting diet, South Pacific waters, winter 2014. (a) Stomach content analysis. (b) Stable isotopes analysis (models combined)

euphausiids with 20% (Figure 2). The isotopic values for all species are summarized in Table 1. The blue whiting showed values of −18.6 ± 0.9 δ^{13}C and 16.4 ± 2.2 δ^{15}N, which is common in a mesopelagic predator (Figure 3). The most important prey groups indicated by the isotopic analyzes were the fishes with 60%, followed by euphausiids with 25% and shrimps with 13%. The remaining prey items were considered incidental or rare food in the diet and did not exceed 1% (Figure 1b).

4 | DISCUSSION

The results of this study provide new data, opposite to findings of technical reports from the Chilean Fisheries Grant Office that showed crustaceans as the major prey in the southern blue whiting diet. The present study found that the *Lampanyctus* are the most abundant prey in the stomachs of southern blue whiting, confirming that our results differ from previous reports from the southern Pacific and also from the results reported by Brickle et al. (2009) for Atlantic waters, which considered *M. australis* to be a carcinophagous predator. In contrast, the data suggests that the southern blue whiting is an ichthyophagous predator with a marked preference for myctophids (Table 1), reaffirmed by the feeding strategy obtained from bi-plot (Figure 3). Indeed, fish are important in number, frequency and weight; the number of prey found in stomachs of *M. australis* may reflect the abundance of prey in the environment and thus will partially infer the environmental offer. In fact, the stable isotopes show that the blue whiting have mesopelagic habits, consistent with the findings in our work.

In this study we found some evidence that southern blue whiting changes its diet in the winter season in southern Pacific waters, thus it is possible to infer changes in their trophic level as a result of euphausiid and amphipod declines in the diet of *M. australis*, which additionally has a direct impact on the feeding strategy of southern blue whiting. For example, a predator may specialize in a major group of prey such as fishes, cephalopods or crustaceans (Cortés, 1997), not discriminating by specific prey species. A recent study by (Lopez, Zapata-Hernández, Bustamante, Sellanes, & Meléndez, 2013) indicates the importance of prey considered rare or accidental food or has a low medium value of the food index (<25%). These authors suggested that some marine predators

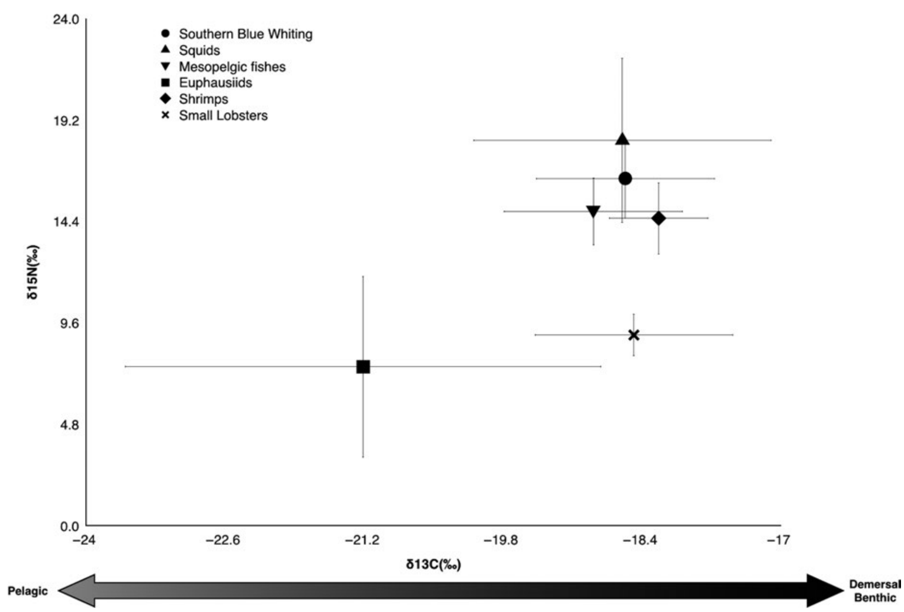

FIGURE 3 Bi-plot of δ^{15}N and δ^{13}C values (mean ± SD) for southern blue whiting and their trophic prey groups in South Pacific waters. Southern blue whiting *n* = 100, Squids *n* = 3, Mesopelagic fishes *n* = 86, Euphausiids *n* = 29, Shrimps *n* = 24, Small lobsters *n* = 3

that present a wide trophic spectrum and few dominant prey in their diet are linked with prey abundance in the environment; thus dominant prey will be abundant in the ecosystem and therefore may be important in the diet, although poor energetically. In contrast, less important prey is scarce in the environment, but rich in energy. The above phenomena is particularly severe because predator and prey have evolved together and thus developed capture and escape tactics involving energetic demands and an eco-physiological process, so this probably implies the structural modification of predator-prey interactions in the ecosystems that they inhabit (Crowder et al., 2008). Therefore, as this study implies, *M. australis* is affected by the change in their diet that involve the food web linkages of the southern part of South America waters. As a predator, *M. australis* feeds on crustacean (euphausiid and amphipods), small fishes (myctophiids), salps, cephalopods, siphonophores and other plankton groups. In turn, they act as a prey, feeding the black-browed albatross *Diomedea melanophrys impavida* (Cherel, Waugh, & Hanchet, 1999), rock-hopper penguin *Eudypes chrysocome* (Cherel et al., 1999), kingclip *Genypterus blacodes* (Dunn, Connell, Forman, Stevens, & Horn, 2010), southern hake *M. australis* and other species of sharks and rays.

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