



Are the diets of sympatric Pygoscelid penguins more similar than previously thought?

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Abstract

In recent years, functional changes in Southern Ocean are becoming more noticeable, due to climate change and increasing human impacts, including a growing fishery that is concentrating in the Antarctic Peninsula (AP) region. Antarctic krill *Euphausia superba* is often the primary prey species for animals such as *Pygoscelis* penguins, a sentinel species for ecosystem monitoring and management. During the last two decades in the AP gentoo penguin numbers (*Pygoscelis papua*) have increased and their range has shifted southward, in contrast to the decline in numbers of Adélie (*P. adeliae*) and chinstrap (*P. antarcticus*) penguins. Given divergent population trends, the goal of this study was to examine differences in their diet, and size structure of Antarctic krill recovered from penguin diet samples. The study is based on diet samples collected during the austral summers on King George Island (South Shetland Islands) where *P. adeliae*, *P. antarcticus*, and *P. papua* breed in mixed colonies. Results indicate that the penguins consumed krill of similar sizes during the breeding period. In contrast to prior diet studies, we found higher proportions of krill in the gentoo diet and changes in the percentage of krill in the diet relative obtained during 1970s. The similarity in diets among all three species suggests that the availability prey items (e. g., fishes) may be changing and driving higher dietary overlap. Moreover, we also check differences in krill length among penguin individuals and we did not find any statistically significant differences. We also found plastic debris in penguin stomachs during both summers.

Keywords Penguin diet · Pygoscelid · Antarctic crustacean · Dietary overlap · Plastic debris

Introduction

The marine ecosystem in the Antarctic Peninsula region is strongly dependent on the availability of a small, swarming crustacean, *Euphausia superba*, (hereafter krill), which is

the food base for numerous whale, seal and seabird species (Hill et al. 2006). For some of the predators, such as Pygoscelid penguins, krill can constitute up to 99% of their diet (Tierney et al. 2008; Juárez et al. 2018; Panasiuk et al. 2020). Krill biomass is estimated at around 380 million tons (Atkinson et al. 2009) and its harvesting is regulated by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Krill are predicted to be affected by harvesting and the effects of climate change, including warming sea-surface temperatures, melting of sea ice, and changes in phytoplankton composition and abundance (Hill et al. 2006). In particular, the effects of climate warming on krill growth may have significant implications for krill biomass which can cause negative consequence for dependent predators (Klein et al. 2018).

Among the important krill-dependent predators are penguins, which constitute nearly 90% of Antarctic avian biomass (Croxall et al. 2002). As the main component of Antarctic avifauna, Pygoscelid penguins exhibit extensive overlap in their distributions and nesting sites (Volkman

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et al. 1980; Lishman 1985). They exhibit different foraging locations and foraging-depth ranges during the breeding season, but also during winter period (Hinke et al. 2019; Korczak-Abshire et al. 2021), which helps maintain their co-occurrence throughout the AP region. Despite such differences in niche, the similarity of diet among the Pygoscelid penguins suggests a shared constraint on their performance (Hinke et al. 2007). Their diet is heavily dependent on krill (70 to 100% of the diet) (Volkman et al. 1980; Hinke et al. 2007; Panasiuk et al. 2020), thus their foraging distribution and abundance trends are usually linked with krill biomass variability (Trivelpiece et al. 2011a, b; Stryker et al. 2020).

Relatively few research sites afford the opportunity to examine the diet of the three Pygoscelid penguin species simultaneously. Long-term research on breeding populations of Adélie (*Pygoscelis adeliae*), gentoo (*P. papua*), and chinstrap (*P. antarcticus*) penguins in Admiralty Bay, King George Island included study of their trophic niches. Volkman et al. (1980) and Trivelpiece et al. (1987) demonstrated that gentoo diets contained more fish than Adélie or chinstrap diets. More recently, Miller et al. (2010) highlighted local differences in diets, reporting that from 1997–1998 to 2003–2004 fish constituted 28.8% of a diet of gentoo and 0.6% of chinstrap at Cape Shirreff (Livingston Island), while in Admiralty Bay (King George Island) fish represented 1.6% of a diet of gentoo and 0.1% of chinstrap. Within the last three decades in Admiralty Bay, the breeding populations of Adélie and chinstrap penguins have decreased, while the population of gentoo penguins has increased (Watters et al. 2020), consistent with regional trends (Lynch et al. 2012). Such large-scale changes in the abundance and distribution of each species may affect their competitive relationships for food resources.

The main goal of our study was to analyze the diet composition and krill sizes consumed by sympatric Adélie, gentoo and chinstrap, and to compare our results with historical diet data. As a null hypothesis, we expected similar diet compositions of Adélie and chinstraps, but a higher proportion of fish in gentoo diets. We also expected similar distributions of the sizes, sex, and maturity stages of krill in the diets of three sympatric penguin species that initiate foraging trips from Admiralty Bay, leading to more similar diet characteristics that previously observed. We used two consecutive years of diet data to address our hypotheses related to dietary composition of each species.

Materials and methods

Sampling collection and laboratory studies

Diet samples were collected in the Austral summers (December–February) of 2011/2012 and 2012/2013. Fieldwork was

conducted at King George Island, South Shetland Islands (62° 10' S, 58° 30' W), within the Antarctic Specially Protected Area (ASPA) No. 128 where Adélie, chinstrap, and gentoo penguins breed in five colonies (Fig. 1). Following procedures of the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program (CEMP), the population size, expressed in the total number of occupied nests, and breeding success, expressed as the mean number of chicks alive during the crèche stage per nest were calculated. Diet samples were collected from adult penguins after their foraging trips using the water-offloading technique (Wilson 1984) with CEMP standard methods modifications (see more in Panasiuk et al. 2020). Diet samples were sorted to identify the frequency of occurrence by number and weight of krill, fish, and other, unidentifiable diet items. All krill individuals collected in the diet samples were counted (based on the pairs of eyes for digested animals). Whole, undamaged individuals were sexed, and measured for total length, according to CCAMLR standard protocol (<https://www.ccamlr.org/>): from the anterior side of the eyeball to the tip of the telson (Makarov and Denys 1980). Diet samples from 2011/12 were used to estimate the difference between krill sizes consumed by penguins and to compare with krill sizes presented by Panasiuk et al. (2020). Diet samples from both seasons were used for comparing krill sizes and maturity stages. We only used diet samples that contained at least 30 whole individuals for comparing krill sizes and maturity stages. Sexed animals were grouped into the following clusters: F—females, Fs—sexually active females defined by presence of spermatophores, and M—males. Additional groups—Es and J—were used for individuals without clear sex indication and individuals with damaged bodies (Es), and juvenile individuals.

Statistical analyses

Statistical analyses were carried out using Rstudio software package, Rversion 4.0.3. We used a one-way ANOVA with a Tukey's HSD post hoc test to compare differences in krill length and maturity stages in the penguin diet samples. Additionally, we used a nested ANOVA to compare differences in krill lengths in which krill length was a response variable and years and penguin species were factors with year nested within species. Differences in krill sizes between years were statistically significant ($p < 0.0001$), however, because our main goal was to check differences between penguin species and inter-individual differences within species we pooled samples to examine sex and maturity stages of the krill population eaten by penguins. We also checked interindividual differences in krill lengths using the Kruskal–Wallis test.

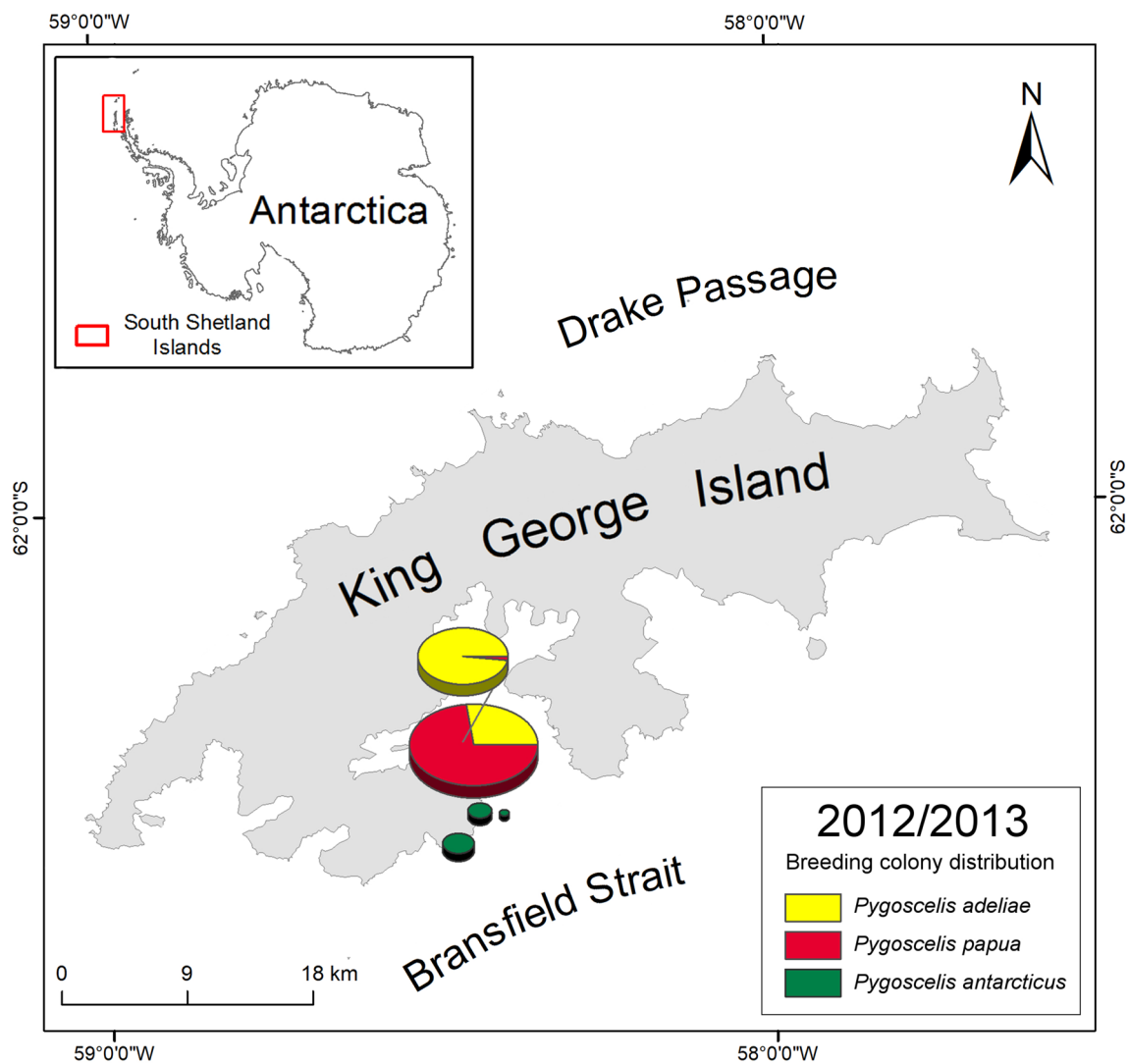


Fig. 1 Breeding colony distribution of Adélie penguins (*P. adeliae*), chinstrap penguins (*Pygoscelis antarcticus*) and gentoo penguins (*Pygoscelis papua*) in 2012/13, within the Antarctic Specially Protected Area No. 128 (ASP 128) at the western shore of Admiralty Bay at King George Island, South Shetland Islands, (contour of the

Antarctic continent coast source: <http://www.marinerregions.org/gazetteer.php?p=details&id=1926>, contour of the King George Island coast source: Scientific Committee on Antarctic Research Antarctic Digital Database, version 6.0, 1993–2015)

Results

Krill, by mass and number, constituted more than 99% of the diet in all samples (Table 1), with only small contributions of other prey, including amphipods, and other euphausiids (*Thysanoessa macrura*, and *Euphausia frigida*) and fish. In case of frequency of occurrence—tiny fish remains or otoliths were reported in 70% of gentoo penguin stomachs in season 2012/2013 and 20% in 2011/2012. For Adélie and chinstrap, however, fish prey was present in first researched season in only 10% of individuals.

Most krill individuals in the diet samples were classified as adults with a median length of 40 mm (mean 39.76 ± 6.93). Juvenile krill were rare (Fig. 2, Table 2)

and were most abundant in the Adélie diet. On average, the largest krill were observed in the diet samples of gentoo penguins, while diet samples from Adélie and chinstrap penguins contained smaller krill (Fig. 2, Table 1). The mean sizes of krill consumed by Adélie penguins was 38.40 ± 7.28 mm and chinstrap penguins was 40.68 ± 5.55 mm, while in gentoo diets was 41.7 ± 6.22 mm (Fig. 3, Table 1). The differences between the length of a krill in the diets were biggest between Adélie and chinstrap penguins and Adélie and gentoo penguins (Tukey HSD, $p < 0.0001$). Smaller difference was noted between gentoo and chinstrap penguins (Tukey HSD, $p = 0.015$). We also checked interindividual differences, and results of the Kruskal–Wallis

Table 1 Population sizes and breeding success of investigated penguins species and composition of penguin stomach content (by weight and number), number of analysed diet samples for two investigated research seasons, mean krill size, and results of nested ANOVA with a Tukey's HSD post hoc

Penguin species	Penguin population size (nest number)	Penguin breeding success	Total stomach samples (individuals)	Prey type (%) by weight/ by number				Season
				Antarctic krill	Fish	Fish occurrence by frequency (%) [*]	Other ^{**}	
Adélie	6862	1.03	20	99.9/99.9	0	10	<0.1/<0.1	2011/2012
gentoo	4886	1.39	20	99.8/99.9	0.1/<0.1	20	<0.1/<0.1	
chinstrap	896	0.92	10	100	0	10	0	
Adélie	5626	0.47	30	99.9/99.9	<0.1/0.1	0	<0.1/<0.1	2012/2013
gentoo	5463	1.09	10	99.9/99.4	<0.1/0.5	70	<0.1/<0.1	(Pana-siuk et al. 2020)
chinstrap	765	0.85	20	99.9/99.9	0	0	<0.1/<0.1	
Number of in-depth analysed diet samples—seasons 2011/2012 and 2012/2013								
Adélie								25
gentoo								15
chinstrap								8
Total number of measured Antarctic krill individuals—seasons 2011/2012 and 2012/2013								
Adélie								2177
gentoo								1324
chinstrap								463
Mean krill size (mm) ± SD—seasons 2011/2012 and 2012/2013								
Adélie								38.40 ± 7.28
gentoo								41.7 ± 6.22
chinstrap								40.68 ± 5.55
Summary results of nested ANOVA—seasons 2011/2012 and 2012/2013								
Dependent variable	Independent variable	Summary of squares	df	F	p			
Krill length (mm)	Season	9359	2	105.19	<0.0001			
Krill length (mm)	Penguin species (Season)	4710	2	52.94	<0.0001			
Summary results of Tukey test—seasons 2011/2012 and 2012/2013								
Species	diff	lwr	upr	p				
CHPE-ADPE	2.279019	1.1669637	3.091074	<0.0001				
GEPE-ADPE	3.292293	2.7401219	3.844465	<0.0001				
GEPE-CHPE	1.013274	0.1564203	1.870129	0.015				

*Fish by frequency—based on identified parts and otoliths presence

**Other—consisted of: amphipods, unidentified invertebrate, pebbles, algae

test showed no statistically significant differences among Adélies ($p = 0.4616$), gentoos ($p = 0.4478$), and chinstraps ($p = 0.4289$).

Female krill formed the majority of the diet for all penguin species (Table 2). The largest average size of krill in each sex and maturity stage was found in the gentoo diet (Table 2). The biggest krill was a 73 mm female with spermatophore (Fs), and this group represented, on average, the largest animals in all samples with mean lengths that varied from 44.43 to 46.45 mm (Table 2). Male krill individuals

were the second largest group in terms of size (both by median and mean value) (Table 2).

We found algae, stones, feathers and other debris in the *Pygoscelis* penguin stomachs (Fig. 4). Some net fragments were identified. They were accompanied by plastic film elements of uncertain origin, although some of them looked like fragments of plastic bags. Most of the plastic debris could be classified as microplastics (1–5 mm; 10 plastic parts), mesoplastics (<5–20 mm; 23 plastic parts) (Barnes et al. 2009) and classified as user plastic (only non-industrial remains of

Fig. 2 Histograms of pooled krill *E. superba* lengths in stomach content of all three penguin species in 2011/12 and 2012/13

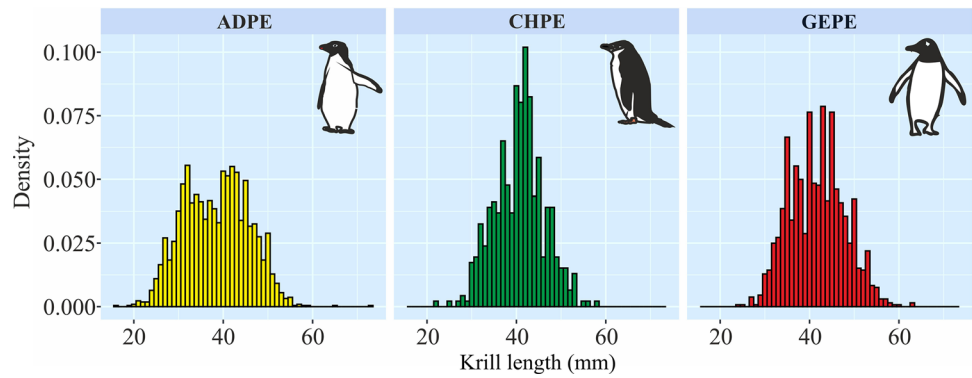


Table 2 Summary statistics of krill *Euphausia superba* reported in pygoscelid penguins (Adélie, chinstrap, gentoo) stomachs content (from both investigated seasons) divided into subgroups: *F* female, *Fs* female with spermatophores, *M* male, *J* juvenile; in both investigated seasons

Species	Sex/stage	No. of indiv.	Mean length (mm)	SD	Range
Combined	F	2204	40.87	5.56	29–73
Adélie		1111	40.28	5.80	29–73
Gentoo		816	41.58	5.53	31–59
Chinstrap		277	41.15	4.34	30–56
Combined	Fs	635	45.34	4.79	31–63
Adélie		326	44.43	4.60	31–58
Gentoo		251	46.45	4.85	31–63
Chinstrap		58	45.59	4.61	37–58
Combined	J	13	30.08	4.82	21–33
Adélie		7	29.43	5.44	21–33
Gentoo		NA	NA	NA	NA
Chinstrap		6	30.83	4.36	22–33
Combined	M	257	42.82	4.33	31–55
Adélie		135	43.26	4.32	31–55
Gentoo		58	42.95	4.39	34–52
Chinstrap		64	41.80	4.18	34–52

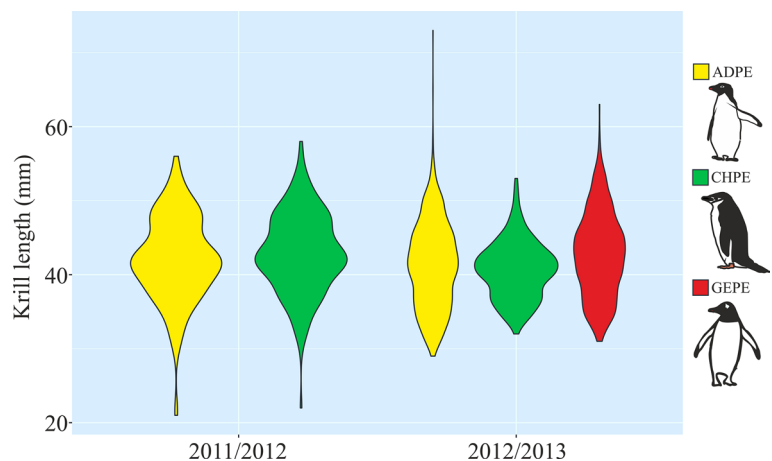
plastic objects) (Van Franeker and Meijboom 2006). In case of color of found debris—there was 1 occurrence of red-pink plastic parts (4 debris in one dietary sample in Adélie stomach) and 7 green strings (5 in Adélie penguin stomach content; 2 in gentoo), while majority (12 debris) were off/white-clear in color. Plastic debris were found in 16 stomach contents (out of 78) which constituted 20% of all samples.

Discussion

Krill dominance and size in Pygoscelis diet

Krill constituted almost 100% of the penguin diets, in weight and by number, during the 2011/2012 summer season, similar to other reports (Miller et al. 2010; Panasiuk et al. 2020). Fishes, in all cases, constituted < 0.1% of mass in the diet (Table 1). The similarities in diet composition among sympatric Pygoscelid penguins observed during our study differ from those observed roughly for decades ago. For example, Trivelpiece et al. (1987) noted that krill constituted 86.5% of in the gentoo penguin diet during the period 1976–1985. Similar proportions were also noted earlier by Volkman et al. (1980), with the krill comprising 84.5% of the gentoo

Fig. 3 Differences in krill *E. superba* length in a diet of the three investigated penguin species between seasons 2011/2012 and 2012/2013



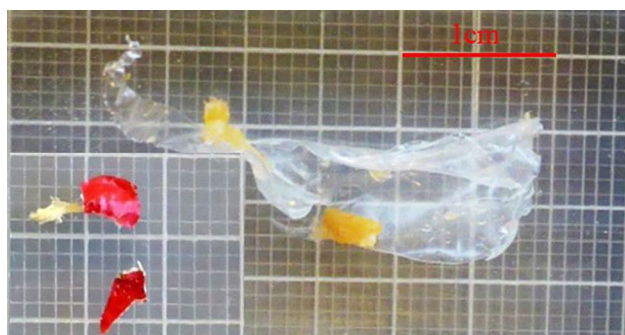


Fig. 4 Example of ingested plastic debris found in penguin diets in the summer season 2011–2012

diet and 99.6% for the two other penguin species (Table 3). Jabłoński (1985) recorded even 48.6% of fish in the gentoo diet (Table 3). We explore possible reasons for the increased similarity in diet below.

Adélie and chinstrap penguins in the broader Antarctic Peninsula region typically exhibit a summer diet-based almost exclusively of krill (Lishman 1985). Such high amounts of krill in the diet of all three species suggest sufficient local availability of krill in the environment during the summer breeding period (Hinke et al. 2007; Nardelli et al. 2021). The apparent increase in the occurrence of krill in the diet of gentoo penguins since the early 1980s may imply a decline in availability of secondary prey items, particularly fish. While we noted that 70% of gentoos consumed fish in 2012/2013 season which would corresponds with Miller et al. (2010) findings in Cape Shirreff (Livingston Island), most of noted presence in our study was based on otoliths presence in stomach content. Gentoo penguins were known to consume *Pleurogramma antarctica* in King George Island vicinity (Volkman et al. 1980). A study of the distribution of *Pleurogramma* on the Western Antarctic Peninsula shelf exposed a gap in its occurrence which could indicate a local collapse of this fish (no individuals smaller than 150 mm were recorded, and after 1990s smaller contribution in predators diet has been noted) (Parker et al. 2015). Evidence of a decade's long decline in the occurrence of fish in Antarctic fur seal diets (Klemmenson et al. 2020) provides supporting evidence for potential changes in the preyscape available to penguins in this region. The relative dominance of krill in the diet is also supported by recent results from a molecular study of penguin feces (Zeng et al. 2022) that suggests a diet dominated by Euphausiid species. Therefore, further study is necessary to explain the switch to a diet with higher proportions of krill, especially with increasing population of gentoo penguins in the region, and the concurrent decrease in Adélie and chinstrap penguin populations numbers (Lynch et al. 2012). We note that the stomach contents can be related to sample timing relative to the period of a day

or night foraging. Jansen et al. (1998) and Miller and Trivelpiece (2008) observed during their studies that the diet of chinstrap penguins consists of more fish during nights, and samples for this study were collected only in the afternoons.




In our study, the mean length of krill in all penguin stomach contents was 38–42 mm and adult individuals were the majority (Figs. 2, 3). These sizes are comparable to the findings of Volkman et al. (1980) and Coria et al. (1995), but smaller than the animals noted by Trivelpiece et al. (2011a) from the same area of research. Differences in the length of krill consumed by penguins may be caused by differences in the availability of certain age classes, different foraging areas, or year-to-year differences in prey availability, recruitment, and abundance (Coria et al. 1995; Hewitt et al. 2003; Kokobun et al. 2015; Reiss 2016). It is worth noting that our study area is recognized as a region of occurrence of juvenile krill (Fevolden and George 1984) and cycles of krill recruitment are evident throughout the WAP (Miller and Trivelpiece 2007; Saba et al. 2014; Reiss 2016; Conroy et al. 2020). However, few krill less than 30 mm in length were observed in the diet samples, which suggests that presumably krill recruitment in the area was not high in the preceding year.

Our two-year study confirmed that the largest krill were consumed by gentoo penguins, while the smallest animals were typically found in Adélie diets (Figs. 2, 3; Table 1). In general however, the krill sizes in the diets of the three penguin species were similar. It is evident that strong dietary overlap exists between *Pygoscelis* penguins in the study area, and that dietary overlap may be much more pronounced than reported in the past (Volkman et al. 1980; Jabłoński 1985; Lishman 1985; Trivelpiece et al. 1987).

Krill sex and stages in *Pygoscelis* diet

During this study, a preference for female krill was evident across penguin species (Table 2). In over 3800 measured krill individuals, only 6.5% were recognized as males. Similar results were observed by Volkman et al. (1980), Reid et al. (1996), and Lynnes et al. (2004). In our study female krill with attached spermatophores constituted more than 20% of all measured females. The disproportionate occurrence of female krill in the diet of predators also was surprising for Reid et al. (1996) around the South Georgia, who surmised that predators opted to catch the largest available krill—gravid females. Sexually active females were the most numerous group in predator diet and net samples in researched done by Reid et al. (1996). Hill et al. (1996) suggested that for macaroni penguins, the predominance of female krill in the diet could be a result of capture avoidance by faster swimming male krill. The higher proportion of female krill in penguin diet may also point to selectivity for the largest individuals available. In the Bransfield Strait,

Table 3 Comparisons of composition of pygoscelid stomach contents by weight (%) at King George Island populations in different years (*Amp.* amphipods)

Type of prey	Volkman et al. (1980) King George Island: 1977–1978			Jabłoński (1985) King George island: 1978–1979, 1979–1981			Miller et al. (2010) King George Island: 1997–1998 to 2003–2004 gentoo, 1997–1998 to 2007–2008 chinstrap			Juárez et al. (2018) King George Island: 2003–2015			Presented data 2011/2012			Presented data 2012/2013		
	Krill	Fish	Amp	Krill	Fish	Other	Krill	Fish	Other	Krill	Fish	Other	Krill	Fish	Other	Krill	Fish	Other
ADPE 	99.6	0.1	0.3	72.7	7	20.3	–	–	–	Mean 99.90	Mean 0.03	–	99.9	0	<0.1	99.9	<0.1	<0.1
CHPE 	99.6	0.3	0.1	38.2	34.9	26.7	Mean 96.7	Mean 0.1	Mean 3.3	–	–	–	100	0	0	99.9	0	<0.1
GEPE 	84.5	15.4	0.1	40.4	48.6	11	Mean 98.4	Mean 1.6	0	–	–	–	99.8	0.1	<0.1	99.9	<0.1	<0.1

juvenile krill generally form the majority of the population, while adult females represent a smaller fraction of population (Siegel 1983; Fevolden and George 1984). Therefore, the dominance of female krill in penguin stomachs affirms selectivity for the largest krill individuals available. The female krill carrying spermatophores were also the largest krill in the available diet samples with a mean length of 45 mm for all species (Table 2). The preponderance of females in the diet may also be affected by digestion. Irvine (2002) suggested that smaller males are usually much more affected by the sampling methods and preservation than females, and tend to break. Those factors may lead to the underestimations of smaller males in samples and could explain the relatively small number of males < 40 mm present in the diet samples.

Krill availability in *Pygoscelis* diet and their breeding success

Many reports suggest a direct linkage between reproductive success of predators and fluctuations in krill abundance and structure (Lynnes et al. 2004; Trivelpiece et al. 2011b). In the 2011/2012 breeding season, the abundance of Adélie and chinstrap penguins was larger than during the 2012/13 breeding season (Table 1). The situation was in opposite for gentoo penguins. The breeding success of all three penguin species, however, was higher in 2011/2012 than in 2012/2013 (Table 1), similar to other breeding locations like the Lions Rump (Korczak-Abshire personal observations) (ASP 151), and the Stranger Point (Juárez et al. 2020). This suggests that the 2011/12 season may have been better for the penguins. During our study we did not find any considerable differences in diet composition, krill size, or numerical of krill between both seasons. However, in a krill dominated system, we may not expect the diet composition of penguins to change considerably, but the performance of birds can be negatively affected if foraging trip durations are long (e.g., Hinke et al. 2007). Episodic phenomena, including heavy snowfall events (Spring 2012 and January 2013—personal observation), can also negatively affect reproductive performance (see Hinke et al. 2012). For example, the strong wind, rainfalls, and thick snow events affect the increase of chicks' energy input and lower thermal insulation factors. Thus, the observed difference in breeding success between years may reflect meteorological anomalies during incubation and guard stages.

What is the reason for dietary overlap?

Historical data shows a distinction between chinstrap and gentoo trophic niche based on diet differences (Volkman et al. 1980) and foraging ranges (Trivelpiece et al. 1987). However, climate change in Antarctic Peninsula region

(Meredith and King 2005) and shifts in penguin population trends may affect the trophic niche of the *Pygoscelis* penguins. Both Adélie and chinstrap breeding populations have decreased in the northern Antarctic Peninsula region (Korczak-Abshire et al. 2012; Juárez et al. 2015). For example, in Turret Point Oasis (King George Island) from 1980 to 2008 the population of Adélie decreased by 84.06% and chinstrap by 50.09% (Korczak-Abshire et al. 2019). In case of gentoo penguins at Stranger Point/Cabo Funes, South Shetland Islands Juárez et al. (2020) noted that their population between 2000/2001 and 2018/2019 increased by more than 60%. The first observations of this trend were made in 1990s by Ciaputa and Sierakowski (1999) and they suggested that penguin population trends and krill abundance were linked. Population changes among gentoo and chinstrap penguins are related to temperature and its anomalies (Petry et al. 2016), while the decline in Adélie penguin numbers is correlated with reduction of sea ice during winter season (Juárez et al. 2015). Taking into consideration increases in air temperature from 1981 to 2011 during summer, autumn and winter seasons, along with increases in sea-surface temperatures and increased variability in sea ice extent (Kejna et al. 2013), we should expect a response in birds population numbers. Yet, between the 2011/2012 and 2012/2013 summer seasons, we didn't detect substantial differences in krill size composition in *Pygoscelis* stomachs. Similarity in diet composition across the penguin species can be connected with a lower availability of krill or other alternative prey items with an increasing competition between them. If the numbers of Adélie and chinstrap penguins are in decline, while gentoo populations rise, it could indicate that gentoo penguins are expanding their trophic niche to occupy the vacancy created by decreasing populations of its congeners, and this possibility was also discussed by Miller et al. (2010).

Plastic debris in penguin stomachs

One of the first observations of ingested plastic by marine vertebrates south of the Polar Front was in a snow petrel (*Pagodroma nivea*) in the 1980s (Van Franeker and Bell 1988). Similar findings for other Antarctic predators remain rare (Waller et al. 2017). We found plastic debris in the *Pygoscelis* penguins stomachs in two consecutive seasons. Among Antarctic penguins, evidence for plastic ingestion was noted from penguin scats (Bessa et al. 2019) in the regions of Bird Island (South Georgia) and Signy Island (South Orkney Islands), and in regurgitate (Panasiuk et al. 2020) collected from birds at King George Island (South Shetland Islands). Although the Southern Ocean has smaller concentration of micro- and macroplastic than other parts of the World Oceans (Suaria et al. 2020), observations of plastic debris in the penguin stomachs during two breeding

seasons (now one decade ago) suggest that its occurrence in diets is not a spurious finding. We found that Pygoscelid penguins are also able to ingest larger pieces of plastic (Fig. 4) and this could indicate additional potential mechanisms to impact penguins.

While there are grounds for supposition, answer the question: are the diets of sympatric Pygoscelid penguins more similar than previously thought? definitely needs more data. It is possible that widely studied belief about the decline of *E. superba* (e.g., Atkinson et al. 2009) could be now facing its turning point with confirmed big aggregations of returning whales, as fin whales noted in 2018 by Herr et al. (2022). Such situation could suggest that if there is enough of krill to support dietary needs of some predators groups this could also be a reason for higher percentage of dietary overlap of pygoscelid penguins. However, to regard this as a trend—such observation as in presented study need to be continued, as well as studies on what drives these changes.

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Author contributions JW-B was responsible for the laboratory analysis, dataset preparation, results interpretation, conception, preparation and management of the manuscript. AP responsibility was the coordination of sample collection, statistical analysis with interpretation, and in manuscript preparation. MK-A provided data and results interpretation of penguin population. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Data availability The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval All applicable institutional guidelines for the care and use of animals were followed.

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