

## Dear Editorial Team of Biogeosciences

### Authors Comments

#### Responses to comments by Reviewer

The authors clearly did a lot of work including an additional year of dive data into analyses and they have clarified most of the questions I had about methodology. My remaining comments center on interpretation of some of the findings that have now been included in the Discussion section, and some important caveats that should be made clear. The Discussion section's paragraph topics also seemed to 'jump around', and I think edits for flow and concision in the Discussion would improve the manuscript.

⇒ We thank to the reviewer for the valuable comments and suggestions. As recommended, we have added descriptions regarding the method to determine the dosage of anesthetic administered to the Weddell seals, as well as the actual dosages used. In the Discussion section, we have toned down the potential interspecific competition between Weddell seals and emperor penguins and provided further explanation. We have also included a statement clarifying that our head measurement represents prey capture attempts, but may not reflect actual foraging success or the quality or quantity of prey obtained. Lastly, to make the Discussion paragraphs flow as presented in the Results section, we edited the paragraph topics by combining the separated comparisons with previous studies into a single paragraph. The detailed changes are described in our point-by-point responses.

The use of the word 'foraging' in many places in the discussion when comparing multiple studies that used very different metrics as proxy, was at many times quite confusing. For example, the authors stated 'their [Goetz 2023] foraging results showed contrary to our foraging results'. Goetz 2023 and other Weddell seal studies have used area restricted search and first passage time to infer areas/times associated with greater foraging effort. Conversely, this study used prey capture attempts and it seemed that these did not increase in the winter months as ARS had in previous work. There are a ton of possibilities that could account for these differences, and so the method used should be made clear throughout these paragraphs rather than clumping them all together as 'foraging'.

⇒ We agree that ARS is a different proxy since it is a prey search effort. In accordance with the comment, we differentiated the previous ARS estimation by Goetz et al.'s work (2023) with our head acceleration-based measurements. Since we measured the foraging behavior of Weddell seals by recording the number of head movement using an acceleration sensor, our method was to estimate the prey capture attempts. While we have used the term 'foraging' throughout the manuscript, we agree that it should be used more cautiously in certain sections, particularly when comparing our study with others, to avoid confusion. Also, we excluded the criticism on the first passage time estimation since this method is not exactly comparable to our study. Consequently, we have revised the Results and Discussion sections to use more specific terms such as 'prey search effort' to indicate the previous study by Goetz et al. (2023) and have added descriptions of the characteristics and limitations of these foraging proxies.

In Results section, we have revised as follows "Additionally, seals demonstrated higher PrCA events during the daytime, with an average of 4.89 foraging attempts per dive, compared to 2.13 attempts during the nighttime (Fig. 6b; Table 6).".

In Discussion section, we have revised as follows "A previous study on Weddell seals in the Ross Sea showed that seasonal changes for foraging effort were observed, with dive depth and prey search effort (estimated by search effort time in a given space) increasing from summer to winter (Goetz et al., 2023). Additionally, prey search effort was also higher in benthic dives (Goetz et al., 2023). The seasonal increase of dive depth agreed with our findings, but the prey search effort showed the contrary of PrCAs, our foraging measurement. Goetz et al. (2023) observed that the prey search effort was the highest in winter of 2010 to 2012. This could be due to the different seasonal prey availability across the seasons. During winter, our study indicated that prey capture was lower while the previous study by Goetz et al. (2023) showed the prey search effort was higher. To combine the two studies, it seems that the seals had to spend more time to search for prey despite the low foraging success in winter. Still, it is difficult to compare the two studies since there is an approximate 10-year difference. The diet composition of Weddell seals exhibits considerable interannual variability in the Ross Sea area (Goetz et al., 2017). The sea ice extent and the food availability for top predators can vary annually (Ainley et al., 2020). Such variations in sea ice extent can possibly influence plankton blooms and the seasonal prey abundance for seals between the two studies (Arrigo et al., 2004; Lorrain et al., 2009). Our measurement also has a limitation to compare the seasonal change. Prey capture attempts were estimated by 'jerk'

from acceleration sensors attached on heads. Prey capture attempts do not necessarily correlate with the quality or quantity of the prey successfully obtained. For example, jerk could be overestimated when handling larger prey items, as the number of handling movements increases (a case of Australian fur seals, *Arctocephalus pusillus doriferus*, Volpov et al., 2015). These limitations of foraging proxies may account for the observed differences in their seasonal trends.”.

#### Abstract

Would remove ‘diurnal’ from ‘diurnal light hours’

⇒ In accordance with the comment, we have made the correction as suggested. Rephrased sentence is as follow: “Understanding the foraging behavior of marine animals in Antarctica is crucial for assessing their ecological significance and responses to environmental changes, such as seasonal changes in seawater or light hours.”.

#### Methods

Line 120: What was the dose of Zoletil actually administered to the animals?

⇒ Before anesthetization, the body length was roughly estimated by field researchers and an appropriate dosage of anesthetic was calculated and administered using the proportional relationship between the body length and weight of the Weddell seals. For example, a 2.2 m Weddell seal typically has an average weight of 310 kg, and a dosage of 4.8-6 ml of anesthetic is considered appropriate. We have added this information to the second paragraph of Method 2.1 as follows: “Before anesthetization, the body size was roughly estimated by the field researchers. Then, an appropriate dosage of anesthetic was administered using the proportional relationship between the body length and mass of the Weddell seals (Noren et al., 2008). The dosage administered to each individual (2 to 5 ml) is included in Supplementary Table 1.”

Line 135: I believe this should be reworded to say that --- dive descents were defined as the start of the dive until the first inflection point that exceeded 75% of maximum dive depth (?) As written, it sounds as though the descent only includes the first inflection point and this would only very infrequently be >75% max depth.

⇒ We have made changes to clarify the sentences you were concerned about. Rephrased sentences are “Dive descents were defined as the start of the dive until the first internal point

that exceeded 75% of maximum dive depth. Similarly, the ascent phase began at the first internal point, where depths exceeded 75% of the maximum dive depth, and ending after the dive.”.

Line 275: Should refer to Figure 3 for dive depth

⇒ Thank you for pointing out this error. We have made the correction as suggested.

Rephrased sentence is “Figure 3 illustrates the seasonal changes in dive depth.”.

Lines 282-285: This feels like an incomplete/hanging sentence. It looks like the authors mean that PrCA’s occurred most frequently in benthic dives, even though a small proportion of dives were classified as benthic (?). It also seems like this point would be better made at the very end of the paragraph.

⇒ We have moved the mention of that part to the end of the paragraph to improve the flow and clarity as suggested. The paragraph has been revised as follows.

“In all three years, the Weddell seals tagged in this study exhibited distinct diving behaviors across months. Figure 3 illustrates the seasonal changes in dive depth. The dive depth shows an increasing trend from March to July, whereas the number of PrCA events decreases in June and July compared to March and April. When considering diving depth ( $p < 0.001$ ; log likelihood ratio test between the best model and a model excluding the variable “season”), the shallowest dives were undertaken in April, whereas the deepest diving occurred in July ( $200 \pm 137$  m in April,  $265 \pm 154$  m in July; mean  $\pm$  standard deviation) (Fig. 3; Tables 1 and 2). In terms of PrCA ( $p < 0.001$ ; log likelihood ratio test between the best model and a model excluding the variable “season”), the highest number was observed in April, whereas the lowest occurred in June ( $3.29 \pm 6.11$  in April,  $1.56 \pm 2.59$  in June) (Fig. 4a; Tables 3 and 4). Additionally, PrCA values varied based on water mass and dive type (benthic or pelagic) ( $p < 0.001$  for both; log likelihood ratio test between the best model and a model excluding the variables “water mass” and “dive type”). Based on our water mass definition, Weddell Seals performed many dives (76.76% of total dives) and high frequent observations of PrCAs (86.7% of total PrCA events) in MSW. The kernel density plots of dive distributions on a TS diagram are shown in Supplementary Fig. 4. Notably, Weddell seals displayed a higher number of PrCA events per dive in HSSW, MSW, and ISW compared to AASW (additional 1.14, 0.66, and 0.65 in PrCA per dive for HSSW, MSW and ISW, respectively; Tables 3 and 5). Our seals had 0.58 more PrCA during benthic dives than during pelagic dives (Fig. 4b;

Table 2), despite the fact that benthic dives were not predominant (11,741 out of a total of 64,014 dives, Fig. 4c). From March to July, PrCA consistently decreased during pelagic dives, whereas no significant decrease was observed during benthic dives (Figure 5, Supplementary Table 5).

Line 286: The authors said in the previous sentence that the most PrCA's occurred in MSW but here it sounds like it is actually HSSW?

⇒ The previous sentence means that the majority of total PrCA events occurred in MSW, while the current sentence indicates that the number of PrCAs per dive was higher in HSSW, MSW, and ISW. We have revised these sentences to clarify this distinction. Rephrased sentences are “Based on our water mass definition, Weddell Seals performed many dives (76.76% of total dives) and high frequent observations of PrCAs (86.7% of total PrCA events) in MSW. The kernel density plots of dive distributions on a TS diagram are shown in Supplementary Fig. 4. Notably, Weddell seals displayed a higher number of PrCA events per dive in HSSW, MSW, and ISW compared to AASW (additional 1.14, 0.66, and 0.65 in PrCA per dive for HSSW, MSW and ISW, respectively; Tables 3 and 5).”

Lines 293-294: I think it terminology should be kept consistent with this referring to PrCA's (instead of going back and forth with calling it foraging activities --- this could be taken to mean prey capture attempts or also could presume that all benthic dives are made with the intent that the animals are trying to forage, etc. It's more open ended).

⇒ We maintained the use of 'PrCA' instead of 'foraging' for greater accuracy. The revised sentence is as follows. “Additionally, seals demonstrated higher PrCA events during the daytime, with an average of 4.89 foraging attempts per dive, compared to 2.13 attempts during the nighttime (Fig. 6b; Table 6).”

Lines 302-303: I think the authors mean that the seals made more prey capture attempts in these water masses? It is a bit ambiguous when it is referred to as ‘preference in foraging habitat’ since that usually means whether the seals were simply present in a given location

⇒ We have revised the sentence to clarify that we are referring to the number of prey capture attempts. The revised sentence is “Among these, Weddell seals exhibited significantly higher number of PrCA events per dive for HSSW, MSW and ISW over AASW.”

Lines 312-315: These two sentences essentially say the same thing and could be combined.  
⇒ To make the text more concise, we have revised it into a single sentence as suggested. Revised sentence is “While these proxies are indirect indices and should be interpreted cautiously, acceleration data like the data our CTD obtained is particularly beneficial as it can directly detect PrCA, providing a more accurate measure of foraging activity (Heerah et al., 2019; Allegue et al., 2023).”.

Lines 360-361: But there was no evidence that the two species were doing this. In fact, both the seals and emperor penguins made very similar proportions of deep dives exceeding ~350 m. The inter-specific competition was believed to be primarily between penguins and juvenile Weddell seals (not the adults to a great extent)

⇒ In our data, Weddell seals showed that approximately 13% of their dives exceeded 350 meters, with this percentage rising to 22% in July. Additionally, due to the lack of direct evidence, we have toned down the statement to only suggest the possibility. The revised sentences are “Additionally, seasonal variations in interspecific competition, particularly involving emperor penguins, another apex predator species in the Ross Sea year-round (Burns and Kooyman, 2001; Smith et al., 2012), could affect the foraging behavior of Weddell seals. In winter, emperor penguins must actively seek sustenance to nurture their offspring, potentially intensifying interspecific competition with Weddell seals (Burns and Kooyman, 2001). Given that the diving capacity of emperor penguins is lower than that of adult Weddell seals (Kooyman et al., 1980; Kooyman and Kooyman, 1995; Burns, 1999), Weddell seals may forage at greater depths to minimize interspecific competition. Notably, in our data, deep dives (exceeding 350 m) occurred at a rate of 22.4% in July for Weddell seals, whereas emperor penguins performed deep dives at a rate of less than 10% (Burns and Kooyman, 2001). This suggests a potential seasonal adjustment in foraging strategy, although direct evidence for this behavior remains limited.”.

Lines 363-364: Again it becomes ambiguous when referred to simply as foraging activity, and this makes the paragraph more confusing. The authors should say how this study defined foraging. By defining it right away, the length of this paragraph could be significantly reduced by starting with the explanation that different metrics were used to measure foraging effort between the two studies.

⇒ To avoid confusion and aid understanding, we replaced the term 'foraging' in the mentioned sentence with the more specific term 'prey search effort.' The revised sentence is as follows: "A previous study on Weddell seals in the Ross Sea showed that seasonal changes for foraging effort were observed, with dive depth and prey search effort (estimated by search effort time in a given space) increasing from summer to winter (Goetz et al., 2023)."

Paragraph @ lines ~365-380. This paragraph should be edited for concision. This paragraph is also missing two important points. One is that prey may simply not be as predictable or more difficult to visualize in the dark winter months, so animals may in fact still be performing dives with the intent of foraging but have fewer prey capture opportunities. It also seems from the figures (4c & 6) that the decrease in PrCA's in ~July was primarily driven by a decrease in the number of pelagic dives (there was not a decrease in PrCA's in benthic dives). This point should be made in this paragraph, and that the frequency of PrCA's made during benthic dives appeared consistent throughout the year. The data here suggest that the animals relied more on benthic foraging late winter and this shift was reflected in season changes in PrCA's.

⇒ Thank you for your valuable comments and suggestions. According to our data, Weddell seals in the Ross Sea exhibited similar patterns in both PrCA per dive and daily PrCA, with high values in March and April and low values in June and July. We did not include this in the main text to avoid confusion due to an excess of results. Additionally, we have added another paragraph (3<sup>rd</sup> paragraph in Discussion section) to the discussion, addressing the observation that seals seem to rely more on benthic dives in winter. Added discussions is as follows: "Our data also showed that during the polar night in June and July, the PrCA per dive decreased in pelagic dives, while benthic dives showed no notable change (Figure 5, Supplementary Table 5). This suggests that benthic dives may play a crucial role in Weddell seals' foraging strategy during the winter months, when light conditions are diminished, making benthic prey potentially more reliable than pelagic prey."

The organization of the Discussion section also jumps around quite a bit and could be edited for better flow. For example, this paragraph is followed by another about water masses, but

then back to comparisons of foraging effort with previous work in lines 414-432. This paragraph and the paragraph @ lines 414-432 would seem to go together.

⇒ As suggested, we have combined the comparison with previous studies into a single paragraph. The revised paragraph is as follows: “A previous study on Weddell seals in the Ross Sea showed that seasonal changes for foraging effort were observed, with dive depth and prey search effort (estimated by search effort time in a given space) increasing from summer to winter (Goetz et al., 2023). Additionally, prey search effort was also higher in benthic dives (Goetz et al., 2023). The seasonal increase of dive depth agreed with our findings, but the prey search effort showed the contrary of PrCAs, our foraging measurement. Goetz et al. (2023) observed that the prey search effort was the highest in winter of 2010 to 2012. This could be due to the different seasonal prey availability across the seasons. During winter, our study indicated that prey capture was lower while the previous study by Goetz et al. (2023) showed the prey search effort was higher. To combine the two studies, it seems that the seals had to spend more time to search for prey despite the low foraging success in winter. Still, it is difficult to compare the two studies since there is an approximate 10-year difference. The diet composition of Weddell seals exhibits considerable interannual variability in the Ross Sea area (Goetz et al., 2017). The sea ice extent and the food availability for top predators can vary annually (Ainley et al., 2020). Such variations in sea ice extent can possibly influence plankton blooms and the seasonal prey abundance for seals between the two studies (Arrigo et al., 2004; Lorrain et al., 2009). Our measurement also has a limitation to compare the seasonal change. Prey capture attempts were estimated by ‘jerk’ from acceleration sensors attached on heads. Prey capture attempts do not necessarily correlate with the quality or quantity of the prey successfully obtained. For example, jerk could be overestimated when handling larger prey items, as the number of handling movements increases (a case of Australian fur seals, *Arctocephalus pusillus doriferus*, Volpov et al., 2015). These limitations of foraging proxies may account for the observed differences in their seasonal trends.”

The authors note that ‘jerk’ may not accurately portray what is happening during capture of larger prey that require more handling. But a very important overall caveat that should also be included somewhere in this paper (perhaps in this paragraph) that what the authors have are

prey capture ATTEMPTS. There is no way of knowing from these data whether the prey capture attempts were actually successful with the animal obtaining prey --- or not. There has also been some previous work (Fuiman, Davis, Williams) suggesting that prey capture attempts are more successful during daylight.

⇒ As suggested, jerk measures only prey capture attempts and does not reflect the quality or quantity of the prey captured. Therefore, this difference could explain the discrepancy between our findings and those of the previous study (Goetz 2023), which used a different foraging proxy. We have added discussion as follows “Prey capture attempts were estimated by ‘jerk’ from acceleration sensors attached on heads. Prey capture attempts do not necessarily correlate with the quality or quantity of the prey successfully obtained. For example, jerk could be overestimated when handling larger prey items, as the number of handling movements increases (a case of Australian fur seals, *Arctocephalus pusillus doriferus*, Volpov et al., 2015). These limitations of foraging proxies may account for the observed differences in their seasonal trends.”.