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Systematic Map Protocol

Title
What strategies do herbivores employ to exploit carnivorous plants?

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Background
Carnivorous plants are a diverse group of over 800 plant species that consume arthropods to obtain nutrients (Ellison and Adamec 2018). Surprisingly, these plant predators also defend against herbivores because they serve as hosts for a number of arthropods (Mithofer 2022). But how do herbivores exploit carnivorous plants given that these plants can act as predator and host? Natural histories of carnivorous plants frequently explore herbivore interactions, drawing on intricate life histories and morphological traits to hypothesize how herbivores exploit carnivorous hosts. However, these accounts are scattered across a variety of plants and arthropods, requiring a rigorous synthesis for a comprehensive understanding of how herbivores exploit carnivorous hosts. We propose to produce a systematic map of herbivore offense of carnivorous plants. We will gather and screen evidence from natural history, field, and laboratory studies of herbivores and include literature from all known genera of carnivorous plants. We will interrogate this evidence base using thematic analysis, a qualitative research method to identify and organize themes or patterns across a dataset (Braun and Clarke 2012). Using thematic analysis, we will be able to identify common strategies that herbivores share to exploit carnivorous plants and generate hypotheses of how these interactions evolve. We anticipate that ecologists will use this map to further theory in herbivore offense while conservation biologists will use this map to redefine recovery priorities for many of these herbivores in their imperiled habitats.

Theory of change or causal model
Generally, herbivores have a negative influence on their hosts, but herbivores on carnivorous plants bend this assumption because they can also serve as prey. This affirms the need to reconsider how we define herbivory, but before we can explore new hypotheses, we need a better understanding of how herbivores exploit their carnivorous hosts. Data is found across many different plants and studies, prohibiting this understanding. We propose to map the evidence base for herbivores on carnivorous plants as a first step to generate new hypotheses to expand theory underpinning herbivory and its influence on plants.

Stakeholder engagement
Two map authors (BC and LH) conceived of our map question after two years of informal conversations with ecologists at universities and conservation agencies. Ecologists relayed a general

lack of theory concerning herbivores of carnivorous plants, noting a contrast with recent advancements in plant carnivory and defense which produced theory applicable across plant genera. In addition, ecologists observed attention paid towards lepidopteran specialists on carnivorous plants, overlooking non-lepidopteran herbivores. This bias would likely hinder conceptual advancements. Conservation biologists shared many of the same needs as ecologists, emphasizing the need for studies that show how herbivores structure bog communities. We met resource managers tasked with protecting carnivorous bogs along the US Gulf Coast, and their evidence base is restricted to a handful of well-documented herbivores. They need a comprehensive database of herbivores on carnivorous plants to guide policy actions, particularly related to monitoring biodiversity and soliciting conservation research.

Objectives and review question

This map aims to identify patterns of how herbivores exploit carnivorous plants. Primary question: What strategies do herbivores employ to exploit carnivorous plants? Secondary questions: What plant part is consumed or attacked?, What morphological, physiological, and behavioral traits contribute to how herbivores evade plant carnivory?, When do herbivores attack plants?, What arthropod life stage engages with carnivorous hosts?, Is the herbivore thought to specialize on the carnivorous host?, What methods have been used to identify and characterize how herbivores evade carnivorous plants?

Definitions of the question components

Population: any plant belonging to one of the ten carnivorous clades listed in Fleishmann et al. (2018) Exposure: any organism belonging to the Phylum Arthropoda Outcome: any damage reported on any part of the plant after an arthropod feeds on the plant

Search strategy

We plan to search for observational and experimental studies that span from 1875 to present day in research databases, reference lists of eligible studies, and literature traditionally not indexed in databases. We will hand-search references from included studies (i.e. snowball search) after screening literature from research databases. By searching references of eligible studies, we are less likely to scan irrelevant literature while locating overlooked historical studies (Gough et al. 2017). We will hand-search literature not indexed in databases, such as regional science journals from areas with a high diversity of carnivorous plants. We will employ a P-E-O question structure because carnivorous plants can have herbivores after being exposed to certain arthropods. We ascribed population to carnivorous plants, exposure to arthropods, and outcome to plant damage. Population terms will include the term “carnivorous plants”, “insectivorous plants”, known carnivorous plant genera, and synonyms for carnivorous genera. To develop a broad population of host plants, we will search by known carnivorous genera of plants as recognized by Fleishmann et al. (2018), and since generic names change over time, we will also search by synonyms for each carnivorous genera. Exposure terms are arthropod synonyms and insect orders known to contain herbivores. Among our synonyms, we include life stage names, such as larva or nymph, because some arthropods only exploit carnivorous hosts during specific life stages. Outcome terms are common descriptors of plant damage and herbivore offense. Appendix A includes our search queries.

Bibliographic databases

Using queries refined during our pilot search, we will search for literature in Scopus, EBSCO databases, and Proquest Dissertations & Theses Global. EBSCO databases include Academic Search Complete, Agricola, Biological Abstracts, CAB Abstracts, Environment Complete, Medline, and Wildlife & Ecology Studies Worldwide. We will not apply any limiters to database searches, and we will not use the “Apply equivalent subjects” option in EBSCO. Our institutional subscriptions to Biological Abstracts and CAB Abstracts primarily cover from 1990 to present. We did not search

Web of Science (WoS) because our institution does not subscribe to WoS. Our institution has access to BioOne and AGRIS, but we excluded these databases because they do not handle complex search queries well.

Web-based search engines

Typically, web-based search engines, such as Google Scholar, retrieve literature based on relevance, but our queries are challenging to input into these search engines because carnivorous plants have multiple synonyms and common names. In bibliometric databases, we are able to combine plants, their synonyms, and common names using Boolean logic, but web-based search engines do not perform well using Boolean-based queries. We have included alternative search strategies to retrieve grey literature as detailed in later sections of this protocol.

Organisational websites

We will search the online archives of the Tall Timbers Research Institute in Tallahassee, Florida, and the International Carnivorous Plant Society (ICPS) for grey literature relevant to our map question. Both archives feature scientific studies of arthropods on carnivorous plants in unpublished field data, newsletters, and conference proceedings. We will hand-search titles from both sources and include any retrieved studies with other hand-searched literature. Additionally, after screening titles and abstracts from literature retrieved from electronic databases, we will identify prolific authors that published within the past ten years. We will contact these authors to inquire about other studies. After checking that we have not already screened their suggested studies, we will obtain full-texts of their suggestions and include these studies with hand-searched literature for later screening.

Comprehensiveness of the search

We conducted a pilot search to test the comprehensiveness of our query strings. We searched in Scopus, Academic Search Complete, Agricola, Biological Abstracts, CAB Abstracts, Environment Complete, Medline, Wildlife & Ecology Studies Worldwide, and ProQuest Dissertations & Theses Global using a search query that strung together terms from population, exposure, and outcome using the Boolean operator “AND”. We used the (*) wildcard to expand some search terms that have alternative forms. We compared literature retrieved from our pilot search with a list of benchmark literature of herbivores on carnivorous plants. This benchmark list was solicited from stakeholders, and we obtained 22 out of the 25 items on our list. Our list of benchmark literature and results from our pilot search are found in Appendix B.

Search update

We decided to drop outcome terms because it reduced recall of total retrieved literature. We also dropped (lily) and (trap) from our population terms because they share multiple uses with non-carnivorous plants or non-botanical literature, respectively. Instead of (butterwort*), we will search for (Butterwort OR Butterworts). In EBSCO databases, this eliminates results that have (Butterworth) while still including articles that use common names for those species. We will add (commensal*) as we found this term associated with retrieved literature. Because pilot queries were unable to retrieve a book chapter and thesis, we have expanded our search for grey literature. We will use the "Secondary Documents" option in SCOPUS, which are documents extracted from a reference list but are not indexed by SCOPUS. After examining "Secondary Documents" in SCOPUS, we found the book chapter we missed. We also will search Digital Commons, another repository for theses, and this database retrieved the theses we missed. We will also search the following databases from OCLC simultaneously: WorldCat, WorldCat Book, OAlster, PapersFirst, and ProceedingsFirst. Due to the large number of results, Digital Commons and OCLC databases will be searched with plant terms in the title field but insect terms as keywords. The OCLC databases will also include the following: conference*, symposium*, proceeding*, report*, bulletin*, dissertation*, thesis, theses. These resources do not export easily, so two reviewers (BC and LH) will independently examine results from databases. The remainder of our query strings and search strategies stayed the same.

Screening strategy

Two reviewers (BC and LH) will screen literature from each search strategy independently using our eligibility criteria. Prior to screening literature from research databases, we will combine retrieved literature into a single Zotero folder and then de-duplicate results in Zotero. We will export de-duplicated results to Rayyan. We will complete a check for reviewer consistency prior to screening. We will independently screen all literature in two stages, first by title and abstract and then by full-text. During each stage, we will keep Rayyan in blind mode so individual reviewer decisions remain hidden from the other reviewer, and we will assign reasons to exclude studies in Rayyan. After we complete each stage, we will remove blind mode in Rayyan and discuss conflict literature. After we complete screening for studies from databases, we will search reference lists of eligible studies (i.e. snowball search) and scan Ellison and Adamec (2018), regional science journals, and conference proceedings (i.e. hand-search). We will manually enter retrieved studies into Zotero and de-duplicate studies in Zotero. We will export de-duplicated studies to Rayyan. Since we will initially select studies based on their titles, we will not formally screen titles and abstracts as conducted earlier. Rather, we will screen only full-texts in Rayyan as conducted prior for full-texts from databases. We will not test for interrater variability because we would have already ensured consistent agreement earlier while screening studies from databases.

Eligibility criteria

We will screen titles and abstracts using population and exposure elements because outcome elements may not be reported in a title or abstract. For example, titles and abstracts of postgraduate theses include the species of carnivorous plants and arthropods studied but data related to herbivore interactions are found within theses themselves. We will screen full-texts using outcome elements and study language. Eligible populations must belong to one of ten carnivorous clades reported by Fleishmann et al. (2018). All other plant species will be excluded. Eligible exposure includes any organism belonging to the Phylum Arthropod, and all other animals will be excluded. Eligible outcomes include any damage attributed to an arthropod feeding on a carnivorous species, and any plant part can be included. We will exclude studies that cannot attribute damage to an arthropod consuming plant material. Eligible studies must be written in English because we cannot translate non-English literature. This will introduce language bias into our map, which will likely reduce the number of historical accounts identified as eligible for mapping. We will not use study structure as a selection criterion as observed because we anticipate eligible studies will range from natural history surveys to laboratory experiments.

Consistency checking

To assess agreement between screeners, we will complete a Kappa analysis after screening 20% of titles and abstracts obtained from bibliographic databases (James et al. 2016). If the Kappa score is greater than 0.6, we will screen the remaining titles and abstracts. If the Kappa score is under 0.6, we will discuss a subset of conflict literature to re-evaluate how each screener interprets selection criteria, and we will complete a second Kappa analysis on 25% of the remaining titles and abstracts. We anticipate a second Kappa analysis would yield a score greater than 0.6 and we can continue screening titles and abstracts. We will replicate this check prior to screening full-text studies obtained from bibliographic databases.

Reporting screening outcomes

We will report the list of eligible and ineligible studies in our map database. For ineligible studies, we will include which stage they were excluded and why they were excluded. If literature was included after screening for titles and abstracts but we could not obtain its full-text, we will exclude it from full-text screening, but we will record its bibliometric details in a separate list as a part of our map output (James et al. 2016). We will summarize the number of studies included and excluded after each screening stage following ROSES standards (Haddaway et al. 2018).

Study validity assessment
We will not conduct a critical appraisal of study validity.

Consistency checking
N/A

Data coding strategy
To code, synthesize, and interpret our systematic map, we will interrogate our database using thematic analysis, a qualitative method to identify patterns across studies. Data coding in qualitative analysis differs from quantitative analysis because not all data codes are known in advance because some codes are generated during analysis. This requires flexibility, and consequently, our coding sheet will not be completely pre-determined as custom for traditional systematic mapping. Initially, we will extract plant species, arthropod associates, and plant parts damaged by arthropods, but we do not know all codes until we complete our analysis. This allows us to explore different coding schemes that might later form themes. For example, after becoming familiar with studies through reading, we may notice seasonality of herbivore attack, and subsequently, we can add fields to our coding sheet related to host phenology and herbivore offense. Codes are validated if they can be coalesced into themes during later stages of analysis. Two of the map authors (BC and LH) will use MAXQDA, a qualitative research software program to code and extract data. We will report all extracted data and codes in a database submitted with our map report, and this database will identify which codes were validated as themes.

Meta-data to be coded
We will extract bibliometric data such as title, author, publication type, and year, and we will extract ancillary data, specifically study design, duration, and geographic location. Ancillary data also includes frequency of arthropod sampling and methods used to collect arthropods. Finally, we will extract data relevant to bog conservation, such as if study locations are protected areas or study plants are imperiled species. Each of these data types–bibliometric, ancillary, and conservation–will be entered into separate data tables and later summarized in our map report in relation to themes generated from thematic analysis of eligible studies.

Consistency checking
Before coding studies using our initial coding sheet, we will check intercoder reliability to ensure agreement in code assignments. We will randomly select 10% of the studies from the database, and we will assign codes to data within these studies in MAXQDA independent of the other coder. After coding this subset, we will calculate a Kappa statistic for each code (O'Conner and Joffe 2020). If 75% of codes have a Kappa statistic above 0.6, we will discuss conflict codes and continue coding the remainder of the map database. Conversely, if we do not meet this target, we will randomly select the same number of studies and repeat this protocol to ensure intercoder reliability. Because thematic analysis involves multiple rounds of coding, we will complete this intercoder check after each round. We will report Kappa statistic values for all codes used. We will also check consistency for extracting meta-data concerning bibliometric, ancillary, and conservation data. We will randomly select 10% of eligible studies, and we (BC and LH) will extract meta-data for each type of data table. Afterward, we will compare entries to identify and discuss discrepancies.

Type of mapping

Thematic analysis treats coded data differently than traditional systematic mapping. Rather than tabulating codes and producing graphs, we will compare coded data produced by each author. We will identify codes that share similarities and collapse them as a theme that describes a meaningful pattern related to how herbivores exploit carnivorous plants. Once we have our initial set of themes, we will compare how well these themes describe all the coded data and how well these themes describe the entire map database. We will report definitions of our themes in the discussion section of our report, and we will produce a thematic map to summarize how our themes relate to our original map question.

Narrative synthesis methods

Unlike quantitative methods, thematic analysis does not analyze data and then report, but rather they occur simultaneously (Braun and Clarke 2012). In our discussion, we will use relevant data extracts to illustrate our themes and explain any hypotheses about herbivore offense generated from our themes.

Knowledge gap identification strategy

We will provide bar charts of plant genera and arthropods to highlight knowledge clusters or define knowledge gaps that underpin herbivory patterns drawn from thematic analysis. Frequency data, such as that presented in graphs, are not customary in qualitative analysis because magnitudes of codes or themes do not relate to their strength. For example, it cannot be inferred from a bar chart displaying carnivorous hosts which genus has the highest number of arthropod herbivores. However, this bar chart can be used to infer which hosts have provided the majority of information concerning herbivores, thereby defining taxonomic biases inherent to patterns generated. These biases represent knowledge clusters concerning certain plants or insects, and conversely, absence of other plants or insects represent knowledge gaps that warrant further primary research. We will also use meta-data to identify knowledge clusters and gaps. We will use bar charts and descriptive statistics to characterize bibliometric, ancillary, and conservation meta-data that inform biases and gaps in how studies were conducted.

Demonstrating procedural independence

The authors do not have previous publications relevant to this research.

Competing interests

The authors declare no competing interests.

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Author’s contributions

BC, LH, and JH conceptualized map question and protocol. BB completed pilot searches and LH contributed to the production of search terms. BC wrote the first draft of this protocol with input from all authors, and all authors contributed to revisions.

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