Title: DONANA FRUGIVORY CAMTRAP*: A dataset of foraging ecological interactions recorded with camera traps in the Doñana National Park*

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Open Research statement:

INRTODUCTION

Ecological interactions are at the core of the Web of Life that supports Earth systems (Begon et al. 2006) and are therefore essential to understand ecosystem services and functioning (Loreau et al 2001). No species on Earth lives without interacting with other species, yet consideration of ecological interactions as a component of biodiversity has received limited attention. Recording, quantifying and assessing ecological interactions is an urgent need to better understand the contribution of biodiversity to ecosystem functioning.

Frugivory is an animal-plant interaction crucial for ecosystem functioning that have been shaping the co-evolution of animals and plants for more than 80 My (Erikson, 2014). Plants provide food for animals, while animals provide dispersal services for plants becoming a central process in plant populations where natural regeneration is highly dependent on seed dispersal by animals (Jordano, 2000). Monitoring plant-frugivore interactions poses an important challenge because it is a labor-intensive activity that often leads to incomplete data samples (Gotelli and Colwell, 2011). Moreover, it has several limitations when comparing or replicating results from different sources (Quintero et al. 2022). However, the latest technological advances currently allow us to obtain quality data from the field opening an opportunity for individual or community level approaches to understand frugivore assemblages and ultimately the seed dispersion function.

The Doñana National Park (SW Spain) is a unique protected area characterized by a rich diversity of Mediterranean ecosystems, which harbors a great biodiversity, evidenced by more than 1300 plant species, more than 300 bird species and 50 mammal species, including iconic species such as the western imperial eagle *Aquila adalberti* and the Iberian lynx *Lynx pardinus* (Green et al. 2016). The provision of fleshy fruits for seed dispersal (endozoochorous dispersal syndrome) is a common evolutionary strategy in Doñana, where a high proportion of woody species are adapted to endozoochorous seed dispersal by vertebrates (Jordano, 2000), making Doñana a key site for monitoring animal-plant interactions in the Mediterranean. Despite the high level of protection Doñana National Park is currently facing the effects of global change especially through land use change, resource overexploitation and introduction of invasive species (de Felipe et al. 2023 , Zorrilla-Miras et al., 2014, Valdés, 2015) that are affecting the frugivore assemblage (Mendoza & Jordano, 2021). Changes in seed dispersal may reduce the seed removal rates (Pizo 1997), the dispersal distances (Donatti et al. 2009) and survival probability of plants (Rother et al. 2016), not only affecting the dispersal service but also the functionality of several ecosystem services (Banks-Leite et al. 2014; Dhirzo et al. 2014).

Over the past two decades camera traps for wildlife monitoring has expanded our understanding of distributions and ecological relationships of vertebrates (O'Connell et al. 2011; Ahumada et al. 2013). Camera trapping have been used in behavioral studies focused on activity periods (Suselbeek et al. 2014), daily activity patterns (Leuchtenberger et al. 2014), road crossing (Villalva et al. 2013), human-wildlife conflict (Johnson et al. 2006) and scent making (Delgado et al. 2011) among others. However behavioral studies using cameras traps are still in their infancy (Caravaggio et al. 2017), especially in relation to foraging behavior. The use of video recordings focused on focal plants allows the documentation of detailed data on the behavioral component of interacting species, but pipelines to work efficiently with high volumes of videos are still unstandardized and underdeveloped. Current advances in Artificial Intelligence applied to image recognition

(Leorna and Brinkman, 2022; Velez et al., 2023) along with the cost reduction of camera trap devices allows gathering and managing high quality data in a reasonably amount of time, therefore with an affordable budget.

We have created the *Doñana camera trap frugivory* dataset to better understand animal-plant interactions in Doñana and unravel the links that maintain the process of seed dispersal and their ecosystem services before further diversity loss. We collected, organized and standardized camara trap records focused on fleshy fruit plants from 2018-2023 collating the most comprehensive camara trap dataset of frugivory interactions ever assembled for Doñana and to our knowledge in any other area. The dataset includes 10,831 records for 60 species (50 birds, 10 mammals) gathered from 13 different plant species. The most frequently recorded animal species per taxa were: mammals - *Cervus elaphus* (1671 records) and birds - *Sylvia melanocephala* (1572 records).

This data paper offers valuable information for studying ecological interactions at individual and community level from both zoocentric or phytocentric perspectives. The methods presented raise opportunities for new studies on animal-plant interactions and encourages the implementation of this approach in other regions, allowing us to gain a deeper understanding of animal-plant assemblages and interactions as crucial components of Biodiversity.

Class I. Data Set Descriptors

A. **Data set identity**:

DONANA FRUGIVORY CAMTRAP*: A dataset of foraging ecological interactions recorded with camera traps in the Doñana National Park*

B. **Data set identification code**:

DataS1.zip

Metadata S1

C. Data set description

Originators:

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2. **Abstract**:

Ecological interactions are a key component of biodiversity and essential for understanding ecosystem services and functioning. However, consideration of ecological interactions as a component of biodiversity has received limited attention. There is an urgent need to record, quantify and assess ecological interactions to better understand the contribution of biodiversity to ecosystem functioning.

Using a standardized camera trap protocol, we monitor animal-plant interactions in Doñana, a highly valuable national park in SW Spain, collecting field data on frugivore interactions (records of pairwise interactions between plant and frugivore species) from 2018 to 2023. The dataset presented here includes 10,831 frugivory interactions for 60 vertebrate species (50 birds, 10 mammals) recorded on 13 different plant species that dominate the fleshy fruit assemblage of the region. The most recorded species per taxa were: mammals - Cervus elaphus (1671 records) and birds - Sylvia melanocephala (1572 records). The most important general pattern that we note is that deer *Cervus elaphus* have a central role as an antagonist frugivore species that consumes (but do not disperse) most of the fleshy fruit species in Doñana, performing as a seed sink in this ecosystem. This is opposed to the bird frugivore species such as those from the Sylvidae family that are widespread in the region acting as legit seed dispersers appearing as crucial species to maintain the dispersal service for most focal species.

This study compiles the most comprehensive dataset of frugivory interactions based on field data ever assembled, providing valuable information for the study of animal-plant interactions at the individual and community level from both zoocentric or phytocentric perspectives. The dataset presented provides opportunities for new studies, and the methods designed encourage the implementation of this approach in other regions, allowing a deeper understanding of animal-plant assemblages and interactions as crucial components of biodiversity.

D. **Key words/phrases**:

Data paper, Doñana, animal-plant interactions, mutualism, frugivory, frugivores, seed dispersal, camera-trap, 2018-2023.

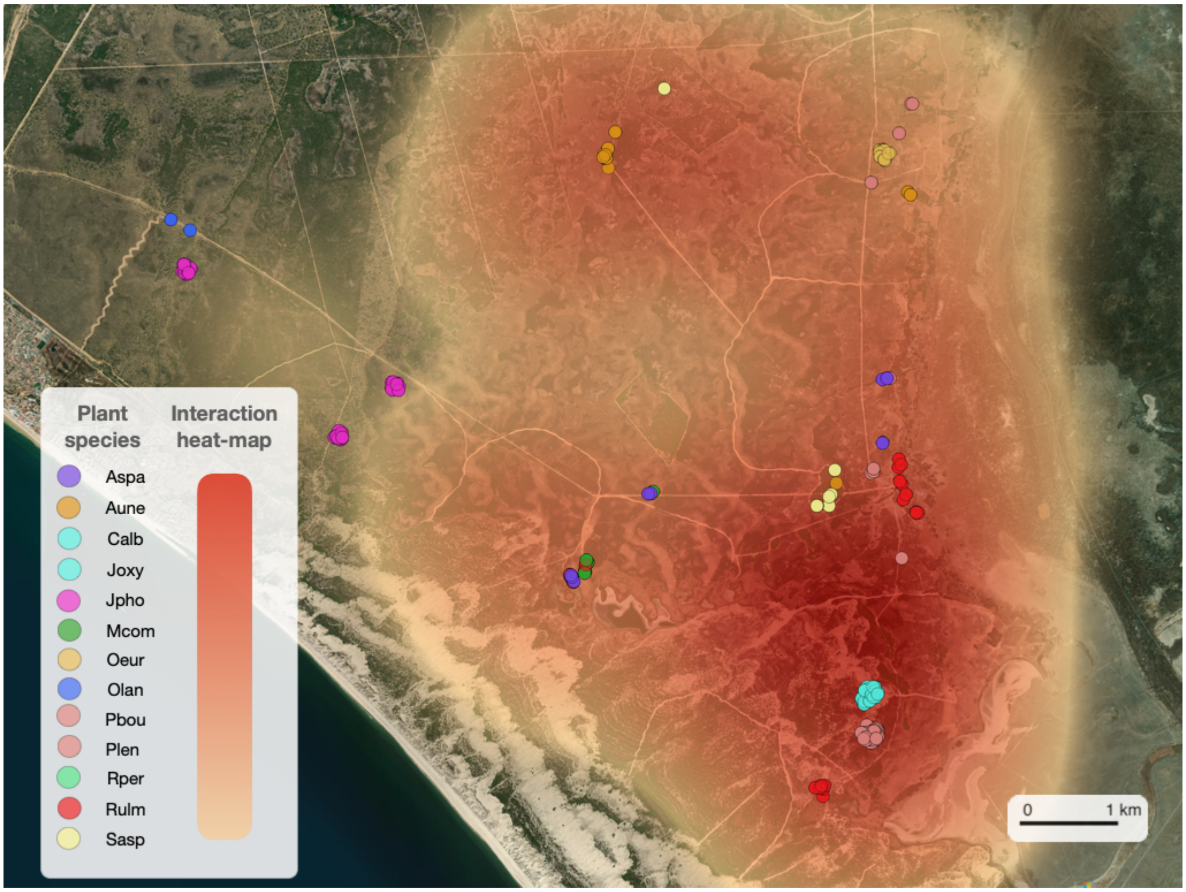

Figure 1. Study area. The figure shows the study area and the individual plant locations. Dots represent plant individuals colored by species (n =13). Note that *Juniperus oxycedrus* do not appear in this map and it is located 15 Km SE from the map lower limit. The yellow-reddish transparency represents the heat map of interaction intensity for the dataset. Red corresponds to high occurrence of interactions while yellow correspond to low levels of interaction.

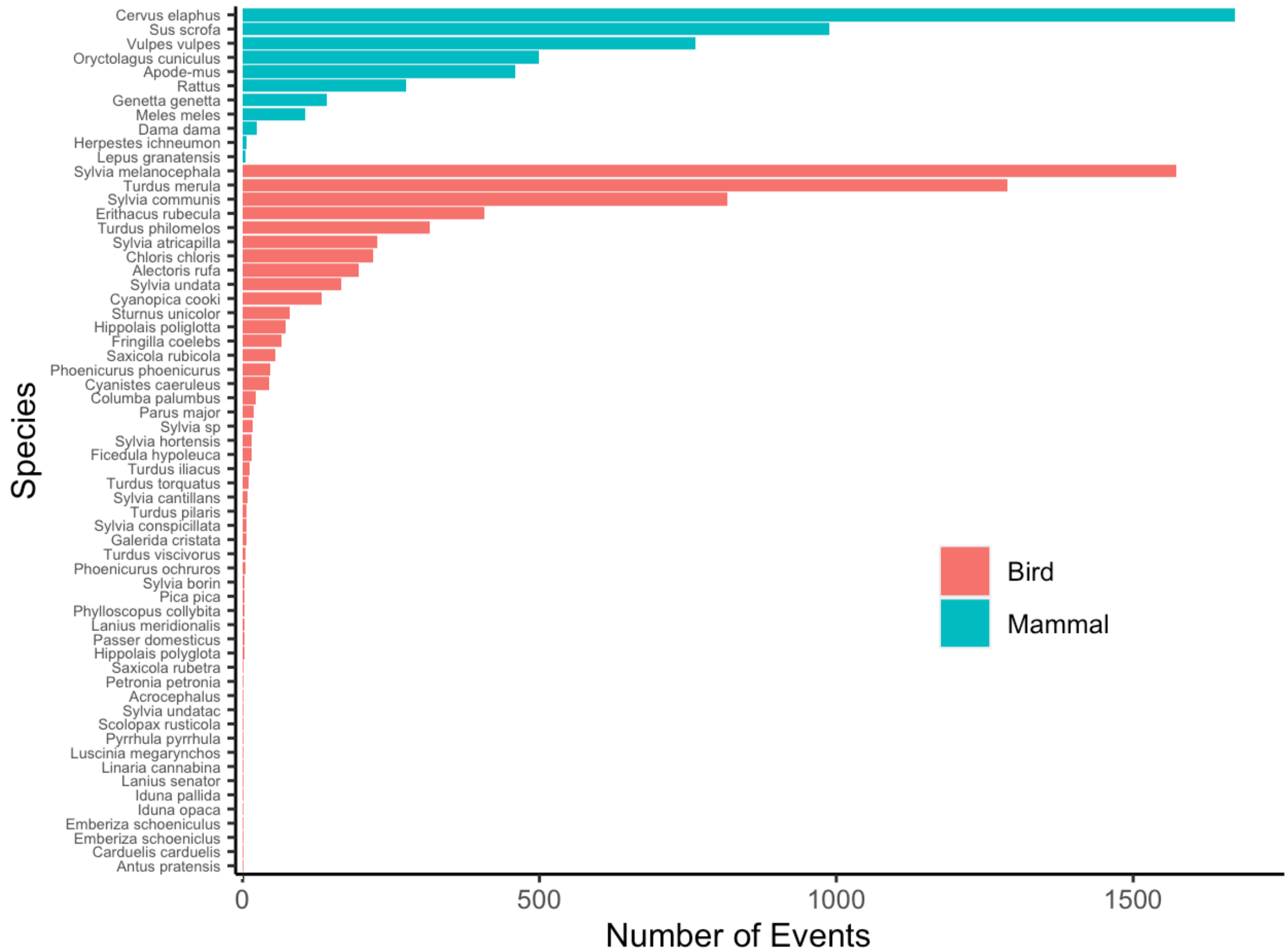

Figure 2. Number of recorded species. We overall recorded 10.832 observations of frugivory events from 10 mammal species and 50 bird species.

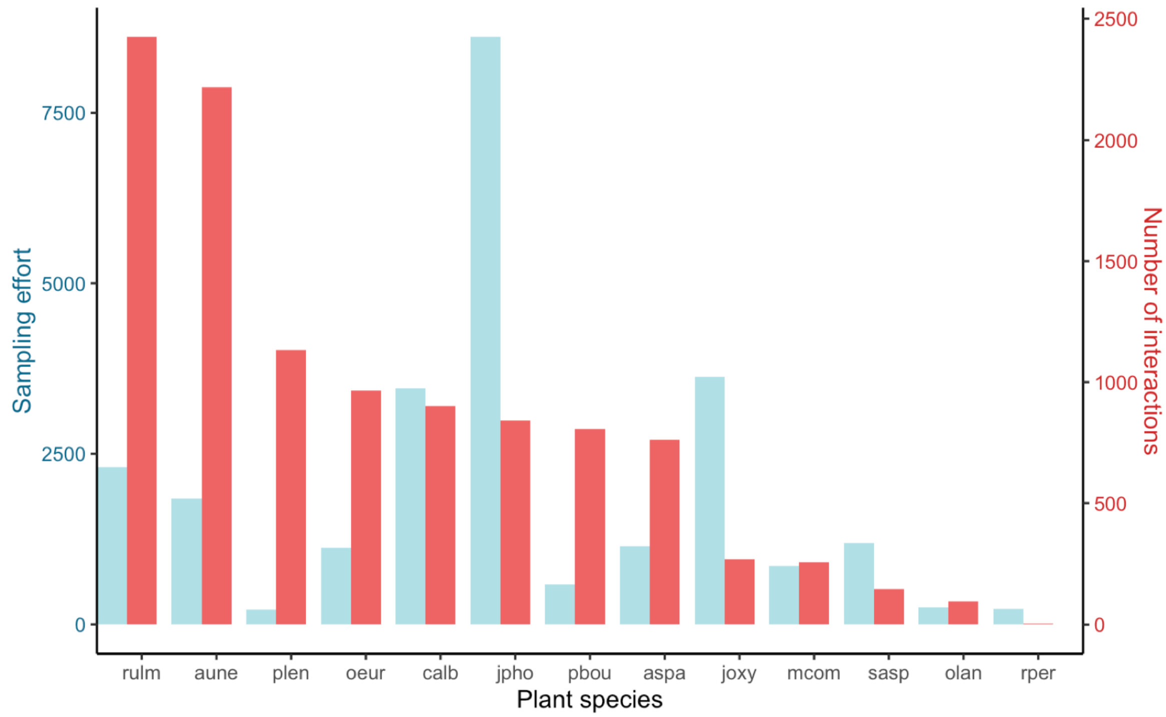

Figure 3. Interactions and sampling effort. The figure shows sampling effort along with the number of interactions for each plant species. Sampling effort is represented in left y-axis (blue) and number of interactions in right y-axis (red). Here we illustrate the independence of sampling effort from interaction records for some of the species. Those plant species with high sampling effort not necessarily record high number of interactions (i.e., jpho) and vice versa (i.e., rulm).

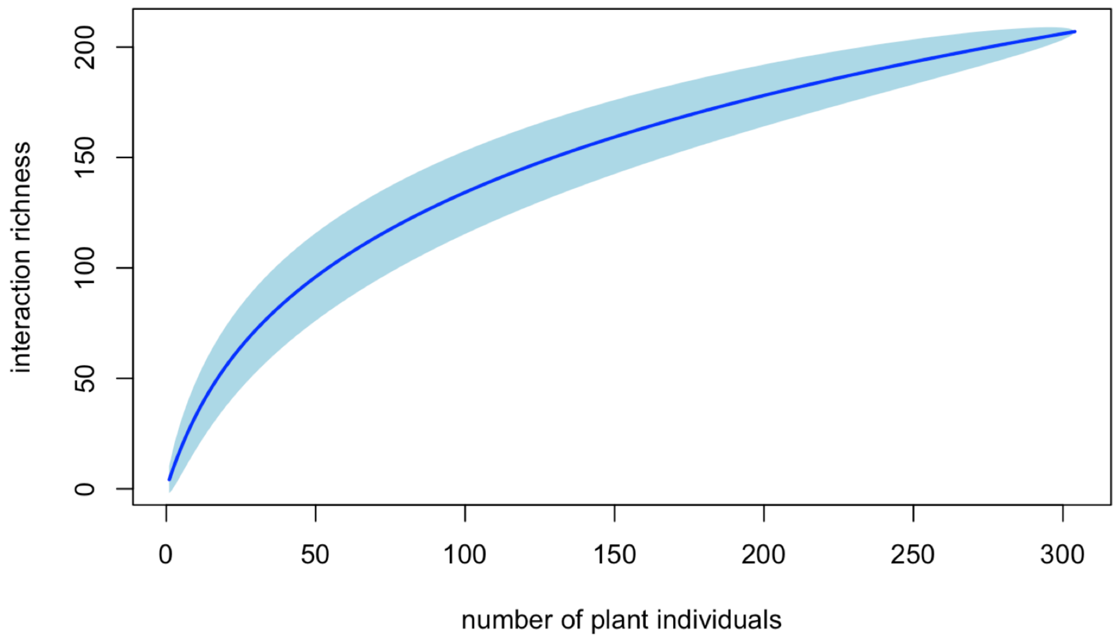

Figure 4. The figure shows the interaction accumulation curve (IAC) where the number of unique pairwise interactions (y-axis) accumulate as the number of sampled species increases as a proxy of sampling effort (x-axis). The accumulation curve performs similarly to a species diversity accumulation curve analysis. In our sample the curve approaches the asymptote, meaning that not many more new interactions can be expected to be found by further sampling effort. Blue line shows the mean estimate and light blue shadow shows the 95% confidence interval around the estimate.

Class II. Research origin descriptors

A. Overall project description:

See Class II.B.

1. **Identity**:

A dataset compilation with information of foraging ecological interactions for mammals and birds recorded with cameras in Doñana National Park.

2. **Originators**:

The Doñana frugivory camtrap was obtained by the Integrative Ecology group in the context of BioInteract work package as part of the Sumhal-Wp5 project. Design and coordination of fieldwork was conducted by Pablo Villalva, Elena Quintero, Jorge Isla and Pedro Jordano. Data compilation was assessed by the former and corresponding author. The following collaborators were part of the support team:

Field work: Elena Quintero, Jorge Isla, Pablo Villalva, Pablo Homet, Gemma Calvo.

Graphs and statistics: Pablo Villalva

Dataset standardization: Pablo Villalva

Co-authorship coordination: Pablo Villalva and Pedro Jordano

Map generation: Pablo Villalva

Manuscript writing: Pablo Villalva and Eva Moracho

Species identification and validation: Pablo Villalva, Jorge Isla, Pedro Jordano, Elena Quintero, Margaret Hempp, Carlos Gutierrez Expósito.

3. **Period of study:**

21/11/2018 to 17/04/2023

4. **Objectives**:

The primary objectives were twofold: (1) To collect field data on frugivory interactions using remote cameras. This involved an intensive fieldwork and data management to obtain interactions between frugivores and fruit-bearing plants within Doñana National Park. (2) To summarize individual based information related to frugivory events, making it available for use in both fitocentric and zoocentric studies of ecological interaction. Our comprehensive database may be used to understand the complex ecological relationships between plants and animal consumers. By providing this information, we facilitate further research into the dynamics of animal-plant interactions and their implications for both plant and animal communities within Doñana Natural Park and encourage other research groups to repeat this effort for other regions in search of meta-analytical results.

5. Sources of funding:

This study was funded by MICINN through European Regional Development Fund [SUMHAL, LIFEWATCH-2019-09-CSIC-4, POPE 2014-2020]

B. Specific subproject description

1. Site description

Doñana National Park is a unique protected area located in Huelva, SW Spain. It is characterized by a large variety of terrestrial and aquatic ecosystems ranging from pine and cork oak forests to scrublands, grassland, sand dunes, and marshlands. The rich diversity of ecosystems is the main reason for harboring a great biodiversity, evidenced by more than 1300 plant species (170 of which are endemic), over 300 bird species and 50 mammal species (Green et al. 2016).

Plant species have a crucial role in maintaining the mentioned animal diversity through bottom-up processes, while herbivores control vegetation through top-down regulation. However, animals not only maintain plant communities by freely eating upon them, but offer an important ecosystem service as dispersal vectors for a variety of plant species. The offer of fleshy fruit for seed dispersion is a common evolutionary strategy in Doñana. In fact, up to 64.3% of woody species in Spanish Mediterranean scrublands are adapted to endozoochorous seed dispersal by vertebrates (Herrera, 1984, Jordano, 1984), becoming a central process in Mediterranean plant populations where natural regeneration strongly depends upon seed dissemination by animals (Jordano, 2000).

The local plant populations studied here are located in the Doñana Biological Reserve, a core area of 6,794 ha within Doñana National Park with the higher protection level and low management intended for ecological research being, therefore, an outstanding site for research in ecological and evolutionary processes. In this area fleshy fruit species are spread throughout the landscape generally occurring in isolated patches, some species are virtually continuous across the landscape such as *Olea europapea* and some are associated with ecotone areas, such as *Rubus ulmifolius* while others are in strong association to specific soils such as *Corema album* that occupies coastal dunes.

2. Experimental or sampling design

Our approach for monitoring animal-plant interactions in natural habitats consists in the strategic placement of camera traps, aimed at specific plant species, referred to as focal plants. These cameras are set in video mode, providing us with valuable insights for identification of animal species and behavior.

This video-based monitoring method offers several advantages over traditional camera-trap techniques based in still pictures. By capturing movement, we are able to identify animal species and their behavior, allowing us to gain a deeper understanding of the complex interactions between animal and plant species. Additionally, by an accurate examination of videos we are able to determine those specific individuals that are especially difficult to determine otherwise, annotate foraging behaviors or even estimate consumption rates for some species.

We monitored 304 plant individuals from 13 different plant species during their fruiting season in a 5-year time span providing a powerful dataset of animal-plant interactions in natural habitats. By accurately identifying species and capturing animal behavior, our dataset offers the information to gain insights into the functioning of complex ecosystems.

3. Research methods

The field sampling involved the simultaneous deployment of 70 cameras (50 Browning Dark Ops, 10 Bushnell Trophy cam Aggressor and 10 GoPro), in replicated positions to target different individual plants (n = 304), throughout the fruiting season of the 13 focal plant species. Sensor triggered camera traps were used for 12 focal species while continuous recording with Go-Pro cameras was used for sampling Pistacia Lentiscus (see limitation section for more information about this method or Quintero 2021 for full methods). Cameras traps were checked at regular intervals, weekly or biweekly depending on the plant species and period of the year. For an effective management of such a large and complex data set we adapted the structure from Camera Trap Data Package (Camtrap DP) to our sampling design, obtaining the main structure for controlling camera-trap data at three levels: Deployments, Revisions and Observations.

A large amount of information is generated by this type of monitoring which can present challenges, especially in environments with high wind levels. In these conditions, incorrect triggering can easily occur through the movement of grasses and tree branches, leading to a large number of empty images. To mitigate this issue, we designed a protocol that streamlines the process of generating large databases from video recordings and reduces the time and effort required to do so (find the protocol for ecological interaction sampling with camera traps in the GitHub repository https://github.com/Cyanopica/Ecological-interactions-camtrap-protocol

Camera traps were set up to record 10 second videos to optimize digital storage. This setup resulted in several videos that recorded the same interaction event sequentially and thus bearing high temporal autocorrelation. We collapsed all videos within 5 minutes interval to avoid temporal autocorrelation derived from the sampling method considering independent event those occurring in different 5 minutes intervals. The interaction strength will be then relative to the duration of the consumption event.

4. Taxonomic Data

Identification of species was assessed by experienced field researchers and ornithologists, namely Pablo Villalva, Jorge Isla, Pedro Jordano, Elena Quintero, Margaret Hempp and Carlos Gutierrez Expósito.

C. Data Limitations and Potential Enhancements

Our dataset compiles information on mainly animal-plant interactions of mammal and bird species in focal plants. Different plant species respond better to different sampling methods (Quintero et al., 2022) reason why during the project we recorded interactions with different methodologies (i.e., seed traps-barcoding, direct observations, camera traps and mist nets-barcoding) trying to obtain the most comprehensive interaction data for each species. This fact results in an unbalanced sampling effort for the camera trap database alone that should be considered when using this dataset. For instance, for a community level approach we recommend subsampling those species with high number of sampled individuals (*Pistacia lentiscus* and *Juniperus phoenicea)* to avoid the sampling effort bias. These facts may also limit the use of some plant species for an individual fitocentric perspective (i.e. *Rubia peregrina* with only two individuals should be removed from individual level assessments) but still offers valuable insights for community level and zoocentric approaches.

In the other hand only *Pistacia lentiscus* from the set of plant species was recorded with GoPro cameras rather with camera traps, resulting in important differences in the used methodology. Unlike plants recorded with camera traps, therefore continuously recording for weeks, *Pistacia lentiscus* cameras recorded 2 hours/day during the peak of foraging action in the mornings. This method was efficient as it gathered a great number of interactions with less sampling effort when compared to camera traps that are active 24 hours/day. A sampling effort correction should be applied in order to use this data in community level approaches. This limitation also restricts *Pistacia lentiscus* data for studying animal foraging patterns because temporal data acquisition is strongly biased by the method employed (recorded only during the morning).

An improvement of this dataset will be to combine the different methods conducted in animal-plant interaction surveys. This approach is under development and will be soon published as a complementary dataset requiring a significant processing and data merging which significantly reduces the amount of information contained in this camera-based database alone, losing much of the quantitative information and versatility of the data presented in this database.

Class III. Data set status and accessibility

A. Status

1. Latest update: 25/06/2023
2. Latest archive date: 25/06/2023
3. Metadata status: Latest update on 25/06/2023 refers to the submitted version of the revision process.
4. Data verification: 25/06/2023

B. Accessibility

1. Storage location and medium:

Original dataset can be accessed on the GitHub Inc. repository (https://github.com/XXX). All the data - both the updated version and complementary material - are fully available for public use and research purposes. The dataset will be updated on a regular basis on the GitHub repository and the acquisition of additional data is possible by contacting the authors of this manuscript.

2. Contact persons:

Pablo Villalva, Dept. Integrative Ecology, Estacion Biologica de Doñana – CSIC – C/ Americo Vespucio 26, Sevilla, Spain. E-mail: villalva@ebd.csic.es

Pedro Jordano, Dept. Integrative Ecology, Estacion Biologica de Doñana – CSIC – C/ Americo Vespucio 26, Sevilla, Spain. E-mail: jordano@ebd.csic.es

3. Copyright restrictions: None
4. Proprietary restrictions: Please cite this data-paper when using its data in publications. We also request that researchers and educators inform us of how they are using this data.
5. Costs:

We break down the cost of data acquisition into four broad categories: Field staff (54 k€), data curation staff (24.5 k€), equipment (18 k€) and others (5.5 k€). The overall data acquisition amount is 102. 000 €

Class IV. Data structural descriptors

A. Data set file

1. Identity:

DataS1.csv

2. Size:

10.831 records, xx columns, 2,3 MB

3. Format and storage mode:

Comma-separated values (.csv)

B. Variable information

Identity	Definition	Data type	Example
plantSp	Plant species scientific name. Acronym with first letter from gender and 3 first letters from species.	string	AUNE
plantId	Plant individual unique identificatory.	string	AUNE003

animalSp	Scientific name of the interacting animal species.	string	Vulpes vulpes
dateTime	Date and time at which the recording started. Formatted as an ISO 8601 string with timezone designator (YYYY-MM-DDThh:mm:ss±hh:mm).	datetime	2015-01-01 03:38:40
behaviour	Foraging behavior of the interacting animal.	datetime	eating
coexistence	Recording of another animal with foraging behavior in the same moment.	boolean	TRUE
nCam	Number of cameras installed in the same Plant_ID.	integer	2
days	Sampling effort at the revision level. Number of days that the camera was active and recording.	numeric	11.79
effortPlantSp	Sampling effort at species level. Number of days that a certain species has been recorded.	numeric	584
effortInd	Sampling effort at individual level. Number of days that a certain plant individual has been recorded.	numeric	29.8
duration	Duration of the recording event in seconds.	numeric	20.93
id	Unique identifier for the event. It is a string based on the relative path to the recording files (first file if many files were collapsed).	string	pbou004_rev02 _01010002
long	Longitude of the deployment location in decimal degrees, using the WGS84 datum.	numeric	-6.444530
lat	Latitude of the deployment location in decimal degrees, using the WGS84 datum.	numeric	37.02329
speciesType	Type of animal: mammal or bird.	string	“bird”

C. Data anomalies:

If no information is available for a given record, this is indicated as ‘NA’.

Class V. Supplemental descriptors

A. Data acquisition

1. Data forms or acquisition methods:

We used 60 Browning Dark Ops camera traps and 10 Bushnell Aggressor to monitor focal plants of 12 species while *Pistacia lentiscus* was monitored with GoPro cameras (Quintero et al., 2021). For a detailed view of the sampling protocol with camera trap visit the GitHub repository https://github.com/Cyanopica/Ecological-interactions-camtrap-protocol

2. Location of completed data forms
3. Data entry verification procedures:

All changes and procedures performed to the original data are traceable through R code accessible in the GitHub repository of this paper. The data set was carefully screened by grouping and analyzing each plant species as well as most abundant animal to verify ecological consistency of results.

B. Quality assurance/quality control procedures: Identification and treatment of outliers, description of quality assessments, calibration of reference standards, equipment performance results, etc.

At times camera traps do not display the correct date or time due to malfunction or setup misconfiguration. In our pipeline most Timestamp Issue cases were detected in the field and flagged in the database. In these cases, the correct date and time was set from that from the nearest camera. In the (more unlikely) case that the TI was not detected in the field, the dataset was checked for events outside the sampled date range. These dates were also corrected as the previous Timestamp Issues.

Artificial Intelligence (Megadetector) to detect animal presence performed differently for each plant species (and Md version). Calibration and performance results from the AI applied to each plant species was also analyzed and is being managed as a separate paper.

C. Related materials: None.

D. Computer programs and data-processing algorithms:

We processed video files with Artificial Intelligence for all species with the exception of Juniperus phoenicea that was revised by man-power alone. We analyzed the video recordings from Pistacia lentiscus aided by DeepMeerkat software (Weinstein, 2018). We used Megadetector (Berry et al. 2019) for eliminating empty videos (video recordings without animals) of the rest of species. We used MD.v.4 for first year and MD.v.5 for the second fruiting season right after the release of the enhanced version.

E. Archiving

This dataset is freely downloadable as supplementary material in this publication and new data will be updated to the on the GitHub Inc. repository on a regular basis (https://github.com/XXX). It is also possible to acquire the dataset by contacting the authors of this manuscript. The data published in these repositories and free for use are fully available for public use and research purposes

F. Publications and results:

Quintero, E., Rodríguez-Sánchez, F. & Jordano, P. (2023) Reciprocity and interaction effectiveness in generalised mutualisms among free-living species. *Ecology Letters*, 26, 132– 146. Available from: https://doi.org/10.1111/ele.14141

Quintero, E., Isla, J. and Jordano, P. (2022), Methodological overview and data-merging approaches in the study of plant–frugivore interactions. Oikos, 2022:. https://doi.org/10.1111/oik.08379

Isla, J., Jácome-Flores, M. E., Pareja, D., & Jordano, P. (2022). Drivers of individual-based, antagonistic interaction networks during plant range expansion. *Journal of Ecology*, 110, 2190– 2204. https://doi.org/10.1111/1365-2745.13942

Isla, J., Jacome, M., Arroyo, J.M., Jordano, P. 2023. The turnover of plant–frugivore interactions along plant range expansion: consequences for natural colonization processes*Proc. R. Soc.B.* http://doi.org/10.1098/rspb.2022.2547

G. History of data set usage

1. Data request history: None.
2. Data set update history: None.
3. Review history: None.
4. Questions and comments from secondary users: None.

Literature Citations

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