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A dataset on worldwide penguin diet

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Studying the diet of penguins is essential for understanding their role in marine ecosystems, evaluating their responses to environmental changes, and informing conservation strategies. This manuscript presents the 'Penguin Diet Dataset-v2', a comprehensive compilation of dietary data for 17 out of 19 currently recorded penguin species, obtained through a systematic review of the scientific literature. Spanning the 1980–2019 period and covering 149 global locations, the dataset includes 2.749 dietary entries with both qualitative and quantitative information on prey types. The dataset is enriched with metadata such as geographic locations, time periods, seasons, and life stages, providing insights into species-specific dietary patterns and ecological trends. Key prey groups include fish from the class Teleostei, crustaceans from the class Malacostraca, and mollusks from the class Cephalopoda. The Adélie Penguin and the Magellanic Penguin are the most extensively studied species. This dataset serves as a valuable resource for advancing research on penguin feeding ecology and addressing gaps in knowledge on understudied species, regions, and time periods.

Background & Summary

Penguins, belonging to the family Spheniscidae, are iconic seabirds renowned for their remarkable adaptations to a predominantly aquatic life. Distributed across the Southern Hemisphere and selected regions of the Northern Hemisphere (e.g., Galápagos Islands), the group comprises 19 flightless species, following a recent taxonomic revision that reclassified *Eudyptes chrysocome* into three distinct species: the Southern Rockhopper (*E. chrysocome*), Northern Rockhopper (*E. moseleyi*), and Western Rockhopper (*E. filholi*)[1,2]. Because of their charismatic appeal and their status as some of the most threatened taxa of megafauna, penguins have been the focus of numerous studies on their behaviour[3–5], distributions[2,6,7] and main threats. These threats include human-induced climate change effects, including changes in oceanographic conditions, interactions with industrial fisheries that reduce prey and cause bycatch, and disturbance of breeding colonies[2,8,9]. Numerous dietary studies have further demonstrated how these pressures influence penguin foraging ecology, altering prey composition, trophic position, and foraging effort[10–12].

A thorough understanding of penguin diets is essential for elucidating their role in marine ecosystems, as well as for identifying the specific challenges they may face due to changes in the availability and accessibility of their preferred food sources. As apex predators, penguins' diets reflect the availability, abundance, and diversity of marine organisms, making them key bioindicators of marine ecosystem structure and function[13,14]. Additionally, by analyzing their feeding patterns, penguins serve as sentinel species, offering essential insights into the health and stability of their habitats[13]. Despite the importance of dietary studies on penguins, most existing research has been limited to individual species, specific periods and localized geographic areas, leaving significant gaps in our understanding of the feeding ecology of penguins as a whole. Bridging these knowledge gaps through broader, integrative studies that consolidate existing yet fragmented dietary information is essential for developing effective conservation and management strategies and safeguarding these emblematic seabirds, along with the marine ecosystems they inhabit, in a rapidly changing world.

Here, we address these gaps of knowledge by conducting a systematic review that synthesises available data on penguins' diets. By compiling and synthesizing dietary data across different species, regions, and time periods, we aim to provide a comprehensive picture of dietary preferences and feeding strategies both among and within species. This information is essential for tackling a wide range of ecological and conservation issues, including interpreting population dynamics in response to changes in food availability[15,16], and assessing how environmental changes affecting marine ecosystem structure and function influence penguin diets[5]. Additionally, a consolidated understanding of penguin diets would improve our ability to predict how these

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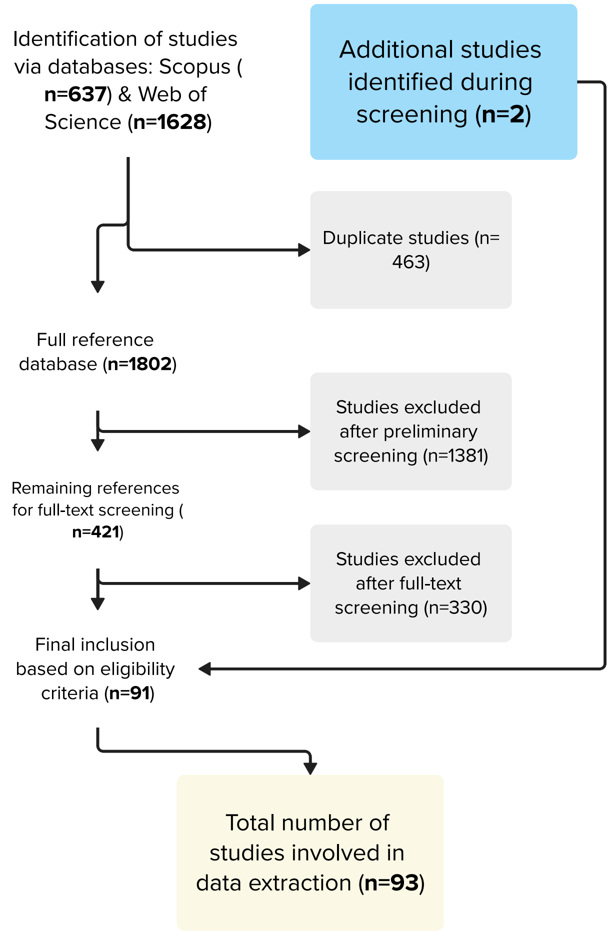

Fig. 1 Flow diagram for the systematic review and selection process used, indicating the number (n) of studies included in this review. The bold numbers are key numerical values associated with the number of studies included in the review.

species might respond to future environmental conditions, and would serve as a foundational resource for future research and conservation efforts focused on these emblematic seabirds.

We employed a systematic review approach to create a comprehensive dataset: Penguin Diet Dataset-v2[17]; provided in '.xlsx' format. This dataset includes 93 scientific papers published between 1985 and 2023, and can serve as a valuable resource for future research. Throughout this manuscript, we also present a structured protocol designed to standardize the literature search, the screening and the data extraction processes, ensuring consistency and objectivity in future updates.

By providing the most comprehensive and up-to-date information on penguin diets, this dataset is poised to encourage researchers worldwide to place greater emphasis on understanding penguin feeding ecology. Moreover, it highlights current knowledge gaps, encouraging further research on understudied species, as well as in lesser-explored geographic regions and time periods.

Methods

Literature search. This systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and rigor in the selection and screening of studies[18]. The steps involved in this systematic review are summarized in Fig. 1. Briefly, Web of Science and Scopus were used as the search engines (accessed in February 2024) covering studies published up to and including 2023 to ensure comprehensive temporal representation of the available literature. The search strategy incorporated specific keywords, including 'penguin*' AND 'diet', resulting in 2265 references in the public domain and the corresponding abstracts. The search results from Web of Science (1628) and Scopus (637) were imported into Zotero (https://www.zotero.org/) to efficiently manage references and remove duplicates. After eliminating duplicate records, a total of 1802 unique studies remained for the screening process. This systematic approach ensured the integrity of the dataset by minimizing redundancy and maximizing coverage of relevant literature.

Literature screening. The screening process followed a structured approach to endure a rigorous selection of studies relevant to penguin diet. The process consisted of three main phases: 1) title and abstract screening; 2) full-text screening; and 3) final inclusion. At each step, predefined eligibility criteria were consistently applied.

Specifically, studies were included if they explicitly focused on penguin diet, provided original empirical and taxonomically resolved diet data (at any taxonomic level), obtained through direct methods (e.g., stomach content analysis) or indirect approaches (e.g., stable isotope analysis). Eligible records provided quantitative metrics such as frequency of occurrence, percentage by number or mass, or index of relative importance. When quantification was not feasible, clearly stated qualitative prey lists were also accepted. We excluded studies involving captive or rehabilitated birds, those reporting only trophic position without prey identity, multispecies datasets that could not be disaggregated, and reviews or modelling studies lacking new empirical data. In cases of duplicate datasets, the most complete and detailed source was retained.

From the initial search in Web of Science and Scopus, 421 potentially relevant publications were identified after the first two screening phases. Following full-text review, 91 studies met all inclusion criteria. Two additional papers were identified through manual screening of reference lists and were subsequently included in the final dataset.

Data extraction process. The full-text screening and data extraction were conducted on 93 different papers[11,12,14,16,19–107]. In addition to dietary information, the dataset was enriched with additional metadata (when available), such as geographic locations, time periods and seasons, life stages, and sex, to facilitate further research on dietary patterns, gaps, and trends (see details in Data Records section).

In cases where the parameter of interest was presented with uninterpretable symbols, such as positive or negative signs, the corresponding data were excluded from the analysis. In cases of incomplete or ambiguous information, assumptions were documented separately. Additionally, when values were provided in a graphical format rather than in tables or text, these were stored in a separate folder for later extraction using GrabIt in Excel. Supplementary sources were often consulted for clarification or missing data.

Data Records

The database Penguin Diet Dataset-v2[17] is stored at Digital.CSIC (http://hdl.handle.net/10261/399953) the open science repository of the Consejo Superior de Investigaciones Científicas (CSIC). This repository adheres to internationally recognized standards, including the Data Seal of Approval and DataCite guidelines, ensuring long-term accessibility and proper citation of scientific datasets.

The database is provided as an easy-to-use '.xlsx' file compatible with widely used Microsoft Office software. The file is composed of different sheets containing dietary data, along with the necessary information for proper understanding and interpretation. The "Dat_entry" sheet includes up to 2,749 dietary entries detailing both qualitative and quantitative predator-diet interaction for 17 out of 19 penguin species. No dietary information for the Galápagos penguin (*Spheniscus mendiculus*) or the Erect-crested penguin (*Eudyptes sclateri*) was found within the scope of our systematic review, based on our predefined search and eligibility criteria. Beyond dietary information, additional metadata is summarized in the "Variables_DDBB" sheet. This sheet also includes the codification for the different levels that each column may contain, as well as the alternative names by which each column can be found in the literature. In the 'Dat_entry' sheet, predators (i.e., penguins) and prey are encoded using an 8-digit sequence that indicates their identities. The precise meanings of these codes are provided in the 'Code_predator' and 'Code_prey' sheets. The 'Code_prey' sheet also includes the taxonomy. Geographic coordinates (latitudes and longitudes in EPSG:4326) for the various locations included in the dataset are provided in the 'Coordinates' sheet. This sheet can be easily imported into any GIS software for the visualization and analysis of the spatial distribution of the data.

Data Overview

Our database reduces fragmentation in the available literature by compiling and harmonizing dietary records and their metadata across species, seasons, life stages, regions, and methods. This enables robust meta-analyses, transparent gap mapping, and method-aware comparisons.

Dietary information included in this dataset was gathered using a range of methodologies, primarily stable isotope and stomach content analyses, along with additional approaches such as direct observation and DNA metabarcoding (see 'Code_method' in Penguin Diet Dataset-v2 – Dat_entry). The dataset covers the period from 1980 to 2019 and includes data from 149 locations worldwide (see Fig. 2). The Adélie Penguin (*Pygoscelis adeliae*), Magellanic Penguin (*Spheniscus magellanicus*), and Little Penguin (*Eudyptula minor*) are the most represented species in the dataset, accounting for 20%, 17%, and 16% of all records, respectively. The remaining species have fewer than 10% of the total records (Fig. 2). Additionally, 93% of the total records provide quantitative information on one of the dietary metrics, while only 7% provide qualitative data (presence of a specific prey). Although dietary information for penguins is differentiated by gender, the sex remains unidentified in 81% of the cases. In terms of penguin age distribution, adults (36%) and chicks (34%) constitute the most widely represented categories in the dataset. With respect to seasonality, only 27% of dietary information is not attributed to any specific season, while 3% pertains to year-round studies and 7% covers multiple seasons. Among individual seasons, the austral summer is the most extensively studied, accounting for 45% of the total records. In contrast, the contributions of the other seasons to dietary information each comprise less than 10%.

A total of 430 distinct prey types, spanning 15 different phyla (excluding plants and protozoa), were identified. Of these, 55% were classified to the species level, while the remaining 45% were only classified to a higher taxonomic level. The number of distinct prey types identified varies among penguin species, as does the diversity of phyla present in their diets (Fig. 2). The Little Penguin and the Gentoo Penguin (*Pygoscelis papua*) have the highest number of identified prey types, with 118 and 91, respectively. However, while the prey of the Little Penguin belongs to eight different phyla, the prey of the Gentoo Penguin is limited to only three phyla. In terms of the number of distinct prey items identified, the Southern Rockhopper Penguin (*Eudyptes chrysocome*), the Magellanic Penguin (*Spheniscus magellanicus*), the Southern Rockhopper Penguin (*Eudyptes chrysocome*), and the Adélie Penguin (*Pygoscelis adeliae*) also stand out as key species, with 68, 67, and 65 prey types reported,

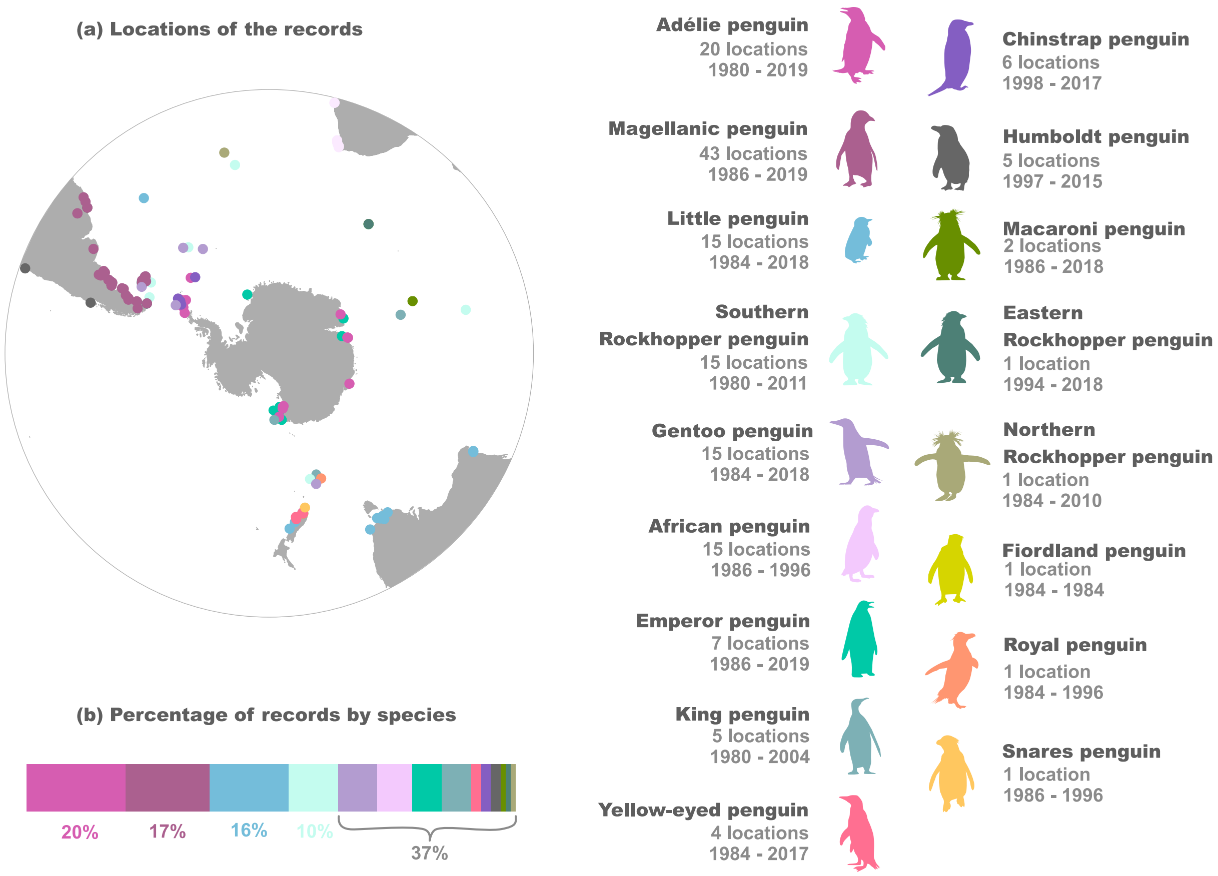

Fig. 2 (**a**) Geographical distribution of the locations of the dataset. For each species is also indicated the number of locations and the period of time covered by the specific records of each species. (**b**) Percentage of the contribution of each penguin species to the final dataset according to the number of records. Species contributing less than a 1% have been excluded from this graphic.

respectively. The Adélie Penguin has the highest number of phyla reported in its diet, while the Magellanic Penguin and the Southern Rockhopper Penguin have five and four phyla, respectively (Fig. 3).

Among all identified prey, the majority belong to the phylum Chordata (51%), with fish from the class *Teleostei* (e.g., *Engraulis anchoita*) comprising the largest proportion, accounting for 78% of this phylum. The phylum Arthropoda is also a significant component of the penguins' diet (30%), with the majority of prey items (87%) belonging to the class *Malacostraca* (e.g., *Euphausia crystallorophias*). Additionally, the phylum Mollusca is an important prey source for penguins, comprising 17% of their diet, with the vast majority of these items (87%) belonging to the class *Cephalopoda* (e.g., *Doryteuthis gahi*).

In addition to this qualitative information, the database includes a total of 4,050 records across various metrics, offering quantitative insights into penguins' diets. Most of this information refers to occurrence-based metrics such as the percentage of frequency (Frequency(%); see Penguin Diet Dataset-v2 – Variables_DDBB), accounting for 38%, and quantity-based metrics such as the percentage by number of each prey type (Number(%)), accounting for 33% (Fig. 4). The dataset also includes information on the percentage by weight, the Index of Relative Importance (IRI), the results of mass-balance isotopic mixing models, and the Relative Read Abundance (RRA(%)), although these represent a smaller proportion of the total records.

Technical Validation

Data were extracted from published studies following a predefined protocol to ensure consistency and minimize bias. Two independent reviewers conducted both the title-abstract and full-text screening based on predefined inclusion criteria. The whole process was supervised by three additional and independent experts. To enhance accuracy, any discrepancies were resolved through discussion among reviewers and supervisors, ensuring a consistent interpretation of the information.

The dietary records included in the dataset, along with associated metadata (e.g., time periods and seasons, life stages, and sex), are derived from studies published in scientific, peer-reviewed journals, ensuring their reliability and accuracy. Each dietary record in the dataset is associated with a bibliographic reference, allowing users to assess the validity of the record, reuse the data, and correct any errors if necessary. The taxonomy of each item identified in the penguins' diet was verified and corrected as needed using the R package *taxize*[108], with the *World Register of Marine Species* (https://www.marinespecies.org/index.php) as the reference database.

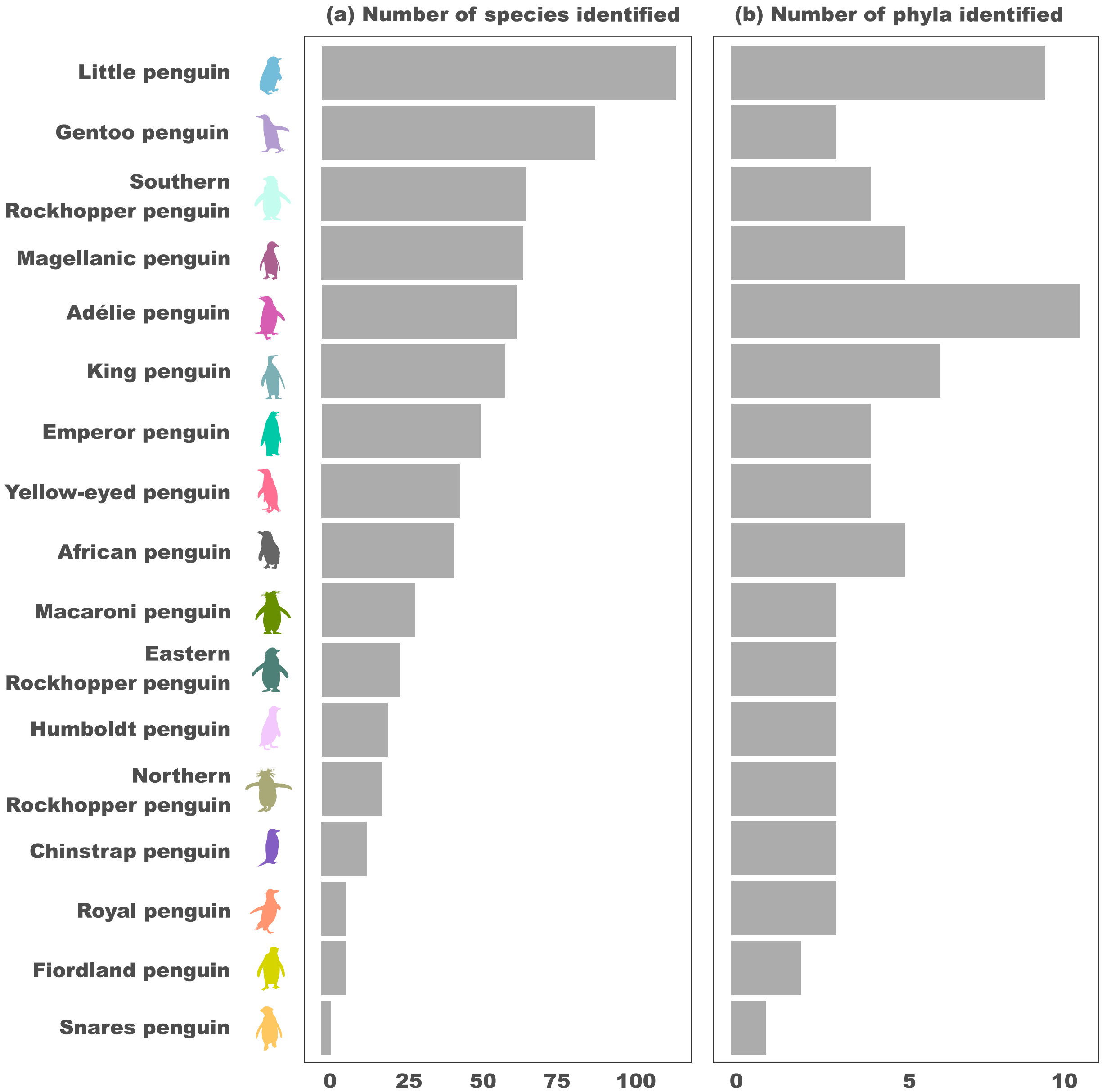

Fig. 3 (**a**) The barplot indicates the number of prey species identified for each penguin species. (**b**) The barplot indicates the number of phyla identified for each penguin species.

In cases where the exact coordinates were not explicitly mentioned, the location name referenced in the study was used to determine the coordinates. This was accomplished by searching the location using Google Earth tool, allowing for the identification of the precise latitude and longitude based on the described site.

Usage Notes

The review of the available literature and the extraction of diet information for this dataset were conducted in 2024. To maintain the accuracy and reliability of the database, we plan to correct any identified or reported errors on an annual basis, and we encourage users to report such issues directly to the corresponding author. In addition, newly published data will be incorporated through comprehensive updates approximately every five years. To accelerate progress and enhance the integration of new data, we recommend standardized reporting of key methodological details, including taxonomic resolution, sampling effort, and quantitative units (such as by mass, number, or frequency of occurrence), to ensure greater comparability across studies.

Data availability

The Penguin Diet Dataset-v2, now publicly available on Digital.CSIC (https://doi.org/10.20350/digitalCSIC/17565, URL: http://hdl.handle.net/10261/399953), brings together dietary data for 17 of the 19 known penguin species. Compiled in an accessible.xlsx format, the dataset includes detailed predator–prey interactions, along with essential metadata to support interpretation and reuse. Users will find clearly organized sheets for diet entries, variable definitions, species and prey codes, and geographic coordinates.

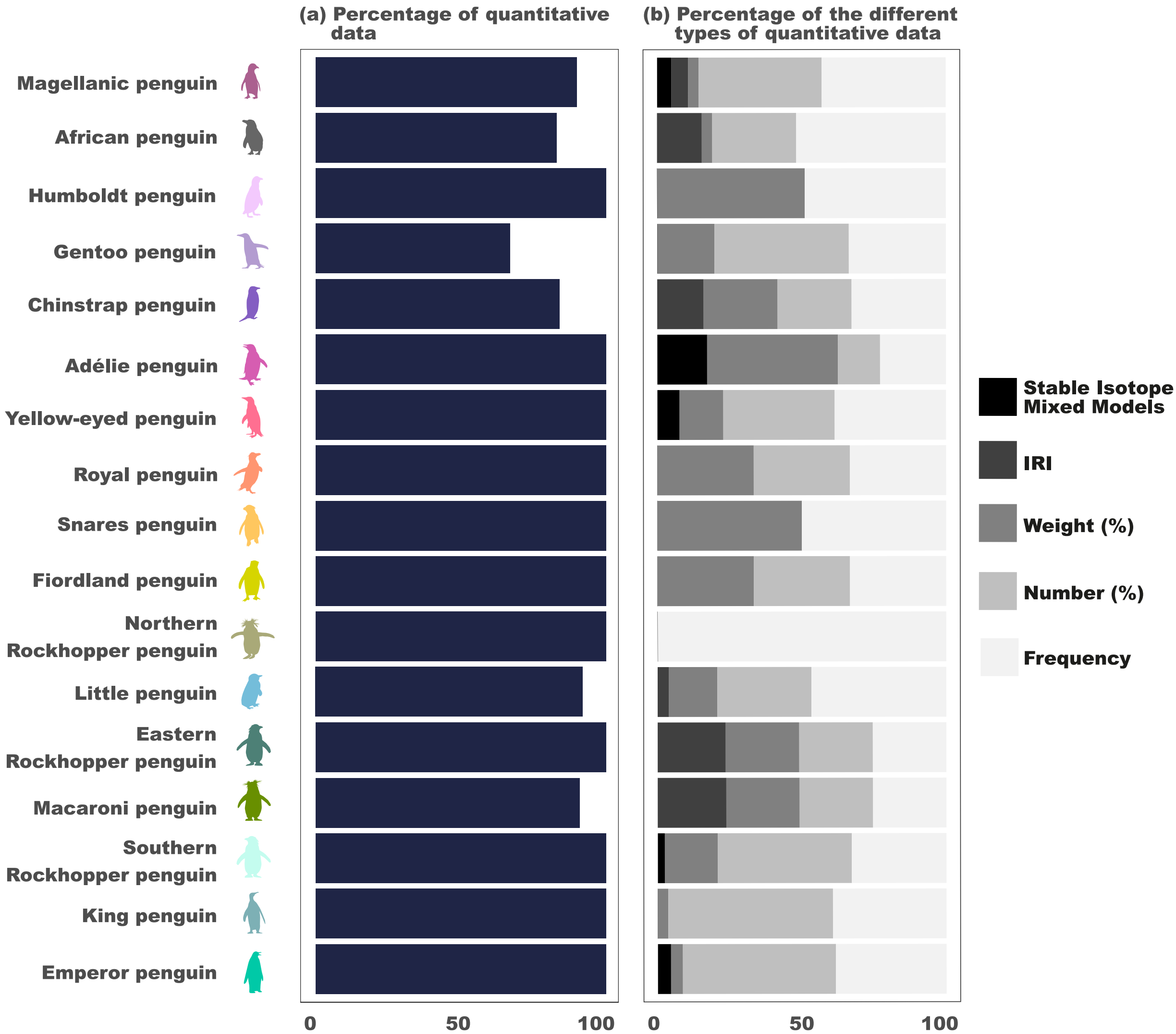

Fig. 4 (**a**) The barplot indicates the percentage of quantitative data present on the database for each penguin species. (**b**) The barplot indicates the percentage of the different types of quantitative data present on the database for each penguin species.

Code availability

No computational code is associated with this dataset, as all information has been exclusively sourced from available literature.

Received: 19 March 2025; Accepted: 11 December 2025;
Published online: 19 December 2025

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Acknowledgements
We would like to thank Helena Buil for her invaluable assistance with literature screening and data extraction. We also sincerely thank the Handling Editor and the two anonymous reviewers for their insightful and constructive feedback on the manuscript and accompanying dataset. This work is supported by the Spanish government through the following projects: SOSPEN (Spanish National Plan for Scientific and Technical Research and Innovation, 2021, PID2021-124831OA-I00), SEASentinels (Spanish National Plan for Scientific and Technical Research and Innovation, 2023, CNS2022-135631), and ProOceans (Spanish National Plan for Scientific and Technical Research and Innovation, 2020, PID2020-118097RB-I00). Additionally, this research is part of the Integrated Marine Ecosystem Assessments (iMARES) research group, funded by the Agència de Gestió d'Ajuts Universitaris i de Recerca (Generalitat de Catalunya), Grant No. 2021 SGR 00435. MG was supported by the FPI-SO fellowship (PRE2022-101875). This study is a contribution to the ICM-TEC (Trophic Ecology and Connectivity Scientific-Technical service of the Institut de Ciències del Mar CSIC; https://www.icm.csic.es/en/service/trophic-ecology-and-connectivity).

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F.R.: conceptualization, methodology, investigation, writing - original draft, supervision, project administration, funding acquisition; C.A.: methodology, investigation, data curation, writing - review & editing; M.G.: visualization, writing review & editing; M.C.: conceptualization, methodology, supervision, writing - review & editing, funding acquisition.

Competing interests
The authors declare no competing interests.

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