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Diet of the Chilean flamingo *Phoenicopterus chilensis* (Phoenicopteriformes: Phoenicopteridae) in a coastal wetland in Chiloé, southern Chile

Claudio N Tobar^{1*}, Jaime R Rau², Norka Fuentes³, Alberto Gantz², Cristián G Suazo⁴, Jaime A Cursach^{2,5}, Alexis Santibañez¹ and Jorge Pérez-Schultheiss⁶

Abstract

Background: The geographical distribution of the Chilean flamingo (*Phoenicopterus chilensis*) includes the southern-central Neotropics. Despite its wide distribution, currently there is no dietary information on its southern distribution range. From June to September 2011, we quantified the diet and prey availability of the Chilean flamingo in the marine wetland of Caulín (41°48' S, 73°37' W), southern Chile.

Results: The prey availability related to both plankton and benthos were four species of copepods, four polychaetes, one foraminifera, and two amphipods. The diet of the Chilean flamingo was composed of foraminifera (*Ammonia beccarii*), copepods (*Harpacticus* sp.) and polychaetes. The most abundant prey items from feces of flamingos were *Ammonia beccarii* and *Harpacticus* sp. The diameter of *A. beccarii* consumed by flamingos ranged between 400 and 900 µm, while its width varied between 100 and 300 µm. The width of *Harpacticus* sp. consumed ranged between 160 and 260 µm. The similarity between flamingo diet and prey availability was 0.553. The diversity of prey organisms in the benthos was higher than that observed from plankton and feces of birds. *A. beccarii* was preferred over other prey consumed by flamingos. This preference is not related to the size of *Harpacticus* sp. but to their ability to swim and escape from flamingos.

Conclusions: The dietary similarity of the Chilean flamingo versus the availability of prey in the environment (plankton and benthos) was 55%, indicating that the Chilean flamingo is a partially selective predator.

Keywords: Copepods; Diet selectivity; Migration; Trophic ecology

Background

There are six species of flamingo in existence worldwide, and three of them are found in the Neotropical region. The most common species in this region is the Chilean flamingo *Phoenicopterus chilensis* (Molina 1782) (Brandolin and Ávalos 2010). Its range stretches from the center-south coasts of Peru and the south of Brazil to Patagonia (Hurlbert and Keith 1979; Fjeldsa and Krabbe 1990; Parada 1990; Rodríguez and Contreras 1998; Araya and Millie 2005). In Chile, this species is currently found from the Paríacota Province (ca. 20° S) to Tierra del Fuego (ca. 52° S) (Araya and Millie 2005). With regard to the nesting habits of this

bird in Chile, it only nests in the extreme North (Venegas 1986), while the populations found in the South nest in Argentinean Patagonia (Von Meyer and Espinosa 1998).

The ecological information published on this species makes reference to observations on certain reproductive aspects (Sosa 1999), geographical distribution and population fluctuations (Johnson et al. 1958; Caziani et al. 2001, 2007; Rocha 1997), nesting, habitat use (Mascitti 2001; Mascitti and Bonaventura 2002; Mascitti and Castañera 2006), and conservation status (Bucher 1992). If we consider its widespread population distribution throughout the country, there are currently no existing publications about the Chilean flamingo's diet nor do we know the prey selection strategy (selective or opportunistic) it uses in the different environments in which it lives. The study carried out by Mascitti and Kravetz (2002) on the Chilean flamingo



* Correspondence: claudiobiomar@gmail.com

¹Departamento de Ciencias Básicas, Universidad Santo Tomás, Los Carrera 753, 5310431, Osorno, Chile

Full list of author information is available at the end of the article

and the Andean flamingo (*Phoenicoparrus andinus* Philippi 1854) and James's flamingo (*Phoenicopterus jamesi*, Sclater 1886) in the Argentinean Andean Plateau do indicate, however, that these species select their prey based on size due to a distinctive characteristic of their beaks, which contain small ridges to capture food when filtering the substrate. Other authors describe the Chilean flamingo as an omnivorous bird that feeds principally on diatoms, nematodes, and planktonic crustaceans (Hurlbert 1982; Hurlbert et al. 1986; Rodríguez 2005). According to the records of Von Meyer and Espinosa (1998), the Chilean flamingo keeps to the intertidal flats of Chiloé's island called *Isla Grande* to feed for most of the year except in summer. The presence of this species in the south of Chile and specifically in Chiloé could be related to its migratory routes as it moves towards Argentinean Patagonia in the spring and summer in search of nesting sites (Markham 1975; Von Meyer and Espinosa 1998). Its presence on the coast of the central and southern regions of Chile is largely associated with estuarial areas, which could be related to the higher quantity of food available in this kind of habitat during the winter season, as is the case with other migratory birds (Muñoz 1994; Cifuentes 2007). The protected coastal areas of the Chiloé Ecoregion and the Patagonian waterways in the south of Chile (ca. 42° to 43° S) provide a combination of nutritional resources and rest areas for resident and migratory birds. They are one of the main wintering sites in the south of the American continent for various species of coastal bird. This results from a combination of the area's oceanographic productivity and its topography (Morrison and Ross 1989). These protected intertidal areas contain high concentrations of phytoplankton (Avaria et al. 1997), which allow macrobenthic communities to be sustained (Quijón and Jaramillo 1993). These macrobenthic communities display seasonal variations in the abundance of benthic organisms. On the other hand, in spite of the high diversity of resident and migratory aquatic birds that live in Caulín Bay, there is in fact no existing information on prey availability in the benthos of the bay's intertidal zone (Cifuentes 2007).

As a result, the objectives of this study were to present the first quantifiable information on the diet of the Chilean flamingo, to quantify potential prey profile availability (zooplankton and benthos), and to determine the size of prey consumed in a marine wetland on the *Isla Grande* island in Chiloé, southern Chile. Our hypothesis was as follows: The Chilean flamingo will not show evidence of dietary selection and will consume the prey present in Caulín Bay opportunistically.

Methods

Study area

Visits to Caulín Bay were carried out over three consecutive days between the months of June and September

2011. Sampling days coincided with the lowest tides, allowing for a greater surface area for sample collection. Potential prey profile availability was quantified, and their feces were collected for diet evaluation. The Caulín Bay (41° 49' S, 73° 38' W) bird sanctuary is found in the northern zone of Chiloé's *Isla Grande* Island, southern Chile (Figure 1). The sand flat features an annual average tide height of around 4.5 m at spring tide and 3 m at neap tide (Cifuentes 2007). The intertidal strip is approximately 600 m at spring tide (Cifuentes 2007). The River Huenque runs through the middle of the sand flat, dividing it into two sectors. The eastern sector is primarily muddy, while the western sector is primarily sandy (Cifuentes 2007). The intertidal zone of Caulín Bay is subject to the constant harvesting of sea products, especially the collection and cultivation of *pelillo* seaweed (*Gracilaria chilensis* Bird, McLachlan and Oliveira 1986) and Bluff oyster (*Ostrea chilensis* Philippi 1845).

Sampling methodology

The Chilean flamingo's available food and the variation of that food over the different months were characterized. Samples of plankton were taken at the feeding sites and the control sites. The feeding sites were located in the intertidal zone of Caulín Bay and were chosen based on observation of the bioperturbations left by the Chilean flamingo during feeding. The bioperturbation is known as a 'feeding ring', and it is produced by the birds' feet churning up the benthos as it swivels on its axis and uses its body as a pivot. It filters the suspended sediment with its beak and then deposits the filtered sediment in the center of the ring (Cifuentes 2007). In order to sample the zooplankton, horizontal sweeps of 800-m transects were made perpendicular to the tideline. To avoid stirring up sediment in the Chilean flamingo's feeding sites, these were undertaken as discreet walks using conical plankton nets (net mouth area 0.3 m diameter by 1.2 m in length), with a mesh size of 150 μ m, to obtain a total of 12 samples.

The taxonomic analysis was carried out in the laboratory with a stereoscopic microscope ($\times 10$ to $\times 30$) and an optical microscope (OM) with $\times 400$ magnification. Taxonomic guides (Araya and Zúñiga 1985; Goddard and Zúñiga 1995) and OM photographs of the different taxa were used to identify the prey. The OM photographs were taken with the aid of a photographic camera (Sony DSC-HX200V, Sony Corporation, Tokyo, Japan) incorporated into the microscope. Once the samples were classified, the frequency that each prey animal appeared was determined. In turn, the abundance and size of each prey animal were recorded for the most frequent prey animals. To record the abundance of the most frequent zooplankton prey, a count was carried out using transects according to the method proposed by Villafañe and Reid (1995).

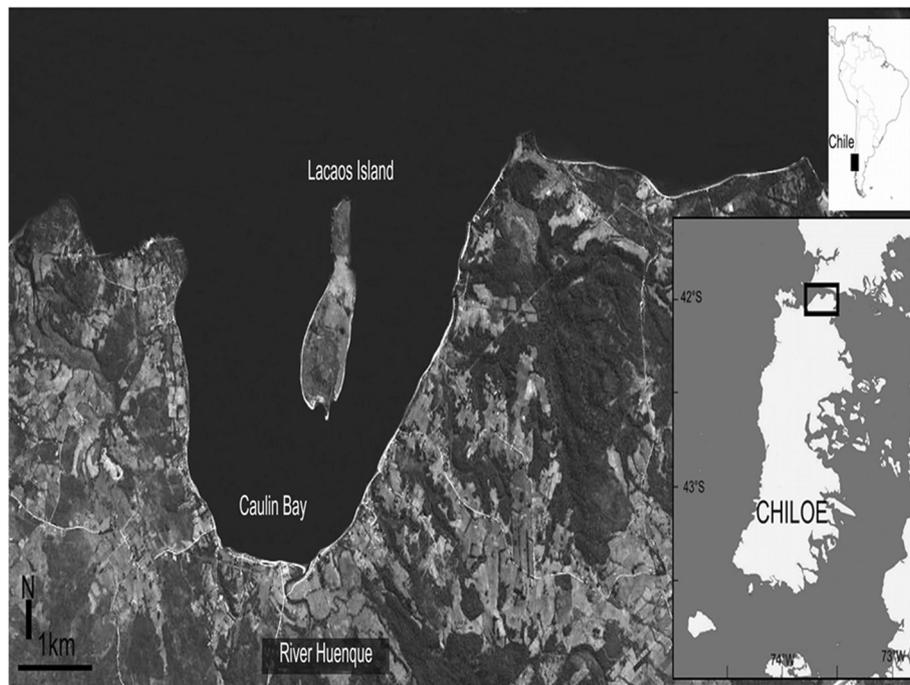


Figure 1 Study area. The intertidal sand flat of Caulín Bay (41° 49' S, 73° 38' W), Chiloé Island, southern Chile.

The Sedgwick-Rafter camera was replaced by a microscope slide and a slide cover of 32 × 25 mm. A 0.05-ml portion was deposited on the slide, and three equidistant horizontal transects were taken avoiding border effects (Fabricius et al. 2005). To obtain the abundance of prey animals per sample, the average of three counts for each of the samples was taken. To measure the most frequent species, LAS Versión 1.5 software incorporated into a Leica EZ microscope (Leica Microsystems Ltd., Milton Keynes, UK) was used.

During the study period, the monthly sampling of macro-invertebrates present in the benthos was taken during the spring tide (Cifuentes 2007). Six random samples were taken from the first 10 cm in depth (three at the Chilean flamingo's feeding area and three at control sites). A corer with a 7-cm diameter was used for this purpose. The samples were studied under a stereoscopic microscope and an OM, and the organisms identified using taxonomic guides (Rozbaczylo 1980; Jaramillo 1982) were preserved in 10% formalin so that the specimens could later be quantified. To obtain the abundance of prey animals per sample, the average of three counts for each of the samples was taken. To measure the most frequent species, LAS Versión 1.5 software incorporated into a Leica EZ microscope was used.

The diet of the Chilean flamingo was evaluated by means of the analysis of a total of 77 feces that were collected during low tide in feeding sites used by the birds. Each feces corresponded to the deposit of an individual adult, which were classified as belonging to this age group via

observation of its plumage using a microscope (×60) during the feeding and subsequent defecation process. The feces were collected once the birds had left the feeding sites. They were subsequently dried at ambient temperature and then processed in the laboratory. The feces were studied under a stereoscopic microscope and OM, and the organisms were identified using taxonomic guides and were preserved in 10% formalin so that the specimens could later be quantified. To quantify and measure the size of the most frequent prey animals (crustaceans and foraminifera) in the feces of the Chilean flamingo, the same methodology was used as for the quantification of available prey. To quantify the polychaetes, one individual corresponded to one pair of jaws since the rest of the polychaete was digested.

Statistical analysis

The similarity of the species present in the environment (plankton and benthos) versus those present in the feces was estimated using Horn's quantitative index of overlap (Rau 2009) and the QUANTAN computational program (Brower et al. 1997). The taxonomic diversity present in the environment and the diversity of prey in the Chilean flamingo's diet were determined using the Shannon-Wiener (H') index and the (Franja 1993) program. The Hutcheson test was used to compare the Chilean flamingo's dietary diversity and potential prey profile availability. This allowed for a comparison of the H' diversity and its associated analytical variances using a test analogous to Student's t test (see Moreno 2001). To

compare the differences in the frequency of occurrence of the Chilean flamingo's most consumed prey with the frequency of occurrence for the prey present in the feeding sites during the different study months, an χ^2 *y* test was used, and in the event that it was significant, Bonferroni simultaneous confidence intervals (BSCI) were formed. A χ^2 *y* test was also used in order to compare the difference in frequency of the sizes of prey consumed by the Chilean flamingo, and in the event that it was significant, BSCI were used. BSCI are ranges of statistical probability that are used in multiple paired comparisons. They have been used to calculate the selection of resources, such as prey and feeding sites (Suazo et al. 2012), since they allow one to establish the significance that an expected probability per category will fall within, or outside of, the interval constructed for the observed probability (Neu et al. 1974; Byers et al. 1984). To compare the monthly differences for the most abundant species of zooplankton in the water column, as well as macroinvertebrates present in the benthos at the feeding sites used by the Chilean flamingo during the study months, the nonparametric Kruskal-Wallis test was used with a significance level of 95%. The online statistical package (<http://vassarstats.net/>) was used for all statistical analysis.

Results

Prey availability

Four species of copepod were identified in the water column in the feeding sites used by the Chilean flamingo. Of these, three were described at the level of the genus

and one at the level of the order. The most abundant copepod during this study was *Harpacticus* sp. (Table 1). No significant differences were recorded in the availability of zooplankton during the study months (Kruskal-Wallis test $H_4 = 23.138$; $P = 0.336$).

A total of seven species of organism present in the benthos were identified: four polychaetes, a foraminifera, and two amphipods. The most abundant species both in the feeding sites and in the control sites during the study period was the polychaete *Perinereis gualpensis* (Jeldes 1963) (Table 1). No significant differences were recorded in the availability of organisms in the benthos during the study months (Kruskal-Wallis test $H_4 = 0.666$; $P = 0.881$).

Dietary analysis

A total of three prey categories were identified; the foraminifera *Ammonia beccarii* Linné 1758, the copepod *Harpacticus* sp., and the remains of polychaetes (jaws). No frustules nor diatoms were observed. The most abundant preys in the feces of the Chilean flamingo were *A. beccarii* and *Harpacticus* sp. (Table 2). The diameter of the foraminifera consumed by the flamingo ranged from 400 to 900 μm with a positive selection (preference) for organisms within the range of 500 to 700 μm ($\chi^2 = 132.104$, g.l. = 5, $P = 0.0001$). The width of the foraminifera ranged between 100 and 300 μm , with a positive selection for organisms within the range of 200 to 300 μm ($\chi^2 = 32.649$, g.l. = 2, $P = 0.0001$) (Figure 2). The width of *Harpacticus* sp. consumed by the Chilean

Table 1 Monthly variation (mean \pm SD) of planktonic and benthic organisms

Species	June	July	August	September
Plankton				
Copepods				
<i>Harpacticus</i> sp.	40 \pm 85	14 \pm 11	24 \pm 17	17 \pm 25
<i>Halicyclops</i> sp.	4 \pm 3	2 \pm 3	4 \pm 4	6 \pm 8
<i>Dactylopusia</i> sp.	6 \pm 4	1 \pm 1	-	3 \pm 4
Cyclopoida	1 \pm 2	-	-	-
Benthos	a/c	a/c	a/c	a/c
Polychaetes				
<i>Nereididae</i>	6 \pm 7/6 \pm 3	-	-	-
<i>Perinereis gualpensis</i>	17 \pm 15/16 \pm 15	29 \pm 14/42 \pm 12	23 \pm 24/27 \pm 21	-
<i>Boccardia</i> sp.	-	5 \pm 1/7 \pm 4	6 \pm 5/10 \pm 8	-
<i>Polychaete</i> sp.	-	-	1 \pm 2/1 \pm 1	36 \pm 43/7 \pm 10
Foraminifers				
<i>Ammonia beccarii</i>	3 \pm 1/6 \pm 7	-	1 \pm 2/1 \pm 2	-
Amphipods				
<i>Corophium insidiosum</i>	8 \pm 14/8 \pm 13	-	1 \pm 1/1 \pm 1	-
<i>Heterophoxus</i> sp.	1 \pm 2/1 \pm 1	-	-	-

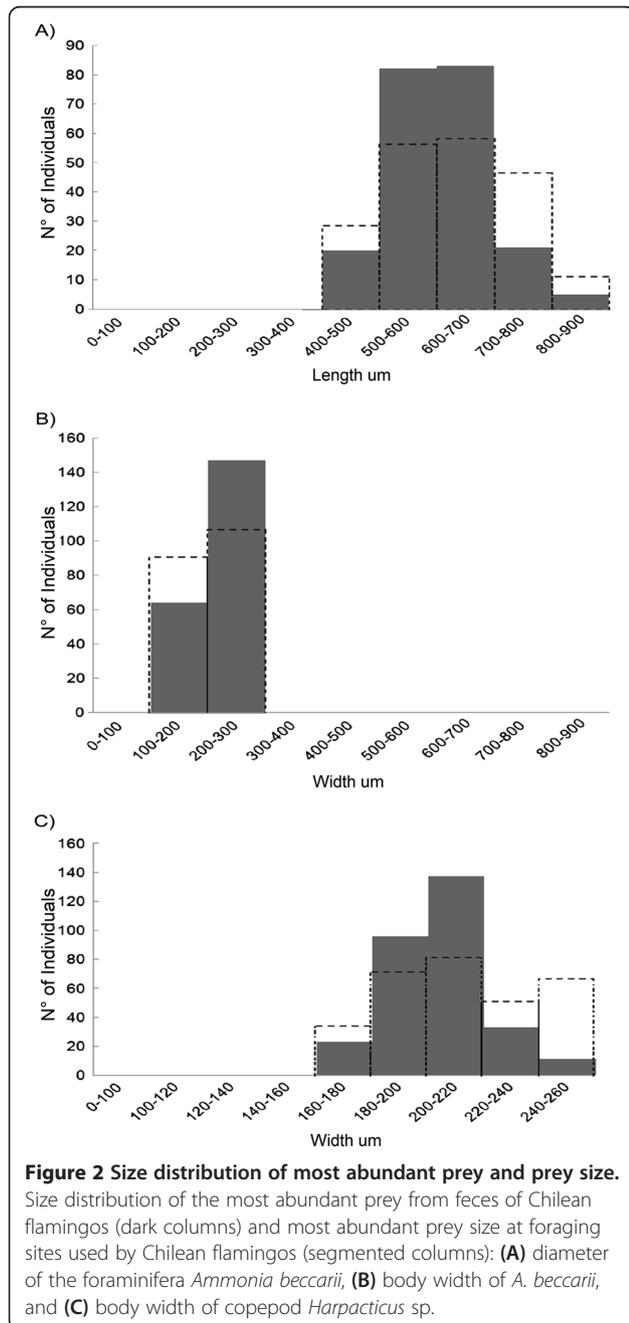
The organisms were present at (a) foraging sites used by the Chilean flamingo and (c) control sites in Caulín Bay.

Table 2 Prey abundance (Ind*ml⁻¹) observed in the feces of the Chilean flamingo

Species	Ind*ml ⁻¹
Polychaetes	87
<i>Harpacticus</i> sp.	992
<i>Ammonia beccarii</i>	2,370

Table 3 Diversity of preys ($H' \pm S^2$) in different types of substratum and in feces of the Chilean flamingo

Type of substrate	Trophic diversity (H')
Benthos	1.35 ± 0.01999
Zooplankton	0.706 ± 0.0065
Feces	0.717 ± 0.00355



flamingo ranged between 160 and 260 μm with a positive selection for organisms within the range of 180 to 220 μm ($\chi^2 = 195.400$, g.l. = 5, $P = 0.0001$) (Figure 2).

The dietary similarity of the Chilean flamingo versus the availability of prey in the environment (plankton and benthos) was 0.553. The diversity of prey present in the benthos was greater than that which was observed for the zooplankton and that which was present in the feces of the Chilean flamingo (Table 3). On comparing the diversity of prey present in the environment and in the feces, significant differences were only found for the paired comparison of the prey present in the benthos (Hutcheson t test = 4.032; $P < 0.05$).

With regard to the frequency of occurrence in all of the feces, the foraminifera (*A. beccarii*) was observed to prevail over the rest ($\chi^2 = 4973.52$, g.l. = 6, $P = 0.0001$). According to the Bonferroni simultaneous confidence intervals (BSCI), the prey item *A. beccarii* was consumed above the level expected by chance, and therefore, it was positively selected by the Chilean flamingo. Meanwhile, the *Harpacticus* sp. and the polychaetes were negatively selected (rejected) since they were consumed at levels lower than those expected by chance (Table 4).

Discussion

The diet of the Chilean flamingo is considered omnivorous, since it feeds both on phytoplankton (i.e., diatoms) and on zooplankton (i.e., copepods, brachiopods) (Rodríguez 2005). However, according to the information presented in this study, the diet of the Chilean flamingo in Caulín Bay was carnivorous and its trophic spectrum was made up of three kinds of invertebrate prey just as has been recorded by other authors in lagoons that this flamingo uses for feeding in the Andean Plateau (Hurlbert 1982; Hurlbert et al. 1984,

Table 4 Prey selection of the Chilean flamingo in the study area from June to September 2011

Prey	P observed	P expected	Bonferroni intervals
<i>Harpacticus</i> sp.	0.287	0.840	0.183 ≤ P_1 ≤ 0.391* (-)
Polychaetes	0.028	0.150	0.000 ≤ P_2 ≤ 0.066* (-)
<i>Ammonia beccarii</i>	0.685	0.010	0.578 ≤ P_3 ≤ 0.792* (+)

Bonferroni's simultaneous confidence intervals were applied to assess observed versus expected proportion of consumed prey. *Statistically significant differences $P < 0.05$ (-) corresponded to prey items consumed less than expected by chance, and (+) consumed in greater proportion than expected by chance. $\chi^2 = 4973.52$; $P = 0.0001$.

1986). In spite of the fact that diatoms were observed in the areas used by the Chilean flamingo for feeding, no diatom frustules were seen in the feces. The absence of diatom frustules in the diet of the Chilean flamingo may be due to the smaller size of these organisms (CN Tobar, pers. observ. 2011), which are not caught by the filtering ridges found in the Chilean flamingo's beak (Mascitti and Kravetz 2002). When the Chilean flamingo's beak is closed, this functional sieve has at least 80 μm between the side ridges of the proximal part of the beak and spaces of no more than 959 μm in the curved and distal parts (Mascitti and Kravetz 2002). The diatoms found in the marine wetlands of Caulín Bay are between 20 and 105 μm in size, smaller than the diatoms found in the Chilean Altiplano Lakes (between 58 and 140 μm), which are the main food of the Andean flamingo (*Phoenicoparrus andinus* Philippi 1854) (Tobar et al. 2012). The information contributed by Mascitti and Kravetz (2002) on the diet of the three flamingo species suggests that the filters found in their beaks create differences in the size of prey selected by each of these birds.

The potential prey profile availability with regard to zooplankton was represented by just four species while eight were recorded in the benthos. For the more abundant species both in the zooplankton and in the benthos, variations in abundance were recorded throughout the different sampling months.

With regard to the prey consumed most frequently by the Chilean flamingo, the foraminifera *A. beccarii* and the copepod *Harpacticus* sp. stood out. The size of both the diameter and the width of the foraminifera and the width of the copepod are consistent with the size of organisms (>100 μm) consumed by this flamingo in the lagoons found in the Argentinean Andean Plateau (Mascitti and Kravetz 2002). The dietary similarity of the Chilean flamingo versus the availability of prey in the environment (plankton and benthos) was 55%, indicating that the Chilean flamingo is a partially selective predator. The Chilean flamingo's prey selection is not governed by the nutritional elements provided by the prey consumed, but rather by the morphostructural restrictions of the bird's beak. With regard to the flamingo's positive selection for *A. beccarii* ahead of *Harpacticus* sp., this is not related to its size, but rather to the prey's escape behavior, due to the swimming capabilities that copepods use to avoid falling prey to the Chilean flamingo (Hurlbert 1982).

Conclusion

The diet of the Chilean flamingo in Caulín Bay was carnivorous and its trophic spectrum was made up of only three kinds of invertebrate prey. The potential prey profile availability with regard to zooplankton was represented by just four species while eight were recorded in the benthos. For the more abundant species both in the zooplankton and

in the benthos, variations in abundance were recorded throughout the different sampling months. The prey consumed most frequently by the Chilean flamingo, the foraminifera *Ammonia beccarii* and the copepod *Harpacticus* sp. stood out. The size of both the diameter and the width of the foraminifera and the width of the copepod are consistent with the size of organisms (> 100 μm). The dietary similarity of the Chilean flamingo versus the availability of prey in the environment (plankton and benthos) was 55%, indicating that the Chilean flamingo is a partially selective predator.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

CNT, JAC, AS conceived the study and participated in its design and coordination. JRR, NF, AG participated in the design of the study and performed the statistical analysis. JPS participates in the taxonomic identification. All authors read and approved the final manuscript.

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Author details

¹Departamento de Ciencias Básicas, Universidad Santo Tomás, Los Carrera 753, 5310431, Osorno, Chile. ²Laboratorio de Ecología, Depto de Ciencias Biológicas y Biodiversidad & Programa IBAM, Universidad de Los Lagos, Casilla 933, 5310887, Osorno, Chile. ³Departamento de Acuicultura y Recursos Agroalimentarios, Universidad de Los Lagos, Casilla 933, 5310887, Osorno, Chile. ⁴Department of Animal Ecology and Systematics, Justus Liebig University Giessen, Heinrich-Buff-Ring 38, 35392, Giessen, Germany. ⁵Programa de Doctorado en Ciencias mención Conservación y Manejo de Recursos Naturales, Universidad de Los Lagos, Casilla 557, 5310887, Puerto Montt, Chile. ⁶Centro de Estudios en Biodiversidad (CEBCh), Magallanes 1979, 5312498, Osorno, Chile.

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