Vibrissae length as a morphological proxy for foraging behaviour in pinnipeds

Authors:

Stoehr, Svenja[1*]; Childs, Alexandra[1]; Krüger, Oliver[1,2]; Piedrahita, Paolo[3]; Schwarz, Jonas F. L.[4,5]

Affiliations:

1 Department of Animal Behaviour, Faculty of Biology, Bielefeld University, Bielefeld, Germany

2 Joint Institute for Individualisation in a Changing Environment (JICE), Bielefeld University and University of Münster, Bielefeld, Germany

3 Facultad de Ciencias de la Vida, Escuela Superior Politécnica del Litoral, Guayaquil, Ecuador

4 Institute of Marine Sciences, University of California Santa Cruz, California, USA

5 Biometry and Environmental System Analysis, University of Freiburg, Freiburg im Breisgau, Germany

*Corresponding author: Svenja Stoehr; svenja.a.stoehr@gmail.com

Keywords: foraging, behavioural polymorphism, morphological proxy, pinniped ecology

ABSTRACT

Foraging behavior is a key driver of ecological and evolutionary processes, with individual specialization shaping how populations respond to environmental change. Polymorphisms in foraging strategies can both enhance and limit behavioral flexibility at the population level, making it crucial to study individual variation. However, studying foraging is notoriously difficult, and while biologging has significantly advanced our understanding of individual specializations, its limitations in sample size and potential ethical concerns highlight the need for alternatives. In this study, we introduce a complementary, non-invasive method using relative vibrissae length (RVL) measured from images as a morphological proxy for foraging strategy in Galápagos sea lions (*Zalophus wollebaeki*). RVL differs significantly between distinct foraging behaviours: benthic foragers have shorter vibrissae due to abrasion, compared with pelagic foragers. Our method proved highly reliable, demonstrating strong intra- and inter-observer repeatability as well as within-season consistency. Moreover, RVL remained stable across multiple years, indicating long-term persistence in individual foraging specialization. Vibrissae length thus exemplifies how behavioral specializations can shape morphological traits within an individual's lifetime, offering a novel approach to study ecological polymorphisms. The integration of RVL assessments with existing tracking methods can enhance sample sizes and improve our understanding of individual foraging specialization at the population level. Our approach bridges the gap between high-resolution data and broader-scale ecological monitoring, providing a scalable tool for studying foraging strategies in pinnipeds.

INTRODUCTION

Foraging behaviour plays a fundamental role in shaping the ecology of species, populations, and individuals. Since foraging directly influences energy acquisition, it affects key life-history traits such as survival and reproduction (Davies et al., 2012). Therefore, understanding how diverse foraging behaviours arise and their consequences on population dynamics is essential for comprehending broader ecological patterns (Bolnick et al., 2003). While species or populations may appear to be generalists, they often consist of ecologically diverse individuals that differ in foraging behaviour and resource use (Araújo et al., 2011; Bell et al., 2009; Bolnick et al., 2002). This variation can have significant implications for how populations adapt to environmental change (Arroyo et al., 2017) and cope with ecological pressures.

Recent studies provide growing evidence of widespread behavioural variation and polymorphism within populations (Araújo et al., 2011; Robertson et al., 2014; Toscano et al., 2016). While foraging behaviour is often examined at the species or population level, individual specialization, where individuals repeatedly use a limited subset of available resources, has emerged as a key factor in ecological research (Araújo et al., 2011; Bolnick et al., 2003). Foraging strategies can differ significantly among individuals of the same population, age, and sex, making it crucial to study these variations to gain a more comprehensive understanding of foraging ecology (Bolnick et al., 2003). These differences can influence competition, resource partitioning, and ultimately, a population’s structure and ability to cope with shifts in the environment (Araújo et al., 2011; Bolnick et al., 2003; Sargeant, 2007). Understanding individual foraging behaviour is therefore not only a step toward refining ecological models but also a crucial component in predicting species responses to environmental change.

Measuring individual foraging differences in the wild is challenging, particularly when large sample sizes are needed to assess the ecological and fitness consequences. Biologging has transformed this field by enabling detailed behavioural tracking, especially in cryptic or hard-to-observe species like marine animals. These devices provide crucial insights into movement, diving behaviour, and resource use, uncovering specialized foraging strategies across diverse taxa (Block et al., 2011; Watanabe & Papastamatiou, 2025), including pinnipeds (Baylis et al., 2015; Breed et al., 2011; Jeanniard-du-Dot &

Guinet, 2021). However, despite its advantages, biologging has limitations. Attaching devices is often invasive, raising ethical concerns and potentially affecting behaviour (Horning et al., 2019). Additionally, logistical and financial constraints restrict sample sizes, making it difficult to study long-term adaptation and fitness consequences. While biologging technology is advancing with devices becoming smaller, more powerful and efficient (Wilmers et al., 2015), complementary, non-invasive methods could expand sample sizes and enhance long-term monitoring of individual foraging strategies.

Morphological traits can serve as valuable proxies for foraging behaviour, offering a non-invasive way to infer how individuals interact with their environment, especially when being able to be measured from a distance. External features have long provided indirect but reliable insights into animals feeding behaviour. Classic examples include the specialized beak shapes of Crossbills (*Loxia curvirostra*, Benkman, 1993) and the body and wing shapes in bats reflecting their foraging styles (Fenton & Bogdanowicz, 2002). Typically, these relationships between external morphology and foraging behaviour emerge at the species level through long-term evolutionary processes. However, differences that develop within populations and an individual’s lifetime have been documented. In Eurasian oystercatchers, individual feeding specialization in prey type and handling leads to morphological differentiation in bill shape (Swennen et al., 1983; Van De Poll et al., 2009). By identifying such measurable traits linked to foraging specialization, researchers can assess behavioural patterns across larger sample sizes than biologging typically allows.

One such proxy has been identified in Galápagos sea lions (GSL), a species known to exhibit foraging polymorphism (Jeglinski et al., 2013; Schwarz et al., 2021; Villegas-Amtmann et al., 2013). The isolated and fluctuating environment of the Galápagos Archipelago challenges resident species to adapt to variable conditions (Grant & Grant, 2014; Wikelski & Thom, 2000), making it an ideal place to study behavioural flexibility and specialization. Schwarz et al. (2022) could identify that specialized foraging behaviours result in distinct and temporally stable patterns of vibrissae abrasion, making it possible to use vibrissae length retrieved from photographs as an indicator for foraging. Individuals foraging benthically along the seafloor and hunting for prey on and in the sediment showed stronger abrasion and consequently shorter vibrissae compared with pelagic foragers hunting in the open water column. This highlights how even in species with diverse prey availability, such as GSL, individuals may exhibit feeding specializations with limited behavioural plasticity (Schwarz et al., 2022; Swennen et al., 1983) and studying morphology could provide valuable insight.

The aim of this paper is to provide a detailed evaluation of using relative vibrissae length (RVL) from images as a proxy for foraging behaviour and assess its applicability. Specifically, we test both intra- and inter-observer repeatability as well as repeatability across photographs to demonstrate the reliability of this methodological approach. By analysing RVL also across multiple years, we demonstrate the temporal stability of foraging strategy over time. Further, we explore whether differences in RVL are exclusive to adults or already detectable in juveniles. Beyond establishing RVL as a behavioural marker, we discuss the broader implications of using vibrissae length as a non-invasive alternative to biologging, highlighting both its advantages and limitations. Our approach not only offers a potential tool for studying other pinniped species, but also highlights the potential external morphology has in representing behavioural polymorphism for ecological research. Ultimately, our findings illustrate how a non-genetic variation in morphological traits can provide unexpected insights into an animal’s foraging strategies.

MATERIALS AND METHODS

Study details

This study was carried out within a breeding colony of Galápagos sea lions (*Zalophus wollebaeki*) on the islet of Caamaño, located near Santa Cruz Island in the centre of the Galápagos archipelago (0°45’ S, 90° 16’ W). The colony has been monitored since 2003 and during annual field seasons, the birth and growth of pups is documented, individuals are captured and tagged, and population census are carried out (Trillmich et al., 2016). The vast majority of animals are individually marked with flipper tags (Allflex®) and thereby recognizable, hence detailed life history data are available.

Dive data were collected on 34 lactating females with dependent offspring in the colony during the reproductive seasons (October-December) of 2018 and 2019. Animals were captured using hoop nets and biologgers (MK10, Wildlife Computers, Redmond, WA, USA) were attached to the dorsum for approximately 2 weeks (median 15 days, range 3-22) before being removed again (see Jeglinski et al., 2013 for more details). The loggers collect data on dive depth (every 2 seconds), GPS position through fastloc-GPS (every 4 minutes) and acceleration data (32 hertz). Foraging strategies were established in the previous publication by Schwarz et al. (2022) using an automated broken stick algorithm (Heerah et al., 2014) and Hidden Markov Models. For further details of dive data collection and analysis, see Schwarz et al. (2022).

Measurement of relative vibrissae length

Between 2019 and 2023, in a total of 7 field seasons (four reproductive (October – December) and three non-reproductive (March-April) periods), photographs were taken of tagged females with their head in profile and the tip of the longest vibrissae visible. This resulted in 476 images from 115 individuals contributing to this study. Relative vibrissae length (RVL) was calculated as the ratio of the relative distance (in pixels) from the upper point of the nostril opening to the tip of the longest vibrissae and the relative distance (in pixels) from the upper point of the nostril opening to the *Caruncula lacrimalis* of the eye (see Figure 1). To further our understanding of the potential life-stage dependency of vibrissae length differences, we additionally photographed juvenile animals (1-4 years of age) starting in 2021. This resulted in a dataset of 234 images from 96 juveniles sampled over six field seasons (four reproductive, two non-reproductive). Images were processed and measured using the software GIMP (The GIMP team, GIMP 2.10.32). The methodology is based on Schwarz et al. 2022.

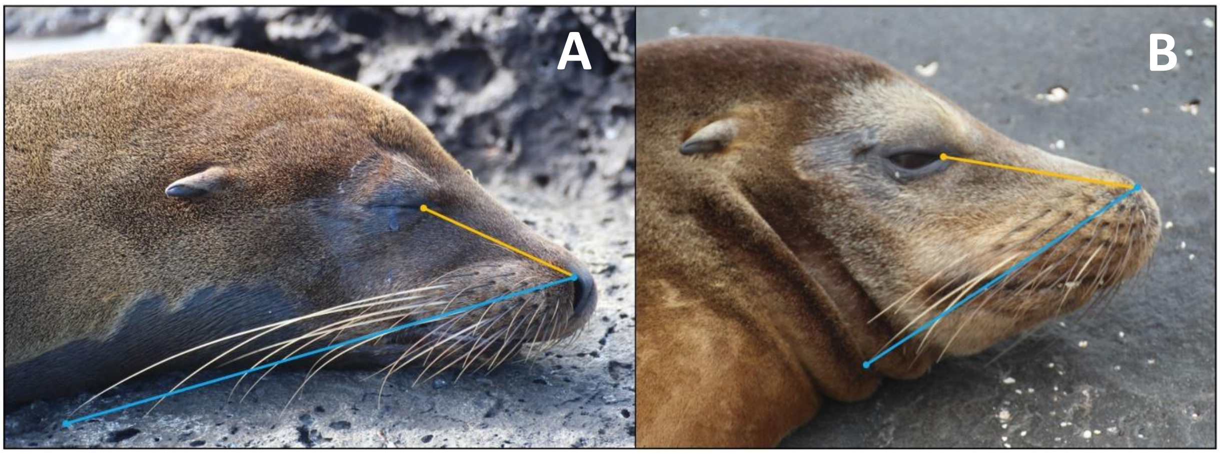


Figure 1. Example images of females in profile with long (A) and short (B) vibrissae, illustrating the measurements used to calculate relative vibrissae length. Orange: nostril opening to the eye. Blue: nostril opening to the tip of the longest vibrissae. (Images by S. Stoehr)

Relationship between foraging strategy and RVL

For 32 adult females, RVL measurements as well as foraging strategy, previously determined by Schwartz et al. (2022), were available. A linear model was used to analyse the relationship between RVL and foraging strategy, including female age as additional explanatory variable.

To determine the threshold for RVL that differentiates benthic and pelagic foragers, we visually assessed the distribution of RVL values. The RVL distributions of known benthic and pelagic foragers were overlaid, and a threshold was selected at the point of minimal overlap between the two groups (Fig. S1). Individuals with mean RVL above this threshold were assigned to the benthic foraging group, while those below were classified as pelagic foragers. To evaluate the accuracy of this classification, we compared the RVL-based group assignment to the known foraging strategy derived from dive data. This classification approach based on RVL allows for inferring foraging strategies in individuals without biologging data in future studies.

Repeatability of RVL measurements

All images were processed and RVL was measured by a primary observer. To test the intra-observer reliability, a subset of one image of 83 adult females (reproductive period 2019) was re-measured by the same observer six months after the initial measurements. This same subset was additionally measured by two other observers to test for inter-observer reliability. Within and between observer repeatability was tested using the R package rptR (Stoffel et al., 2017). The same package was used to test for within- and between-season variability of RVL of both juvenile and adult individuals separately. Within-season variability was tested for all individuals where two images within the same season were available, to assess the reliability of the method across pictures. If an individual had repeated measurements from multiple seasons, all were included (females: 154 repeat measurements on 115 individuals; juveniles: 168 repeat measurements on 81 individuals). For between-season repeatability, only individuals with RVL measurements from at least two seasons were included, excluding repeat measurements within the same season, resulting in 82 adult females with a total of 289 measurements and 34 juveniles with 85 measurements, respectively.

Comparison of RVL across age groups

To investigate whether differences in vibrissae length are exclusive to adults or are already detectable at an earlier life stage, we compared mean RVL of juveniles and adult females from three separate seasons with the largest sample sizes (autumn 2021: n = 37 juv, 63 fem; spring 2022: n = 37 juv, 53 fem; autumn 2022: n = 23 juv, 55 fem). To compare the variance and mean of RVL between juveniles and adult females, we used a linear mixed model (LMM) fitted with restricted maximum likelihood (REML). The model included life stage as a fixed effect and sampling season as a random effect to account for potential inter-seasonal variation: RVL_mean ~ life stage + (1|season). A variance structure allowed for different variances between groups. To test for differences in variance, we performed Levene's test for homogeneity of variance.

RESULTS

Relationship between foraging strategy and RVL

The linear model revealed a significant relationship between vibrissae length and foraging strategy ($F_{(2,19)} = 13.31$, $R^2 = 0.584$, $p < 0.001$), with pelagic individuals showing higher RVL than benthic individuals ($ß = 0.69$, $p < 0.001$, Figure 2). Age was not a significant predictor ($ß = 0.03$, $p = 0.163$). The strong significant effect of foraging strategy remained when removing age from the model (see Table S1).

The median RVL was 2.35 (IQR: 1.69–2.43) for benthic foragers (n = 12) and 2.79 (IQR: 2.67–3.08) for pelagic foragers (n = 20). The IQRs of the two groups do not overlap, indicating a clear distinction in the spread of RVL between the two foraging strategies, supporting the validity of classification based on RVL. While benthic foragers show slightly greater variance in RVL values, there is no significant difference in variability between the groups ($F_{(1,30)} = 1.28$, $p = 0.266$).

The comparison of RVL distributions between benthic and pelagic foragers indicated a threshold of 2.48 (benthic < 2.48, pelagic > 2.48), representing the point of minimal overlap. Using this threshold, 28 of the 32 females with known foraging strategies from biologgers were correctly classified using RVL, resulting in an accuracy of 87.5%.

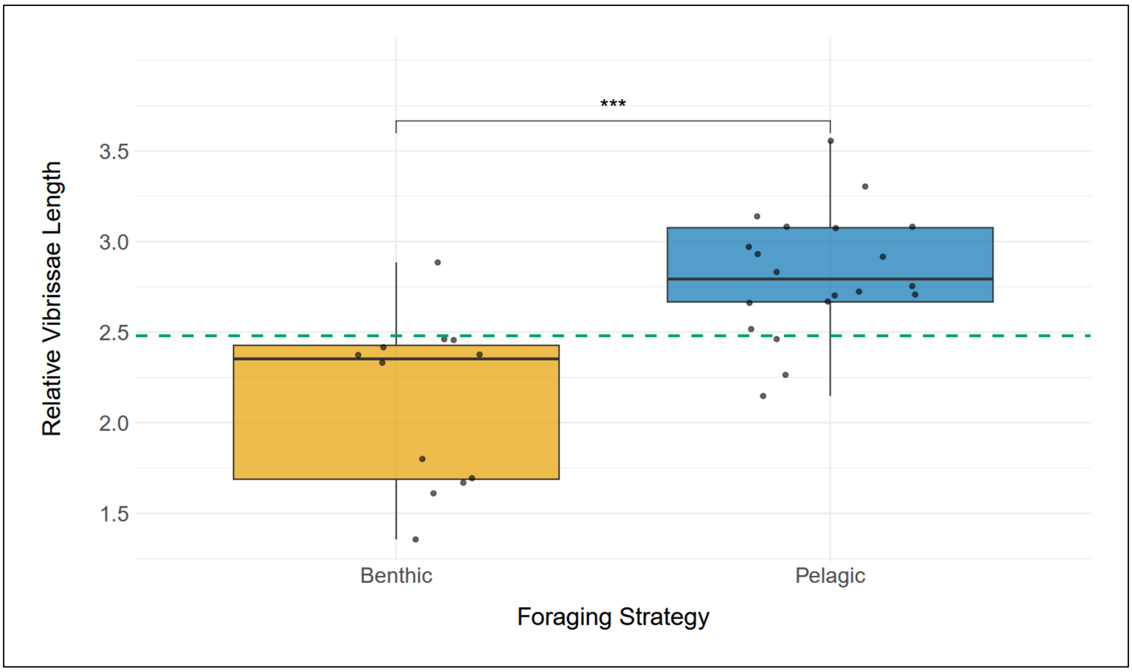


Figure 2. RVL comparison of benthic (orange) and pelagic (blue) foragers (*$p < 0.001$).** Median, upper and lower quartiles are displayed and individual data points (n=32) are shown as black dots. The green dashed line indicates the RVL threshold (2.48) between the two groups.

Observer Reliability: Intra- and Inter-Observer Repeatability

The intra-observer repeatability, assessed by the primary observer measuring the same images six months apart, was high (R = 0.99, 95% CI: [0.987, 0.994], SE = 0.002). Similarly, inter-observer repeatability, based on measurements from three different observers, was high as well (R = 0.98, 95% CI: [0.968, 0.985], SE = 0.004). Both results were highly significant according to the likelihood ratio test ($P_{intra} = 6.41e{-}75P_{inter} = 6.4e{-}120$) and the permutation test (P = 0.001). These findings confirm that, once properly established and standardized, the method remains highly reliable and repeatable across different observers.

Repeatability of RVL measurements across seasons and age groups

Overall, RVL measurements are highly repeatable in adult females, whereas juveniles exhibit markedly lower stability (Figure 3). Repeatability estimates for RVL were assessed both within and between seasons. For adult females, within-season repeatability was very high (R = 0.91, 95% CI: [0.873, 0.931], $p < 0.001$), demonstrating a strong reliability of the methodological approach. While the within-season repeatability validates the methods, the high between-season repeatability (R = 0.80, 95% CI: [0.730, 0.856], $p < 0.001$) demonstrates the stability of RVL in females over multiple years, indicating that RVL is a stable trait. In contrast, the repeatability of RVL in juveniles was considerably lower, with moderate within-season repeatability (R = 0.66, 95% CI: [0.52, 0.763], $p < 0.001$), and low between-season repeatability (R = 0.20, 95% CI: [0, 0.452], p = 0.047) with overall wider confidence intervals. These results suggest that the reliability of the methodological approach is not as high in juveniles as it is in adult females. The considerable low repeatability between seasons on the other hand, together with the wider confidence intervals, demonstrate a lack of RVL stability in juvenile sea lions in their first years.

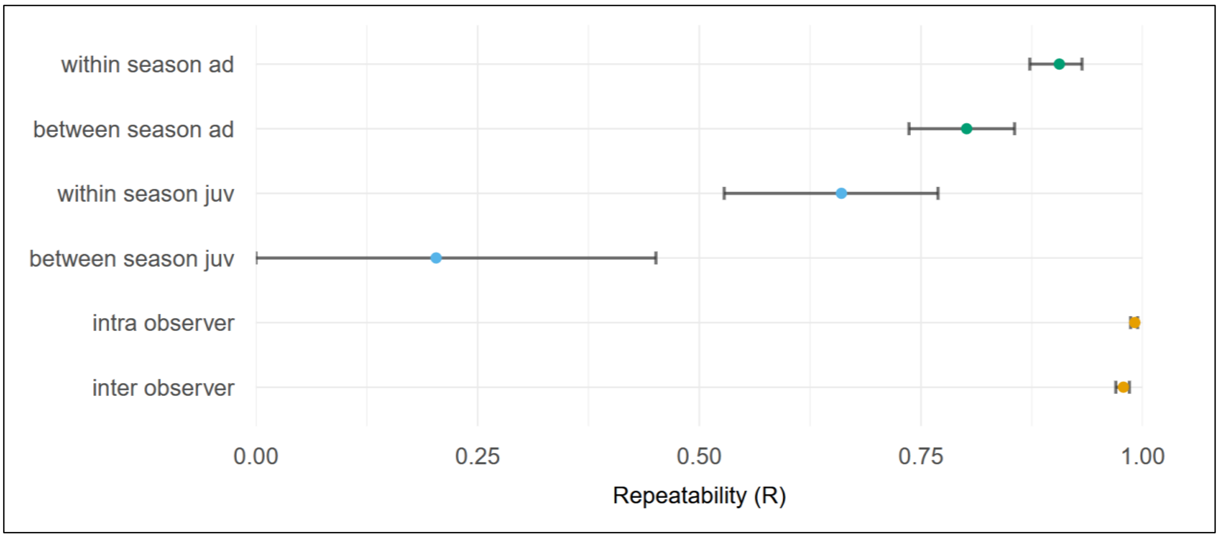


Figure 3: Repeatability estimates of RVL measurements in adult females (green) and juveniles (blue) within and between sampling seasons; and for method validation through intra- and inter-observer checks (orange). Horizontal error bars indicate 95% confidence intervals.

Comparison of RVL across age groups

The linear mixed model revealed that mean RVL did not differ significantly between juvenile and adult females ($\beta = -0.042$, SE = 0.054, t(264) = -0.79, p = 0.43). However, the variance in mean RVL between the two groups differed significantly, with adult females showing greater variability (variance ratio = 1.85; Levene's test: F = 30.79, $p < 0.0001$). This suggests that while the mean vibrissae length is similar across life stages, adult females exhibit a wider range of RVL (Figure 4), reflective of individual behavioural differences in foraging as described above. Season had no detectable effect on RVL (random effect variance = 1.85e-05). These results indicate that individual differences in RVL persist across time, confirming the stability of the observed variation and the robustness of RVL as a foraging-related trait.

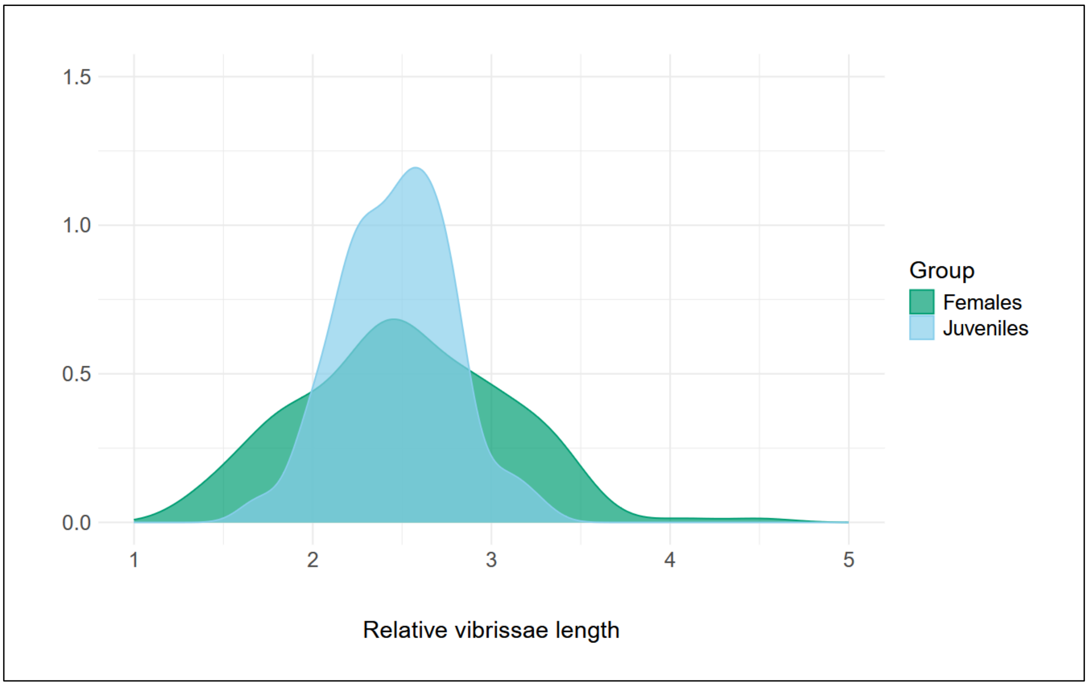


Figure 4. Density distribution of mean RVL of juveniles (blue) and adult females (green).

DISCUSSION

Our analysis confirmed that individual differences in vibrissae length are linked to distinct foraging strategies in Galápagos sea lions. Moreover, RVL remained stable across multiple years, indicating long-term persistence in individual foraging specialization. We also found that this morphological polymorphism is not detectable in juveniles, suggesting that foraging specializations develop primarily in adulthood.

Vibrissae length reflects foraging strategy

We could confirm that vibrissae length differences observed within the population are not merely random phenotypic variation but instead reflect the distinct foraging strategies that have been established for GSL (Schwarz et al., 2022; Villegas-Amtmann et al., 2008). Specifically, the significantly shorter vibrissae observed in benthic foragers are likely the result from increased abrasion that is found within this foraging strategy. Dietary studies have shown that GSL of this colony frequently prey on burrowing cusk-eels (*Chilara taylori* and *Otophidium indefatigable*, Páez-Rosas & Aurioles-Gamboa, 2014), which requires the sea lions to dig within the substrate. This is further supported by body pitch data from biologgers, indicating that benthic foragers regularly orient their bodies toward the sea floor (Schwarz et al. 2022). Over time, this consistent higher level of abrasion at the snout results in shorter vibrissae that distinguishes benthic from pelagic foragers, who experience considerably lower levels of abrasion hunting in the open water column. Using vibrissae length as a morphological proxy to classify females into foraging strategies showed high accuracy, as 87.5% of females were put into the same strategy as identified by dive analysis. However, a small number of individuals were misclassified, as animals with intermediate RVL values may be more difficult to categorize compared to individuals from the ends of the RVL spectrum. This highlights the importance of assessing how reliably vibrissae length differences can be measured using RVL derived from photographs.

Reliability of RVL

When testing the reliability of measuring RVL with photographs, both the effect of the different images and angles, as well as the human component, must be considered. The high repeatability of RVL measurements within season (R= 0.91) as well as the exceptionally high intra- and inter-observer repeatability (R = 0.99 and R = 0.98) address these concerns respectively and demonstrate the accuracy and reproducibility of this method. The high within-season repeatability further suggests that a single well-taken image per individual can provide a reliable estimate of RVL, making the method highly suitable for large-scale data collection. To minimize measurement error, images should be taken in perfect profile, as angle distortions could artificially alter the apparent length of the vibrissae and reduce measurement accuracy (Sadou et al., 2014). However, with proper standardization, RVL measurement could potentially even be automated, as seen in other studies utilizing machine learning for image-based data extraction (Gray et al., 2019; Kühl & Burghardt, 2013).

The more moderate within-season repeatability of RVL in juveniles suggests that this approach is not universally effective. Given the slow rates of vibrissae growth and abrasion, significant within-season changes in RVL are unlikely. Instead, the lower repeatability in juveniles likely stems from reduced between-individual variability. Since repeatability depends on the ratio of within-individual to between-individual variation, lower diversity among juveniles decreases repeatability, even if measurement error and individual vibrissae length remain stable. In contrast, the greater between-individual variation in females enhances their repeatability, making RVL a reliable marker for foraging strategies in this group.

Benefits & limitations of RVL-based classification

Having established the reliability of RVL as a proxy for foraging strategy, it is important to consider both advantages and limitations of this approach. A key benefit of RVL-based classification is its non-invasive nature, allowing for data collection from a distance using images rather than requiring direct handling of the animals. In contrast, traditional biologging studies on pinnipeds and other wild animals require capture, and in some cases sedation, for device attachment, sometimes requiring a second capture for retrieval. While best-practice protocols exist for the use of telemetry devices on pinnipeds (Horning et al., 2019; Wilson & McMahon, 2006), extended and repeated handling can induce stress with potential negative consequences (Champagne et al., 2012; Cooley et al., 2025; Harcourt et al., 2010). RVL measurements, however, can be obtained remotely, minimizing disturbance while also reducing logistical constraints. While biologging technology continues to advance and becomes more accessible (Chung et al., 2021; Wilmers et al., 2015), it still involves significant costs and logistical efforts. In contrast, RVL assessment requires only a camera, making it a cost-effective alternative, and allowing for significantly higher sample sizes due to its simplicity. Another major advantage of this method is its suitability for longitudinal studies, as individuals can be photographed repeatedly over time. This facilitates long-term monitoring of foraging strategies, enabling researchers to track behavioural shifts across life stages or in response to changing environmental conditions.

However, the accuracy of the RVL method depends on prior knowledge of foraging behaviour, as RVL-based classification relies on validation from biologging data. Without such reference datasets, distinguishing foraging strategies solely from vibrissae length would be invalid. Furthermore, unlike biologgers, which can provide fine-scale data on movement, physiological and environmental parameters (Chung et al., 2021; Watanabe & Papastamatiou, 2025), RVL classification offers only a broad behavioural categorization and lacks detailed insights into individual foraging strategies. Another limitation is the requirement for uniquely identifiable individuals, as tracking changes over time necessitates consistent re-identification of the same animals. Further, the method's effectiveness relies on the ability to obtain high quality, reliable photographs, which may be challenging for more cryptic species or ones not as habituated to human presence. While the limitation of indirectly measuring vibrissae length through photographs, rather than directly, is inherent to the non-invasive nature of the method, careful standardization of image collection protocols will contribute to maintain reliability.

Significance of morphological indicators

Morphological traits have long been recognized as indicators for foraging behaviour in animals (Grant et al., 1985; Kay, 1984). Typically, such traits arise through evolutionary processes at the species level as adaptations to diet (Fenton & Bogdanowicz, 2002; Hulsey & García De León, 2005; Moermond & Denslow, 1985). However, in some cases, morphological changes occur within an individual's lifetime and remain stable over extended periods, reflecting consistent behavioural patterns. A well-documented example is the Eurasian Oystercatcher (*Haematopus ostralegus*), where specialized feeding behaviours in prey selection and handling lead to distinct bill shapes due to abrasion (Swennen et al., 1983; Van De Poll et al., 2009). Similarly, studies on freshwater fish have shown that body morphology can shift in response to resource availability and diet (Andersson et al., 2005; Hjelm et al., 2001). In those examples where morphological differences arise within a lifetime, diet often influences morphology rather than the other way around. While some morphological adaptations serve a clear functional role, such as optimized foraging efficiency through adapted jaw shape in sunfish *Lepomis humilis* (Hegrenes, 2001), the abrasion-induced shortening of vibrissae in sea lions appears non-functional. This raises the possibility that similar morphological proxies might exist in other species, potentially being overlooked, as they do not seem to serve an obvious functional purpose. Vibrissae length as an indicator of foraging behaviour may be applicable to other pinniped species besides Galápagos sea lion. Vibrissae abrasions in general have been observed in some species, including Weddell seals (*Leptonychotes weddellii*) and New Zealand sea lions (*Phocarctos hookeri*) (D. Costa, L. Chilvers, pers. communication). More broadly, abrasion-related indicators could exist in other taxa, highlighting the need for broader exploration of morphological traits as behavioural proxies.

Biological implications of foraging specialization

Beyond establishing a novel morphological proxy, our findings provide biological insights into the long-term stability of foraging strategies in GSL**.** RVL measurements remained stable across multiple years (R = 0.80), despite vibrissae being a continuously growing structure. Otariids do not shed their vibrissae

(Cherel et al., 2009) and while growth rates are known to vary by age and sex, they are estimated at 0.1 ± 0.05 mm per day (*Z. californicus*, Rosas-Hernandez et al., 2018), which would translate to approximately 3.5cm per year and could significantly change RVL. However, the observed stability of RVL values across multiple sampling seasons and years suggests that vibrissae abrasion patterns, shaped by foraging strategy, are maintained. This level of stability has not been previously described for GSL, with individuals keeping their vibrissae length and thus their foraging strategy throughout the measurement period (3.5 years) and likely beyond.

In addition, our results indicate that specialization into distinct strategies, reflected by stable RVL, is found primarily in adulthood. Juveniles exhibit a narrower RVL distribution, despite having similar mean values to adults, and show low repeatability of RVL across seasons (R = 0.20). This suggests that the foraging behaviours affecting vibrissae length are not yet established during those early stages of life. These findings align with previous studies showing that once juvenile GSL start foraging independently, they often occupy distinct foraging niches that do not overlap with those of adults (Jeglinski et al., 2012). However, it appears that once individuals specialize into benthic or pelagic strategies as adults, they maintain those consistently over time.

Foraging specializations have been widely documented across taxa (Ceia & Ramos, 2015; Sheppard et al., 2021; Toscano et al., 2016) and specifically in pinnipeds (Baylis et al., 2015; Kernaléguen et al., 2015; Seguel et al., 2022). Specialization can enhance foraging efficiency and reduce intraspecific competition. However, it may also increase vulnerability to environmental change, as specialists are less adaptable when resources fluctuate (Araújo et al., 2011; Bolnick et al., 2003; Sargeant, 2007). Understanding the long-term stability and ecological consequences of such specializations is therefore essential for assessing population resilience under changing environmental conditions.

Conclusion

This study establishes RVL-based classification from images as a valuable tool for large-scale assessment of foraging strategies in adult female GSL, and potentially other pinnipeds. It provides new insights into the development and persistence of individual foraging specialization, offering a non-invasive and cost-effective method to study behaviour at the population level. While biologgers remain indispensable for detailed behavioural analyses, integrating RVL measurements with existing tracking methods could allow researchers to balance precision with scalability, ultimately improving our understanding of individual specialization and population-level foraging dynamics. Beyond pinnipeds, our findings highlight the potential for morphological traits to serve as indicators of behavioural polymorphisms. This underscores the broader importance of studying behaviour at an individual level - not only to understand species ecology but also to better predict responses to environmental changes.

Acknowledgements:

We thank the numerous field assistants who have contributed to the data collection for their tireless work in the field. We also thank the Galápagos National Park and Charles Darwin Foundation for logistical support. This publication is contribution number XXXX of the Charles Darwin Foundation for the Galápagos Islands. All animal handling was performed under Galápagos National Park scientific permits. This work was supported by the German Research Foundation (DFG) via the collaborative research centre CRC TRR 212, project number 316099922, project B07, and Bielefeld University.

Declaration of interests:

The authors declare no conflict of interest.

Supplementary material:

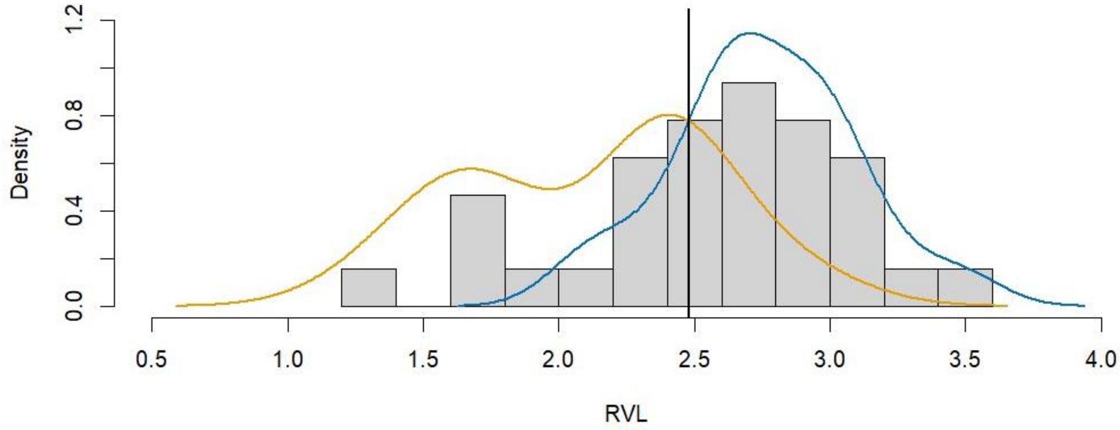
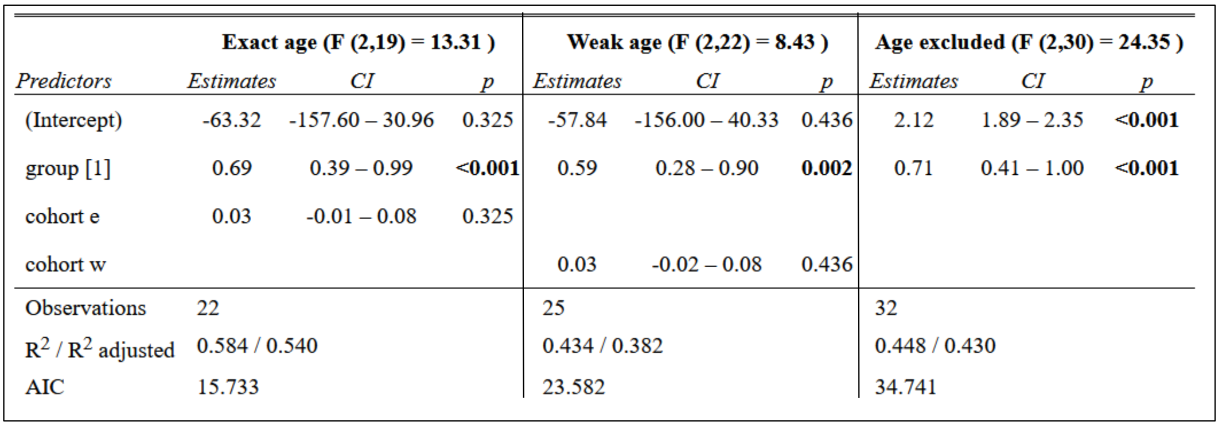


Figure S1. RVL distribution of benthic (orange) and pelagic (blue) foragers and the selected threshold value of 2.48 at the point of minimal overlap between the two groups.



	Exact age (F (2,19) = 13.31)			**Weak age (F (2,22) = 8.43)**			**Age excluded (F (2,30) = 24.35)**		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-63.32	-157.60 – 30.96	0.325	-57.84	-156.00 – 40.33	0.436	2.12	1.89 – 2.35	**<0.001**
group [1]	0.69	0.39 – 0.99	**<0.001**	0.59	0.28 – 0.90	**0.002**	0.71	0.41 – 1.00	**<0.001**
cohort e	0.03	-0.01 – 0.08	0.325						
cohort w				0.03	-0.02 – 0.08	0.436			
Observations	22			25			32		
R^2 / R^2 adjusted	0.584 / 0.540			0.434 / 0.382			0.448 / 0.430		
AIC	15.733			23.582			34.741		

Table S1: Model comparison. Linear model for the relationship between RVL and foraging strategy. Model 1 and 2 include age as explanatory variable. Model 1 only includes animals with exact birth cohort data, while model 2 includes those with birth year known within ±1 year. Benthic foragers serve as the reference group and group [1] represents pelagic foragers. Reported p-values are adjusted using Holm's correction to control for multiple testing.

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