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Making Mediterranean trophic interactions easier to study: the MAISHA dataset

Ivano Vascotto[1,6]✉, Matteo Loschi[1,6]✉, Nikola Holodkov[1], Pasquale Ricci[2], Daniela Cascione[3], Simone Libralato[1], Tomaso Fortibuoni[4], Saša Raicevich[5] & Davide Agnetta[1]

Understanding trophic interactions is essential for ecology and for implementing and managing conservation policies. In the Mediterranean Sea, although dietary studies are increasing, marine trophic data remain fragmented. Here, we present the MAISHA (Mediterranean Archive of Integrated Stomach and feeding Habits Analyses) dataset, which results from a standardization process across 213 stomach content studies involving 287 species (248 of which are fish). Prey and predator data were standardized taxonomically using WoRMS, and diet contributions were normalized. Geographic and taxonomic biases are evident, with most studies concentrated in the Western Mediterranean Sea and a lack of data on bottom prey, such as invertebrates, and top predators (e.g., elasmobranchs). The collection revealed heterogeneity in reported diet measures and in prey taxonomic resolution. This study highlights critical gaps in marine trophic ecology and underscores the need for coordinated, standardized, and open data on trophic interactions in the Mediterranean Sea.

Background & Summary

Trophic interactions represent the feeding relationships among organisms and are a fundamental component for describing energy flow and the functioning of food webs[1,2]. At the ecosystem scale, dietary information supports modeling the structure and functioning of food webs[3]. Trophic interactions are a backbone for ecological studies to elucidate species' roles[4], resilience[5], and ecosystem perturbation[6]. In particular, they are key tools for investigating ecosystem responses to anthropogenic pressures such as habitat degradation[7], nutrient loads[8], overfishing[9,10], and climate change[11]. Thus, given the crucial role of trophic relationships in describing community dynamics, reliable ecological modeling requires accurate estimates of diet composition[12]. Missing or biased dietary data weaken ecosystem-based management[13], marine spatial planning[14], and biodiversity conservation policies[15], and introduce uncertainties into the inputs of trophodynamic models, reducing confidence in the model outputs[16]. Trophic interactions can be investigated with different approaches, such as stable isotope analysis[17], metabarcoding[18], a combination of the two[19], or stomach content analysis, which has traditionally been used[20]. The latter, despite being labor-intensive, time-consuming[21], and biased by digestion rates and prey detectability[22], in many cases represents the essential basis supporting the other techniques mentioned above[21]. Stomach content analysis is a key method for reconstructing the diet of marine species through the identification and quantification of food items in predator populations[20], as well as for the development of indices like prey-specific abundance[23] and food web models[24]. The relevance of trophic ecology across a broad spectrum of modeling methodologies[25] implies that collecting large open datasets on marine organism diets could enable more accurate assessments of trophic interactions, food web structure, and ecosystem stability across regions. Such data can support the implementation of legislative frameworks aimed at assessing marine food web status, such as the Marine Strategy Framework Directive (MSFD) (Descriptor 4, Commission Decision 2008/56/EC), by providing empirical information on trophic relationships required to evaluate food web structure and good environmental status. Despite the considerable number of studies[26,27], trophic data across Mediterranean marine organisms remain fragmented, both taxonomically and spatially, and are sometimes not freely or easily

[1]National Institute of Oceanography and Applied Geophysics – OGS, Trieste, Italy. [2]University of Padua, Padua, Italy. [3]Polytechnic University of Bari, Bari, Italy. [4]Italian Institute for Environmental Protection and Research – ISPRA, Ozzano dell'Emilia, Italy. [5]Italian Institute for Environmental Protection and Research – ISPRA, Chioggia, Italy. [6]These authors contributed equally: Ivano Vascotto, Matteo Loschi. ✉e-mail: ivascotto@ogs.it; mloschi@ogs.it

accessible. To date, no major reviews of existing stomach content studies, accompanied by a single open-access dataset on diet composition, have been published for the Mediterranean region. Worldwide scientific initiatives, such as FishBase[28], aim to gather this information, but their approach omits many diet details (composition, percentages). In such global repositories, the detail and variability of the trophic link of prey species depends on the taxonomic level assigned; for example, only for fish is it often defined at the species level. Detailed trophic data for keystone and structurally relevant food web taxa, including elasmobranchs, marine mammals, and invertebrates[29], have rarely been comprehensively compiled or standardized also in a user-friendly way. Given the limitations of existing datasets for examining trophic interactions, we introduce MAISHA[30] (Mediterranean Archive of Integrated Stomach and feeding Habits Analyses). Our goal is to collect and standardize stomach content information to facilitate the reuse of marine dietary data and to identify major gaps in trophic ecology across Mediterranean regions. MAISHA[30] seeks to compile all trophic interactions within the Mediterranean marine ecosystem. However, the resulting dataset reflects a longstanding research bias toward fish diet studies, which remain the primary source of empirical information in the region. Due to both their ecological importance and the greater availability of data, fish species are the main focus of this compilation effort, providing a solid foundation for future expansions toward a more comprehensive representation of Mediterranean marine trophic interactions.

We encourage the use of MAISHA[30] to construct food webs, assess local trophic indices, determine guild structures, and improve estimates by integrating other data. For detailed single-species studies, we recommend using MAISHA[30] as a guide to the original studies via the digital object identifier and references. The original studies include all non-standardized values and specific details about methodological and technical limitations, which are only briefly summarized here.

Methods

Literature search. A systematic literature search was conducted following the PRISMA methodology[31]. Studies were collected using the web search engine Google Scholar (https://scholar.google.com/), with the search divided into two phases. In the first phase, the search engine was queried for research and review articles published between 2015 and 2025, using the filter available in the Google Scholar options panel. The query was structured as follows:

Mediterranean trophic sea OR food OR web OR diet OR prey OR stomach OR gut -freshwater -lake -river

Studies conducted in the Mediterranean Sea were prioritized, but relevant studies from other regions were also included. In particular, considering the spatial and oceanographic proximity and biological connectivity, studies conducted in the Black Sea, Marmara Sea, and along the Portuguese and Moroccan Atlantic areas were always considered eligible. From the resulting list, studies reporting stomach content data of Mediterranean marine organisms were selected. The focus was on studies published in English, French, Italian, or Spanish that used qualitative or quantitative data and had a clear taxonomic scope. Reviews without primary data references, studies focused on aquaculture or freshwater species, and papers with unclear or non-standard dietary methods (e.g., emetics)[32] were excluded. In the second phase, given the recognized importance of fish in structuring marine food webs[9] and the abundance of literature in the Mediterranean area[26], the search engine was queried again, extending the study period and incorporating species from a list of 759 fish species recorded in the Mediterranean Sea[33]. The inclusion and exclusion criteria remained the same as in the first phase.

Data extraction, cleaning, and formatting. For each study, the species name, sampling location, and sample size were recorded. When available, species length data were also recorded. Dietary data were extracted from the studies, including the prey's scientific name and their relative importance (e.g., frequency of occurrence, gravimetric percentage, numerosity percentage). We read the selected studies and entered the relevant information for the database into a Microsoft Excel sheet either manually or using the "From PDF" function of the PowerQuery feature[34].

When diet items were reported with values below a detection threshold (e.g., "$<0.1\%$", "*", etc.), these entries were assigned a fixed proportion of 0.001, provided that the diet composition was expressed as fractions summing to 1. After technical validation, all gravimetric and numerosity percentages were normalized to sum to 1.

Sampling site and time description. The location, longitude, and latitude of the sampling sites from the original studies were reported for each data entry. When the original studies included multiple sampling points, the midpoint coordinates of the specified region were entered using either the region name or the sampling-point map. Because the spatial information in the original studies ranged from precise coordinates to approximate locations derived from maps or study-area descriptions, we did not formally assess the representativeness of the reported midpoint coordinates. These locations should therefore be interpreted as approximate spatial references for each study rather than exact centroids of the sampling distribution. The sampling year was reported for each data entry (format: YYYY). When the original studies covered several years, the truncated midyear within the range was reported.

Data Records

The MAISHA[30] dataset is compliant with Darwin Core (https://dwc.tdwg.org/) and is available through the Global Biodiversity Information Facility (GBIF: http://www.gbif.org/) under the https://doi.org/10.13120/hwpn1e. The dataset is published as a FAIR (Findable, Accessible, Interoperable, and Reusable)[35] open-access resource and is distributed under a CC BY 4.0 license. It is provided as a Darwin Core Archive, which includes an Occurrence Core data file, an Extended Measurement or Fact (eMoF) extension data file, and associated metadata files.

The Occurrence Core contains one record per documented predator/prey occurrence. The file includes the following terms:

- occurrenceID – unique identifier for the occurrence record;
- eventDate – sampling date (reported as year, ISO 8601 format when available);
- decimalLatitude – latitude in decimal degrees (WGS84);
- decimalLongitude – longitude in decimal degrees (WGS84);
- verbatimIdentification – taxonomic identification as it appeared in the original record;
- scientificName – taxonomically validated name of the predator or prey;
- scientificNameID – persistent taxonomic identifier (AphiaID from WoRMS);
- occurrenceStatus – presence or absence status of the recorded taxon;
- basisOfRecord – type of evidence supporting the occurrence record;
- bibliographicCitation – full citation of the original study;
- references – DOI or URL of the source publication;
- associatedOccurrences – linked predator or prey taxa reported in the stomach contents;
- occurrenceRemarks – identification of the trophic role of the occurrence (predator or prey).

Quantitative diet composition data and sample descriptors are stored in the eMoF and linked to the Occurrence Core via the occurrenceID field. Each row in the eMoF file represents a single measurement associated with a predator or prey occurrence. The extension includes the following fields:

- occurrenceID – identifier linking the measurement to the corresponding occurrence record;
- measurementType – description of the measured variable;
- measurementTypeID – controlled vocabulary identifier (when available);
- measurementValue – reported numeric value;
- measurementUnit – unit of measurement;
- measurementUnitID – controlled vocabulary identifier for the unit;
- measurementRemarks – additional contextual information.

Whenever possible, measurement types and units were mapped to controlled vocabularies from the NERC Vocabulary Server[36] (e.g., P01 and P06 collections). The official vocabulary definitions can be accessed via the link in the eMoF sheet using the measurementTypeID column. A brief description of the vocabulary is provided in the measurementType column. Diet data are reported as proportions. Replicate counts are reported as integer values. Length measurements are standardized to centimeters.

Data Overview

A total of 213 studies were collected, 197 of which focused on fish (Teleostei, Elasmobranchii, and Holocephali), representing 287 organisms (248 fish species). Most consumers were Teleostei (211), followed by Elasmobranchii (36), as shown in Fig. 1a. The complete list of species and studies is provided in Supplementary Table S1. Altogether, the diets included almost 1,600 unique prey taxa (Fig. 1b). 66% of the studies analyzed were published after 2010. The data from these studies span more than 40 years, with most samples collected after 2000 (Fig. 1c). For some organisms, several records were collected from different locations, sizes, or years, resulting in 496 unique diets. Most studies (205) were conducted in the Mediterranean and Black Seas or along the Portuguese and Moroccan coasts (Fig. 1d). For some species with no other available sources, studies outside this area were also considered. Records are biased toward the Western Mediterranean Sea (55%), with other Mediterranean MSFD regions contributing less: the Adriatic Sea (6%), the Ionian Sea and Central Mediterranean Sea (6%), the Aegean-Levantine Sea (15%), and the Black Sea (2%). Outside the Mediterranean Sea, the Iberian and Moroccan coasts contributed 10% of the diets, while the remaining 6% came from other areas.

In 75% of the diet records, food items were presented as gravimetric data; in 47%, as percentage numerosity; and in 50%, as frequency of occurrence. In 90% of the recorded diets, food items were available as proportions or percentage contributions to the diet, using at least gravimetric or numerosity data. In 80% of the dietary records, information on specimen length was retrieved, and in 65.4% of these cases, length was reported as a minimum and maximum range. Of the food items classified as Teleostei, 70% were identified at the species level. For Cephalopoda and Copepoda, this percentage was 50%, while only 35% of Malacostraca were identified to this level (Fig. 2a). Malacostraca accounted for most of the food items in the recorded diets (40%), followed by Teleostei, Copepoda, and Cephalopoda (21%, 15%, and 6%, respectively); these groups were mostly identified below the class level. Other classes each accounted for less than 5% of food items (Fig. 2b).

In the most recent review of Mediterranean fish feeding habits[26], it was noted that several commercially or ecologically relevant species were still missing dedicated studies. Our study covers some of them (*Auxis rochei*[37] and *Platichthys flesus*[38]) and includes species not present in the list of 759 Mediterranean fishes[33]: the Mediterranean spiderfish (*Bathypterois mediterraneus*)[39], the spearsnouted grenadier (*Coelorinchus labiatus*)[40], the flatsnout goby (*Ponticola platyrostris*)[41], and the asymmetrical goatfish (*Upeneus asymmetricus*)[42].

The current taxonomic coverage of MAISHA[30] encompasses approximately 32% of the fish species reported for the Mediterranean Sea[33], although coverage varies substantially among taxonomic orders (details for all orders of Actinopterygii are provided in Supplementary Table S2). Several species-rich groups remain poorly represented, including Gobiiformes, Acanthuriformes, Anguilliformes, and Tetraodontiformes, for which less than 20% of the known Mediterranean species are currently covered. In contrast, relatively high coverage was achieved for several orders of ecological and commercial importance, including Gadiformes, Pleuronectiformes, Rajiformes, and Myctophiformes, for which approximately half or more of the known Mediterranean species are

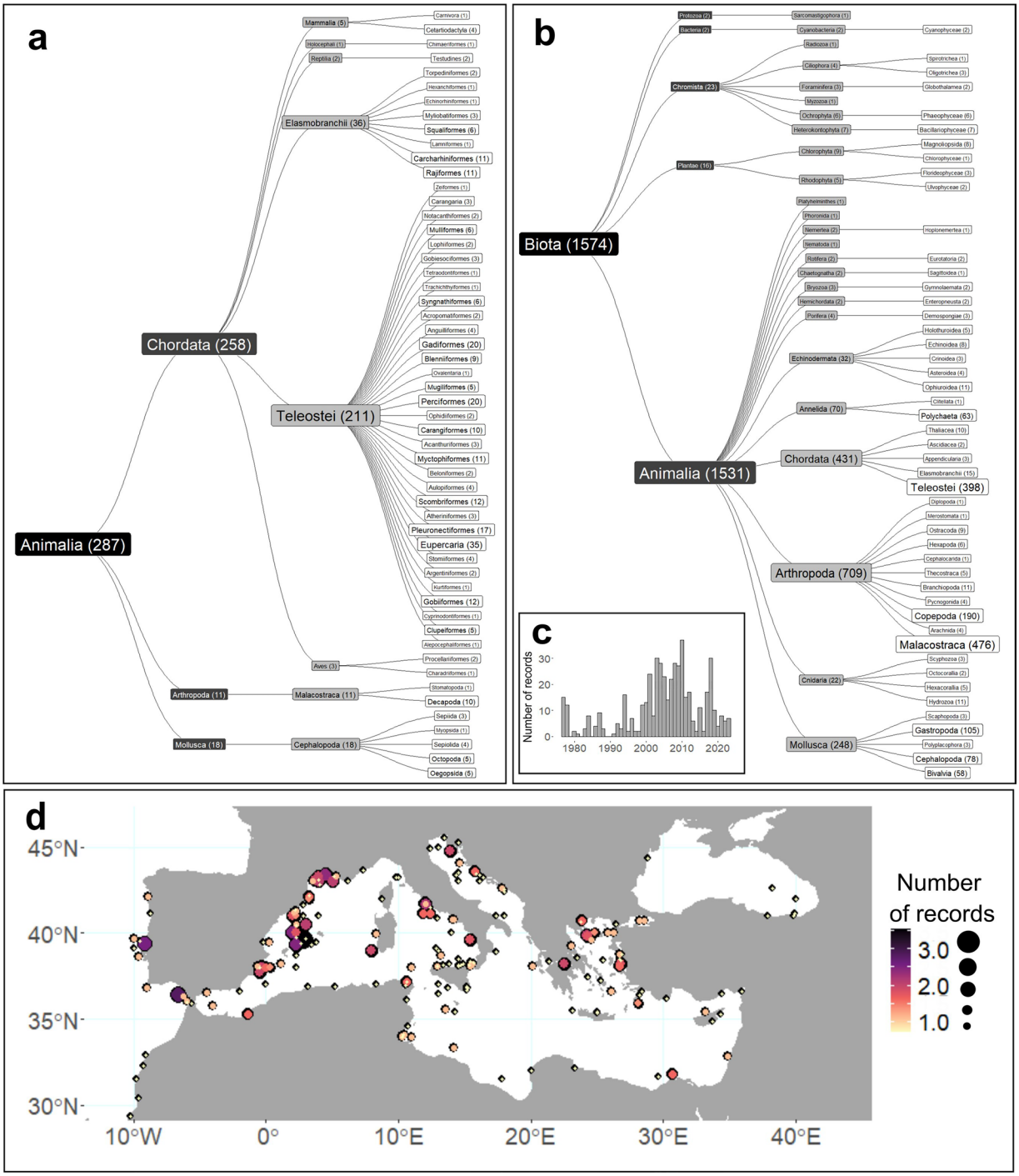


Fig. 1 Taxonomic variability and spatial coverage of the studies analyzed. (**a**) Taxonomic relationships of the predators collected for the dataset. The shades of gray distinguish the kingdom, phylum, class, and order. (**b**) Taxonomic relationships of the prey collected for the dataset. The shades of gray distinguish the domain, kingdom, phylum, and class. (**c**) Dates of the diet records reported in the dataset. (**d**) Spatial distribution of the records considered in the Mediterranean Sea. Each dot represents a recorded diet, and its size and color indicate the number of different diets reported at the same location. The scale is natural logarithmic.

represented. Coverage also appears relatively high for Carcharhiniformes; however, most of the represented species are based on studies conducted outside the Mediterranean Sea. The uneven taxonomic coverage highlights important knowledge gaps in our understanding of Mediterranean trophic interactions. In particular, the poor representation of several species-rich orders suggests priorities for future diet studies and database development, which should focus on underrepresented clades to improve the taxonomic completeness of Mediterranean food-web information.

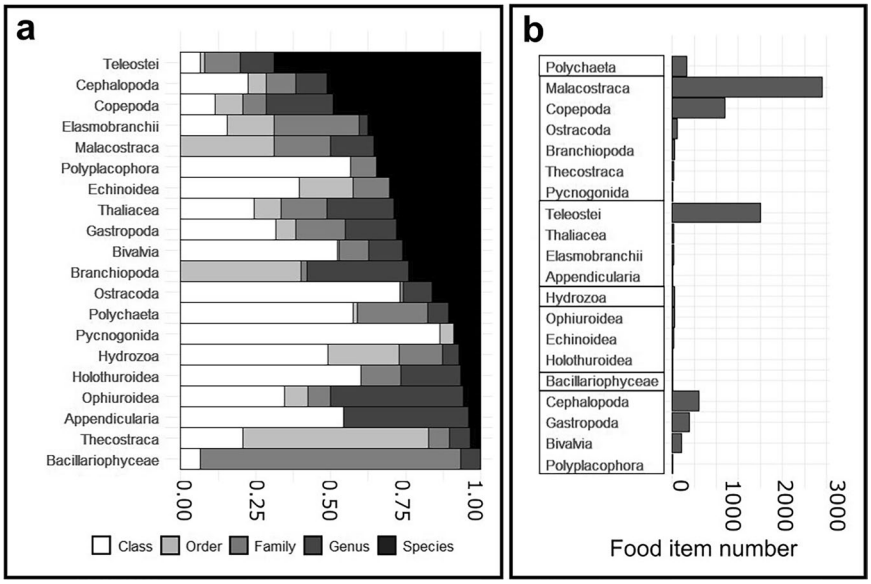


Fig. 2 Taxonomic information of food items in the diets of the analyzed studies. (**a**) Taxonomic detail of the food items within the main classes. The bars represent the proportion of food items identified in a class that were also identified to a lower taxonomic level. The bar labeled "order" includes all possible taxonomic classifications lower than "class" but higher than "order" (such as subclass, superorder, and so on). The same applies to family, genus, and species. Classes are ordered by the proportion of items identified at the species level. (**b**) The distribution of the number of food items among the classes to which they belong is shown. The classes are grouped by phylum and ordered by the number of food items found in the diets.

Moreover, we observed the spatial dominance of the northwestern Mediterranean Sea as a source area for studies, introducing additional bias and reducing confidence in the representation of the basin's trophic structure. A similar bias was observed for stable isotope data[43]. Another form of bias arises from heterogeneity in the taxonomic identification of food items, which is strongly influenced by morphology-based identification methods and the expertise of the stomach content examiner[21]. For some taxa, such as jellyfish, taxonomic identification is limited by the condition of the body parts found in stomachs[22]. In this case, simply increasing sampling effort cannot resolve the bias and thus limits the complexity of trophic network representation. In contrast, other methods, such as genomic tools, could overcome the limitations of morphological identification[44]. The consequence of this heterogeneity is an operational limit to using species-specific trophic positions. Increasing research effort to assess a species' trophic position is not appealing if this information cannot later be used due to insufficient cladistic information on the stomach contents of its consumers.

Technical Validation

After study selection was completed, relevant data were collected, processed, and validated to ensure accuracy. The column order, number, and names were standardized, as was their possible content. We curated and reviewed stomach data, ensuring record accuracy through cross-checks.

After collecting food items, scientific names were validated using AphiaID codes from the World Register of Marine Species (WoRMS)[45] to ensure long-term stability and interoperability. When prey was assigned to a generic group, we assigned it to the most consistent taxonomic group (e.g., wood was assigned to Plantae). The generic name as it appeared in the original record was reported in the "verbatimIdentification" column, while standardized taxonomic names and AphiaIDs were reported in the "scientificName" and "scientificNameID" columns, respectively. Only three food items were not categorized into WoRMS[45] categories: debris (unknown food items of inorganic origin), detritus (unknown food items of organic origin), and unknown (unknown food items of unknown origin).

Data processing involved outlier detection by visual inspection and histogram analysis (Supplementary Fig. S1a). To be considered correct, gravimetric and numeric cumulative composition had to sum close to 1 (from 0.9 to 1.1). This broad range was due to the presence of rounded values in literature. When the study did not provide the composition, entries of gravimetric and numeric percentages corresponded to 1 divided by the number of food items, thus considering all items equally important. The frequency of occurrence was considered correct if the cumulative sum of food items was greater than 1 (Supplementary Fig. S1b). If needed, diet indices were recalculated when raw data were available. All lengths were converted to the same unit, namely centimeters. To identify morphometric errors, length data were matched to existing literature.

Finally, automated quality checks implemented by the GBIF platform were used to verify data uniqueness, format consistency, and controlled vocabulary compliance.

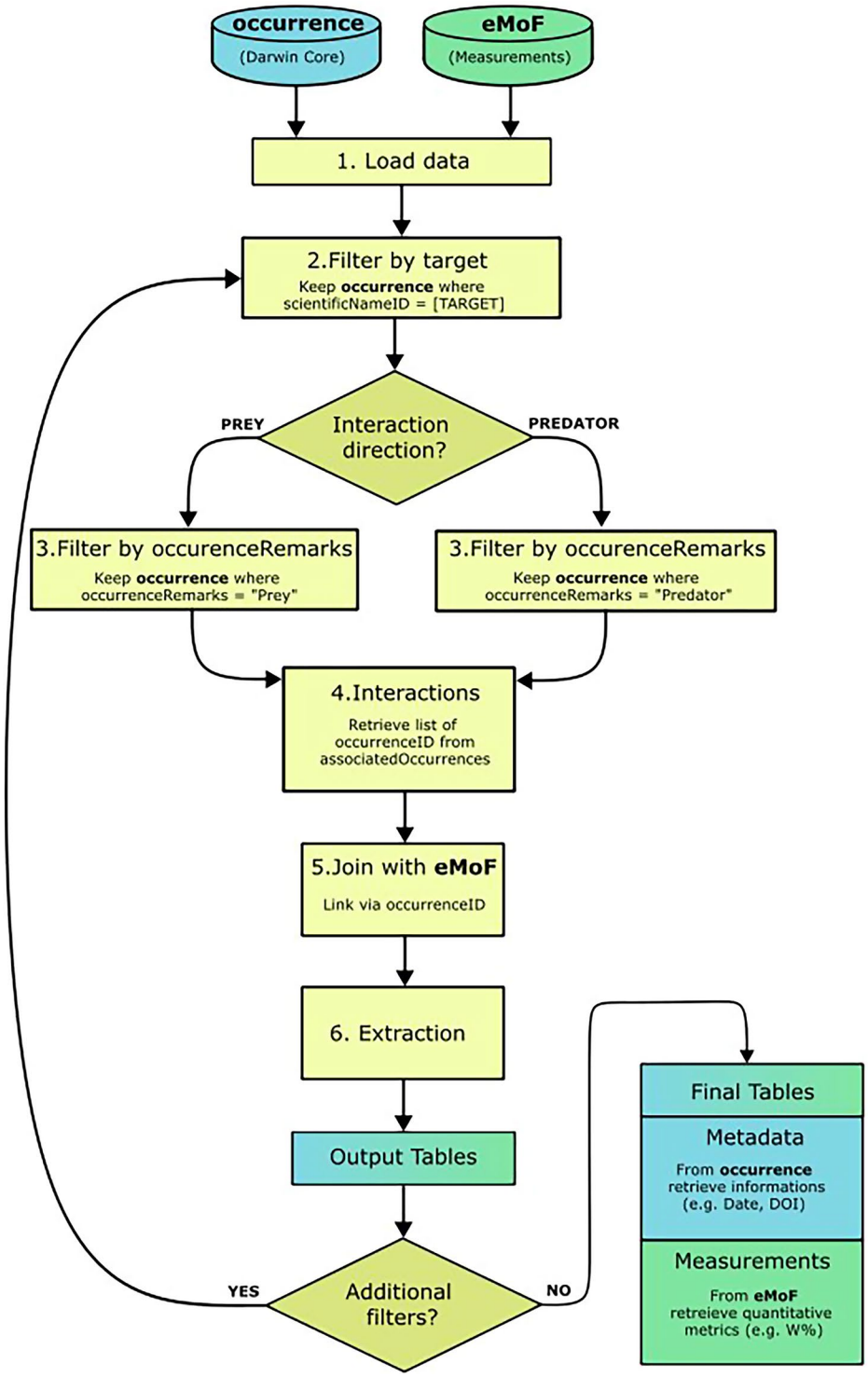


Fig. 3 Flowchart illustrating the use of the MAISHA[30] dataset. The flowchart shows how information can be extracted for a given species, either as a predator or as prey.

Usage Notes

MAISHA[30] is designed to be updated with data from literature and raw data. Figure 3 presents a theoretical flowchart of data extraction from the dataset. Supplementary Figure S2 and Supplementary Fig. S3 show example screenshots of the eMoF and occurrence tables. Data extraction and processing were performed in Microsoft Excel[34] and R version 4.5.1[46] via RStudio version 2025.09.1 + 401[47]. All analyses were conducted with R version 4.5.1[46] via RStudio version 2025.09.1 + 401[47]. Figure 1 and Fig. 2 were generated with the `ggplot2`[48] package version 4.0.0, while Fig. 1a and Fig. 1b were created with the `igraph`[49] package version 2.2.0.

We encourage users to help maintain the quality of this open-source dataset by reporting data errors, deleting records, or adding new records. With their help, we also aim to include taxonomically and geographically neglected parts of marine trophic webs. We will incorporate these edits and newly shared data into updated versions of the MAISHA[30] dataset.

Data availability

MAISHA[30] is available in GBIF at the following link: https://doi.org/10.13120/hwpn1e. The source data entered in MAISHA[30] are listed for each data point in the "bibliographicCitation" and "references" columns. A shortened version is also provided in Supplementary Table S1.

Code availability

No specific code has been generated for analysis of this data.

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Author contributions

I.V. collected and validated the data and wrote the initial draft of the paper. M.L. collected and validated the data and contributed to writing the paper. T.F. contributed to writing the paper. S.R. contributed to writing the paper. P.R. collected and validated the data and contributed to writing the paper. D.C. collected and validated the data and contributed to writing the paper. N.H. reviewed data and metadata and contributed to writing the paper. S.L. contributed to writing the paper. D.A. conceptualized and supervised the work and contributed to writing the paper.

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Competing interests

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Additional information

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Correspondence and requests for materials should be addressed to I.V. or M.L.

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