Hydrological fluctuations determine predator-prey interactions in a semi-arid non-perennial river

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Statements and Declarations

All data are available in the manuscript and supplemental files. The R scripts and interactions used in this study are available in the repository at: https://anonymous.4open.science/r/IntermittentDynamicsNetworks_2024-0E5E/

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ABSTRACT

We investigated predator-prey interactions in the River Tabocas, a non-perennial river (NPR) in Brazil’s semi-arid region, analysing variations between flowing and dry hydrological phases. We analysed predator-prey interactions using fish food items along 1 km of the NPR during flowing (23 sections) and dry (22 isolated pools) phases, identifying 18 predator species and 11 ecological categories of prey. Our results indicate that predators (fish) composition, abundance and environmental variables shift between flowing and dry phases. Despite similar richness, significant differences in fish species composition underscore the importance of temporal fluctuations in predator community dynamics. During the flowing, predator-prey interaction network exhibited a nested pattern. In contrast, the dry phase we observed diverse patterns of predator-prey interaction networks in isolated pools, including nested, modular, specialised, and random structures. Stochastic factors during the dry phase contribute more to the structure of predator-prey network interactions. Predator-prey interactions networks with random structure correspond to isolated pools with fewer predator-prey links and high specialisation rates. Our findings show the importance of identifying priority aquatic refuges to sustain freshwater biodiversity in NPRs. Conservation strategies must account for hydrological variability and stochastic factors to mitigate climate change impacts on the biota of tropical semi-arid NPR.

Keywords: climate changes; drying rivers networks; intermittent streams; fish.

INTRODUCTION

Predator-prey relationships are among the most widespread forms of interspecific interactions, occurring across terrestrial and aquatic ecosystems. These interactions play a fundamental role in shaping community ecological dynamics, influencing species persistence, community composition, and ecosystem functioning (Begon & Townsend, 2021). The dynamics of predator-prey interactions are inherently linked to temporal and spatial changes in species composition and interaction strengths, driven by environmental variability and other factors (Guimarães Jr., 2020). Early research highlighted predation's role in population dynamics and ecosystem regulation, while recent studies emphasise its importance in structuring communities, driving competition, rewiring interactions, and interacting with spatial processes, particularly in fragmented habitats (Thompson, 1960; Poisot et al., 2012; Guimarães Jr., 2020; Suzuki et al., 2023). Additionally, there is growing interest in understanding how environmental changes, such as habitat loss, alter predator-prey dynamics (Tylianakis et al., 2008). However, the consequences of these changes for predator-prey interactions remain poorly understood.

In aquatic systems, predator-prey interactions are shaped by a wide range of environmental conditions that influence community assembly (Wasserman et al., 2016). Factors such as temperature (Wasserman et al., 2016) and habitat complexity can drive shifts in these dynamics as environmental conditions change (Brose et al., 2012). For example, reductions in water volume can concentrate organisms, leading to higher prey densities and changes in predator and prey behaviours, collectively impacting trophic interactions (McHugh et al., 2015; Costa et al., 2022). Non-perennial rivers and streams (hereafter, NPR) provide an ideal context to study trophic interactions, as they exhibit natural cycles of alternating flowing and dry phases that lead to significant shifts in environmental conditions (Datry et al., 2017; Allen et al., 2020).

The hydrological regimes of NPR are influenced by climate, topography, soil composition, vegetation cover, and surface-groundwater interactions (Messager et al., 2021; Price et al., 2021). During flowing phases or after heavy rainfall events, water flows across the channel, connecting pools and depressions along the riverbed that were previously dry (Datry et al., 2017). This phase facilitates the downstream transport of suspended sediments and organic matter, altering the dynamics of the stream ecosystem (Corti & Datry, 2012). The connection of water leads to the homogenization of physical and chemical variables (Gómez et al., 2017), and increases trophic and spatial resource availability, thus generating food webs with larger food chain length (McHugh et al., 2015). Consequently, aquatic organisms, such as fish, benefit from structured habitats and increased resource availability, leading to various foraging opportunities for predators and more complex trophic interactions (Fallon et al., 2022). During dry phases, habitats contract as well as resource availability shift (McHugh et al., 2015; Bonada et al., 2020), leading to changes in trophic interactions (Closs & Lake, 1994). Habitat contraction results in the formation of isolated pools, associated with drastic changes in biotic communities towards lentic-type communities (Bonada et al., 2020; Oliveira et al., 2024). These pools become heterogeneous in structure, with reduced resource availability and fewer prey to forage upon, potentially limiting trophic interactions (Fallon et al., 2022). Such environmental changes often disrupt predator-prey interactions, altering the structure within aquatic communities.

Despite extensive knowledge of community structure in NPR (Davey & Kelly, 2007; Pusey et al., 2018; Rogosch & Olden, 2019; Hedden & Gido, 2020, Crabot et al., 2021), our understanding of predator-prey interactions in NPR remains limited. Most food webs studies in NPR focus on food chain length and trophic niche using isotopes analysis (*e.g.* McHugh et al., 2015; Sabo et al., 2010; Medeiros & Arthington, 2011; Beesley et al., 2020). Only a few studies describe food webs by analysing predator gut content to determine predation (Closs & Lake, 1994; Williams et al., 2003), which allows for the investigation of the structure of predator-prey interactions. The loss of predators in NPR during the dry phase reduces the dimensions of food webs, drastically decreasing *S* nodes in the food web (Closs & Lake, 1994). This process is driven by habitat size reduction and the deterioration of habitat conditions, leading to a disassembly of the food web (McIntosh et al., 2017). However, while some trophic dimensions of food webs, such as reduction in food chain length, respond to dry events (McHugh et al. 2015), others structural properties can be maintained even under extreme conditions (McIntosh et al., 2017). Furthermore, in Brazilian semi-arid, the dry phase can be very long, up to nine months per year, and the low thermal amplitude, with temperatures >25°C, sets this region apart from other arid and semi-arid areas in the tropics (Barbosa et al., 2012).

In this context, several questions remain unanswered regarding predator-prey interactions within food webs of NPR. To address this, we investigated predator-prey interactions in the River Tabocas, a non-perennial river located in the Brazilian semiarid region, exploring how these interactions vary between flowing and dry hydrological phases. We predicted that predator-prey interactions in the flowing phase would exhibit higher levels of nestedness and specialisation, driven by increased water, resource, habitat, richness and abundance of predators (fish). Conversely, during the dry phase, we predicted predator-prey interactions would exhibit greater modularity due to formation of isolated pools which reduce water, resource, habitat, richness and abundance of predators (fish). We discuss the results in the context of improving management strategies to conserving NPRs in semi-arid regions and mitigate the impact of climate change on biodiversity.

MATERIAL AND METHODS

Study area

The Tabocas' NPR (3°26'18.0" S 39°43'52.0" W) is a stream, tributary of the Cruxati River (Fig. 1a), which, in turn, is a tributary of the Mundaú River in the Brazilian semi-arid region. The Mundaú is one of the main rivers of the Litoral Basin, which flows into the Atlantic Ocean. All rivers and streams of the Litoral Basin are intermittent. The region has a predominantly hot tropical semi-arid climate (Aw, according to the Köppen climate classification; IPECE, 2007), with an annual precipitation of 954 mm and average temperatures ranging between 24.2ºC and 35.3ºC. The Tabocas' NPR is a naturally intermittent drainage that flows for four months a year (from March to June - flowing phase). When the flow ceases, the stream splits into isolated pools of different sizes distributed along the dry headwater (Fig. 1a; Supplementary information – Fig. S1). These pools remain filled with water throughout the year and reconnect during subsequent rainy seasons after rainy events.

Predator-prey sampling

We conducted two fish and environmental data sampling, one sampling occasion in each phase (August 2021 and June 2022) in a stretch of approximately 1 km of Tabocas' NPR. The sampling included physical and chemical analysis, substratum assessment, and site structure evaluation. Our study encompassed both the flowing and dry phase, characterised by 23 sections, and 22 isolated pools respectively (Fig. 1b).

During the flowing phase, we delimited 23 sections every 50 metres along the stream, where fish were sampled three times (sub-samples) using seine nets (3.5 × 2.5 metres, mesh size 5 mm). In the dry phase, we conducted the same sampling effort in each of the 22 pools found along the same 1 km stretch, excluding pools without fish. Additionally, during this phase, we measured the length, average width, average depth, and distance among pools.

In each section or pool, we conducted three measurements of the following physical and chemical parameters: temperature, dissolved oxygen, pH, and salinity using the YSI 7000 multiparameter probe (Table S3). Subsequently, we calculated the average value for each physical and chemical parameter. Additionally, we obtained data on substrate composition percentage (including bedrock, large boulder, small boulder, gravel, fine gravel, sand, and mud) and site structure (macrophyte, tree branch, dead wood, root, shading, and marginal vegetation) (Gonçalves-Silva et al., 2022). To avoid observation bias, the same researcher visually determined the percentage of area occupied by these variables of substrate composition and site structure. Moreover, we measured the distance between pools and estimated water volume using average depth, average width, and length of each pool or section (Table S4; Fig. S1).

We randomly selected up to 30 adult individuals of each species from each section and isolated pool for the analysis of fish stomachs to collect the food items. The fish were dissected to remove the digestive tract, and the contents were examined using a stereoscopic microscope. Food items were identified to the lowest possible taxonomic level (Domínguez & Fernández, 2009; Mugnai et al., 2010; Hamada et al., 2014 - see details Table S1) according to the degree of digestion and quantified using the volumetric method (Hyslop, 1980). We calculated the frequency of occurrence (FO%) and relative volume (VO%) of food item categories separately for each individual and phase.

Data analysis

Composition, abundance and richness of predator (fish)

To compare environmental variables between the flowing and dry phases, we conducted Principal Component Analysis (PCA) using the '*PCAshiny*' function. Additionally, to assess differences in fish species composition in flowing and dry phases, we employed non-metric multidimensional scaling (NMDS) (Kruskal, 1964) with the '*metaMDS*' function, based on Bray-Curtis distance matrices. The significance of the influence of the dry and flowing phases on environmental variables and fish abundance was assessed through Permutational Multivariate Analysis of Variance (PERMANOVA) using the '*adonis2*' function, based on Bray-Curtis dissimilarities with 1000 permutations. The sampling sufficiency for flowing and dry phases was assessed through rarefaction analysis using the '*iNEXT*' package in R (Hsieh & Chao, 2024), with 95% confidence intervals. This method allows for the standardisation of sample size and ensures comparability across phases by adjusting for abundance variations (Chao et al., 2014).

To compare the assemblage of predators among the pools, we calculated total and partitioned beta diversity (β) using the '*beta.multi*' function (Baselga 2010; 2012; 2013; 2017; Baselga & Orme, 2012). The total beta diversity is calculated by using the Sorensen dissimilarity measure (β SOR), whereas the Simpson dissimilarity measure (β TUR) calculates the turnover component; nestedness (β NES) is calculated by subtracting total beta diversity and turnover. We used a resampling procedure, computing 1000 random samples, and calculated the average, standard deviation and P-values (Baselga, 2017). Additionally, to assess differences among the environmental conditions in the 22 pools during the dry phase, we integrated them into the analysis using the Partial Mantel test with the '*mantel*' function (Legendre & Legendre, 2012). Subsequently, to examine the relationship between environmental variables and predator richness and abundance we conducted the Pearson correlation analysis (Benesty et al., 2009).

To determine the relationship between the number of interactions (number links >0) and predator richness, abundance, or the extension of the pools (distance to the nearest pool), we used generalised linear models (GLM) with a Poisson distribution (Zuur et al., 2009). The number of interactions was the response variable, and predator richness, abundance, and the extension (metres) were the explanatory variables. We ensured that the underlying model assumptions were met by examining collinearity of fixed effects, random effects distribution, homoscedasticity, independence, and normality of residuals (Zuur et al., 2009). Before analyses, we did not find collinearity using a variance inflation factor test (VIF < 3). We chose the best model using the Akaike Information Criterion (AIC). All analyses were performed in R 4.2.2 (R Core Team, 2023) using the "*vegan*" (Oksanen et al., 2019), "*FactoShiny*" (Vaissie et al., 2020), "*betapart*" (Baselga & Orme, 2012), "*DHARMa*" (Hartig & Hartig, 2017),"*performance*" (Lüdecke et al., 2020), and "*stats*" (R Core Team, 2023) packages. Data and analysis code can be found at https://anonymous.4open.science/r/IntermittentDynamicsNetworks_2024-0E5E/.

Structure of predator-prey interactions during flowing and dry phases

To understand changes in predator-prey interactions within an Tabocas' NPR, we described the resource (prey) used by fish using the relative volume of the food items consumed by the fish of an interaction matrix to represent a bipartite network. This network comprised two sets of nodes: one representing fish species and the other representing food resource types (food items). The links within the network described interactions among fish species and food resource types. A total of 41 food resources identified were categorised into nine ecological groups (Table S1) based on the functional food group approach (Cummins et al., 2005).

We used the metrics nestedness, modularity, and specialisation to describe the structure of the predator-prey interaction networks. Nestedness refers to a pattern where specialist fish species (those that feed on only a few types of prey) tend to feed on prey that are also consumed by generalist fish species (those that feed on many types of prey). In other words, this creates an overlapping, hierarchical interaction structure in the food web, where the interactions of specialists are often nested within the interactions of generalists. To describe the nestedness we used the *'nested'* function with the NODF2 method in the bipartite R package (Almeida-Neto et al., 2008). Higher values of nestedness indicate that the food items consumed by specialist species are included in the diet of generalist species (Almeida-Neto et al., 2008). Modularity refers to the division of the network into distinct modules or subgroups, where species within the same module interact more frequently with each other than with species in other modules. This creates a structure where certain groups of predators (fish) and prey form tightly connected clusters with relatively fewer interactions between species from different clusters. To quantify the modularity, we used the *'cluster_louvain'* and *'modularity'* functions (Blondel et al., 2008). Higher modularity values indicate stronger separation into groups, suggesting that the nodes within each group are more densely connected to each other than to nodes in other groups (Blondel et al., 2008). Specialisation refers to the adaptations that enable certain fish species to become highly efficient at exploiting specific types of prey. This can involve morphological, behavioural, and ecological adaptations that allow these fish to thrive in particular niches within their aquatic environments. To describe the specialisation, we used the *'h2'* function (Blüthgen et al., 2006). We also employed the *'null.model'* function with the *'vaznull'* method to generate randomised predator-prey networks for flowing and dry phases. We utilised the *vaznull* method to randomise interactions keeping the connectance (proportion of interactions performed among all possible interactions between species in the network) of the observed network (Vázquez et al., 2007), we refer to it as a *null model*. For flowing and dry phases of the Tabocas' NPR (Fig. 1b) we simulated 999 networks and then compared the observed and simulated network structures using the Z-score (see details below). We also created a theoretical model to simulate network interactions for the dry phase, using as a basis for creating the simulated networks the actual richness of predators that occurred during the flow period. We refer to it as a *theoretical model based on observed predator richness*. Our theoretical model was adapted from D'Bastiani et al. (2020) and randomly samples the same number of predator species observed in each pool of the dry phase (Table S2). In this model the number of predator species remains constant, while the number of prey can vary among simulated networks. Creating the simulated networks using the observed richness of predators ensures the persistence of the actual interactions observed during the flowing phase. During the dry phase, for each pool observed (Table S2), we simulated 999 networks and then compared the observed and simulated network structures using the Z-score.

To compare network structures during both the flowing and dry phases, as well as among pools (only during the dry phase), we used the Z-score method, as described below: $Z = [x - \mu]/\sigma$ - where, x represents the measure observed in the network, μ denotes the mean, and σ represents the standard deviation of the measure obtained from 999 random networks generated by the null and theoretical models. We compared the observed and simulated network structures using the Z-score to assess the significance or deviation of the observed network from what would be expected under a null hypothesis. In our case, the simulated networks are generated first from a *null model* with the 'vaznull' method and then from a *theoretical model based on observed predator richness* separately. This method allows for comparison of network structure patterns observed versus simulated to control for the effects of network size at different sites, in our case the site is phase or pool (Almeida-Neto et al. 2008; Vanbergen et al., 2017). The Z-score method serves as a baseline for comparison to assess whether the observed patterns in the real network are significant according to the predator richness or if it is merely due to random factors. All analyses were performed in R 4.2.2 (R Core Team, 2023) using the "*bipartite*" (Dormann et al., 2009) and "*igraph*" (Csardi & Nepusz, 2006).

RESULTS

Composition, abundance and richness of predator (fish)

We collected a total of 3,917 specimens across 18 species of predator fish, with 16 species found in each phase (flowing or dry). The sampling effort was considered sufficient based on the resulting rarefaction curves (Fig. S2). *Hemigrammus* sp. and *Crenicichla menezesi* were exclusively found during the flowing phase, while *Trachelyopterus galeatus* and *Prochilodus brevis* were exclusively found during the dry phase (Table 1). However, during the flowing phase the most abundant species was *Phenacogaster calverti* (28.9%), and during the dry phase *Astyanax bimaculatus* exhibited the highest abundance (27.5%).

We observed significant differences in environmental variables between the flowing and dry phases ($F = 83.26$; $p < 0.001$). The first two axes of principal components (PC) in the PCA explained 49.58% of the total variation in environmental variables across the two phases (Table S3; Fig. 2). Substrate diversity, vegetation density, and shading predominated in flowing conditions (see Fig. 2b). In contrast, physical and chemical variables exhibited greater variation in isolated pools during dry conditions (Table S4).

Although predator richness did not vary between flowing and dry phases, we found a significant difference in predator composition ($F = 5.72$; $p < 0.001$) (Fig. 3). The dry phase occupied a large space on the multidimensional scale

(Fig. 3). Isolated pools in the dry phase exhibited significant dissimilarity in predators composition (fish species) (Sorensen 81%: Turnover 67% and Nestedness 14%; Fig. S3). Additionally, we observed a positive correlation of 45% between fish composition and the distance separating pools, which was influenced by physical and chemical variables (Partial Mantel = 0.45; p = 0.008).

The extent of the pools was positively correlated with the richness of predators (cor: 0.58, p = <0.05), high vegetation density (cor: 0.63, p = <0.05), and shading (cor: 0.51, p = <0.05) (Fig. S4a). Additionally, isolated pools characterised by dense vegetation exhibited a negative correlation with the physical and chemical variables such as temperature (cor: -0.43, p = <0.05), salinity (cor: -0.47, p = <0.05) and pH (cor: -0.66, p = <0.05).

Structure of predator-prey interactions during flowing and dry phases

During flowing phase, the structure of predator-prey interactions exhibited a nested pattern (when compared to the null l model with the *vaznull* method), characterised by predator subsets with fewer interactions included in areas where predator species have greater number of interactions (Fig. 4). Among these species, *A. bimaculatus* displayed the highest generalisation, consuming all categories of available food items, whereas *P. vivipara* exclusively fed on organic detritus (Fig. 4). Notably, organic detritus emerged as a food resource occurring in all predators, followed by invertebrate collectors, consumed by 93.8% of the predators, and plant material, which was consumed by 87.5% of the species (Fig. 4). The frequency of occurrence of food item categories observed during the flowing was slightly similar to that in the dry phase (Fig. S5). We observed that organic detritus and collector invertebrate resources were the main food resources in flowing and dry phases (Fig. S5), across all sections and isolated pools, followed by filtering invertebrates and plant material.

During the dry phase, the interaction network in each isolated pool (22 networks) when compared with the null model, exhibited the different patterns and structures. Among these, 19 displayed a pattern with high specialisation (P1-P8, P10, P12-P20, and P22), 12 exhibited random structure (P1-P3, P5-P11, P13, and P15), seven showed nested patterns (P14, P16-P17, and P19-22), two (P12 and P18) demonstrated modular patterns, and one displayed both nested and modular structures (P4) (Fig. 5 and 6; Table S2). We didn’t include the Z-score of specialisation in Fig. 5 because the standardised deviation is so low, resulting in high values (Table S2). We observed a nested pattern in isolated pools located towards the final portion of the 1 km stretch, where at least 78% of the analyzed food item categories were consumed. The frequency of occurrence of items in networks with this nested pattern was higher compared to random networks (Fig. S6). Furthermore, we found a positive correlation between the number of interactions and the predator richness (cor: 0.831, p = <0.0001; GLM: β1=0.153, SE = 0.015, df = 21, z = 10.10, p = <0.0001; Fig. S4.1), as well as with nestedness (cor: 0.51, p = <0.05), while there was a negative correlation with specialisation (cor: -0.51, p = <0.05) and modularity (cor: -0.64, p = <0.05) (Fig. S4b). In the modular networks (P12 and P18), only three predators (P12: *H.*

malabaricus, *O. niloticus* and *A. bimaculatus*; P18: *P. vivipara*, *A. bimaculatus* and *O. niloticus*) exhibit predominantly distinct prey consumption patterns (Fig. 6). Each species forms a separate module, contributing to a high level of general specialisation within the network (h2' = 0.95 and 0.88, respectively). In the nested and modular network (P04), we also observed a high level of specialisation (h2'= 0.92) due to the formation of connection modules similar to those observed in the flowing condition (e.g., *H. malabaricus* mainly consuming fish and *S. notonota* predominantly ingesting organic detritus). The nested pattern was evident in this network as well, with *A. bimaculatus* engaging in all possible connections, while the other predators (*S. piaba* and *C. orientale*) consumed only two specific items.

During the dry phase, large part of the interactions networks in isolated pools (P1, P3, P11, P12, P13, P15, P20, and P22), exhibited a random structure when compared with the theoretical model based on predator richness (Fig. S8-S10) (Fig. 7). These networks corresponded to the isolated pools characterised by the lowest number of predator-prey links and a more equitable frequency of occurrence of food items, up to 54% (Fig. S6), indicating an absence of dominance by any specific item. In contrast, other isolated pools (P2, P4, P5, P6, P7, P8, P9, P10, P14, P18 and P19) exhibiting high values for modularity (above 1.65 Z-score range; Fig. 7), indicating a higher number of specialist predators consuming up to two prey, thus forming distinct modules. Additionally, isolated pools with higher values of general specialisation (h2') for each pool suggested a tendency for the corresponding network to exhibit a random structure (Fig. S7).

DISCUSSION

We corroborated the prediction that predator-prey interactions during the flowing phase would exhibit nested patterns driven by the increased water volume in the river, resources, habitat availability, and predator abundance. However, specialisation was more pronounced during the dry phase due to the reduced availability of resources and, consequently, the lower number of predator-prey links within each isolated pool. Furthermore, the predator-prey interaction networks were predominantly random and stochastic due to the unpredictable formation of isolated pools, which differed from our expectation of a modular pattern for the dry phase. The flowing and dry phases in Tabocas' NPR modify predators composition and environmental conditions, which shape predator-prey interactions. Our findings reveal that the dynamics between prey and predator communities adaptively can respond to these natural habitat fluctuations. During the flowing phase, network structure exhibits a nested pattern, suggesting a hierarchical organisation, which species with broader niches coexist alongside more specialised species. However, in the dry phase, as the habitat fragments into isolated pools, structure of predator-prey interaction becomes more variable. Many isolated pools exhibit a high degree of specialisation in species interactions, with some showing a random structure. Others maintain a nested or modular pattern to a lesser extent, reflecting a diversity of community organisations shaped by the constraints and opportunities presented by habitat isolation. This phase-specific variation underscores the importance of hydrological cycles in driving ecological interactions within NPR ecosystems.

Flowing and dry phases have major differences between environmental variables, showing two contrast habitats for fish assemblages which change from a lotic (river) to a lentic environment (isolated pools) where microhabitats are completely modified. In the flowing phase substrate diversity, vegetation density (macrophytes and marginal vegetation), and shading predominate, increasing the availability of microhabitat for the fish community. In contrast, in isolated pools (dry phase), drying increases habitat heterogeneity, and variable environmental conditions become limiting for the survival of species (Rodrigues-Filho et al., 2020; Gonçalves-Silva et al., 2022). Environmental variations among isolated pools are also linked to recent local events (such as time elapsed since the last rain, duration and quantity of rainfall, and time since flow ceased) as well as pool morphology (Queiroz & Terra, 2020). Regarding predators, flowing and dry phases exhibited differences in abundance and composition, particularly during the dry phase, where isolated pools showed high dissimilarity, whereas more distant pools were more dissimilar than those closer together. Each pool's community comprises a unique combination of species (Rodrigues-Filho et al., 2020; Ramos et al., 2022). This dissimilarity is also supported by dispersal limitations associated with several factors, such as the spatial arrangement of isolated pools (Queiroz & Terra, 2020); and changes in water quality (Pusey et al., 2018); and landscape characteristics and resident biota (Marshall et al., 2016). In this sense, the heterogeneity observed among isolated pools indicates that each individual pool functions as a distinct aquatic ecosystem inside the riverbed (*e.g.* Larned et al., 2010; Bonada et al., 2020; Banegas-Medina et al., 2021). This underscores the need for the conservation of isolated pools, as the dry phase has been largely disregarded (Bonada et al., 2020).

Structure of predator-prey interactions reflects how predator and prey communities organize in response to fluctuating environmental conditions and habitat alterations in Tabocas' NPR. During the flowing phase, we observed a nested pattern in the predator-prey interactions, which represent a hierarchical structure to the connectivity rules of the networked system, resulting in variations in the number of interactions among its components. The consumption of organic detritus, collector invertebrates, and plant material determined the variation in connectivity on the flowing phase. Usually, aquatic invertebrates are the most consumed prey by neotropical fish species (*e.g.,* Rezende et al., 2013; Manna et al., 2019), while organic detritus is not a common trophic resource for neotropical fish species (*e.g.* Dary et al., 2017; Reis et al., 2020; Neves et al., 2021). However, organic detritus was consumed by all species in high proportions probably due to accumulation of organic detritus in Tabocas. Non-perennial rivers have high concentration of organic detritus (von Schiller et al., 2017; Bonada et al., 2020), which are a primary source of dissolved organic matter (DOM) mainly in the isolated pools (Casas-Ruiz et al., 2016), and it can be a crucial basal resource in food webs (Closs & Lake, 1994; Fallon et al., 2022). Organic detritus can lead to higher species diversity and a greater number of weak interactions in food webs, contributing to overall stability (Rooney & McCann, 2012). In this sense, the nested topology can minimize competition loads by varying interactions and maximize species' fitness (Mariani et al., 2019).

The food resources consumed by predators were similar between the flowing and dry phases, except for the increase in the occurrence of filter feeders (zooplankton: cladocera and copepoda) on predators' diet during the dry phase. The higher ingestion of filter feeders (zooplankton) on dry phase is related to the higher abundance of zooplankton on isolated pools due to their lentic conditions. The contraction of Tabocas' NPR into isolated pools resulted in two distinct interaction patterns: nested or modular, as well as random (no specific pattern), which were influenced by the higher specialisation of predators. Nested interactions (nested networks) were described for seven pools that were located closely, those pools had more links due to higher richness in resource and predator. Interactions among different predator species can lead to a more interconnected network, where the presence of multiple predators allows for a wider range of prey species to be utilised (Pinto-Coelho et al., 2021). Modular interactions (modular networks) occurred in only two pools (P12 and P18), driven by high predator dietary specialisation. One pool displayed both modular and nested interaction patterns, influenced by high specialisation and the presence of *A. bimaculatus* consuming all food items, as also observed in the flowing phase. Fish with flexible foraging strategies under varying seasonal conditions can enhance resilience to hydrological disturbances and contribute to food web stability (McMeans et al., 2019). This underscores the importance of *A. bimaculatus* as a generalist predator, connecting all the components of the predator-prey interaction network.

Most predator-prey interactions from isolated pools were random, reflecting an unstable and disassembled state during the dry phase, driven by the highly dynamic environment of the NPR. Random-pattern networks are characterized by fewer links and higher specialisation, as indicated by the negative correlation between the number of interactions and specialisation (h2'). This suggests that the greater the specialisation, the greater the tendency of the network to be random. Food webs dominated by specialist predators are expected to exhibit less stable and oscillatory dynamics than those dominated by generalists (McCann et al., 1998). In this sense, the presence of various predator-prey interaction patterns in the dry phase reflects randomness in species composition and interactions among isolated pools. The theoretical model based on predator richness also indicated randomness, suggesting that predators do not significantly influence the structuring of predator-prey interactions networks in isolated pools during the dry phase. This pattern likely results from high variation in species composition across isolated pools, emphasizing the role of stochastic processes.

The predominance of stochasticity in structuring most predator-prey interaction networks within isolated pools reveals a significant vulnerability of species during the dry phase. The high specialisation of predators makes them sensitive to resource availability in the face of environmental changes, such as alterations in water availability. Furthermore, environmental stochasticity in predator-prey models can directly affect population stability and persistence (Jana, 2014). Therefore, stochasticity should be considered in predator-prey models to better represent the dynamics of natural ecosystems like non-perennial rivers, where ecological interactions are frequently influenced by unpredictable variations. Isolated pools in the dry phase of NPR have often been overlooked, despite evidence pointing to their conservation importance (Bonada et al., 2020). The findings of our results underscore the critical need to conserve these heterogeneous habitats, where predator-prey networks are structured in a stochastic manner, highlighting their unique role in supporting biodiversity and ecological resilience within NPR systems.

Non-perennial rivers with prolonged dry periods, such as those in the Brazilian semi-arid, face escalating threats from climate change. Communities exposed to fluctuating environmental conditions are more susceptible to climate change impacts than those adapted to stable environments (Walther et al., 2002). Multiple environmental stressors, including water flow and temperature fluctuations, significantly impact predator behaviour, thereby shaping predator-prey interactions in tropical freshwater systems (Gvoždík & Boukal, 2020; Zanghi, 2024). Climate change is expected to further reduce the extent of remaining waterways, intensifying species interactions and resource scarcity, which compromises these habitats' ability to support native fish (Jaeger et al., 2014). Isolated pools provide essential refuges that enable species to persist under harsh conditions (Stubbington et al., 2017; Hill & Milner, 2018; Bonada et al., 2020). Despite weakened policy protections for NPR, these habitats are crucial for local species survival and regional biodiversity (Rogosch & Olden, 2019), underscoring the need to identify priority aquatic refuges to sustain freshwater biodiversity in non-perennial rivers (Yu et al., 2022).

While our findings provide valuable insights into predator-prey interactions in Tabocas' NPR, we acknowledge certain limitations that future studies should address. Long-term studies with more frequent sampling are essential to understand how the timing and duration of stream drying affect prey resources available to fish, which plays a critical role in shaping the structure and function of food webs. Additionally, further studies combining stomach content analysis with stable isotope analysis are needed to obtain a more comprehensive view of predator diets in NPR, especially since stable isotope analysis provides a broader timescale of dietary patterns critical for understanding these dynamic ecosystems. For example, applying an energy flow approach to infer network stability (Saito et al., 2024) is essential for gaining deeper insight into predator-prey interactions within the dynamic non-perennial rivers systems. Together, these approaches not only enhance our ecological understanding but also offer valuable guidance for the conservation and management of these unique and variable habitats.

CONCLUSION

Our study highlights the role of hydrological phase shifts in structuring predator-prey interaction networks within non-perennial rivers, demonstrating how the assembly and disassembly processes of these networks respond dynamically to changing environmental conditions. Our insights underscore the need for conservation strategies that recognize and preserve the natural hydrological variability in these ecosystems. In particular, maintaining the natural flow regimes that foster habitat connectivity during flowing phases, while allowing for the isolation effects of the dry phase, may help sustain diverse community structures and trophic dynamics essential to ecosystem functioning. Our findings suggest that conservation plans for NPR freshwater habitats should prioritise maintaining hydrological integrity to support ecological processes that promote biodiversity. Given that climate change and human activities increasingly alter water availability and flow patterns, our research underscores the vulnerability of these habitats to hydrological disruption. By conserving non-perennial rivers and their unique phase-dependent communities, we can protect the species that depend on these systems.

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TABLES

Table 1. Richness and abundance of fish predator species across flowing and dry phases of the Tabocas' NPR, Ceará, Brazil. In abundance columns the values in parentheses represent the number of specimens that had their stomachs analysed to collect prey information.

Family of predators	Species of predators	Hydrological phases	
		Flowing	Dry
Anostomidae	(Lp) *Leporinus piau* Fowler 1941	10 (10)	2 (2)
Auchenipteridae	(Tg) *Trachelyopterus galeatus* (Linnaeus 1766)	0	1 (1)
Characidae	(Ab) *Astyanax bimaculatus* (Linnaeus 1758)	272 (30)	486 (357)
	(Ch) *Compsura heterura* Eigenmann 1915	120 (30)	60 (60)
	(He) *Hemigrammus* sp.	14 (14)	0
	(Pc) *Phenacogaster calverti* (Fowler 1941)	625 (30)	128 (110)
	(Pf) *Psalidodon fasciatus* (Cuvier 1819)	234 (30)	29 (29)
	(Sh) *Serrapinnus heterodon* (Eigenmann 1915)	467 (30)	182 (160)
	(Sp) *Serrapinnus piaba* (Lütken 1875)	134 (30)	174 (158)
Cichlidae	(Co) *Cichlasoma orientale* Kullander 1983	40 (30)	48 (48)
	(Cm) *Crenicichla menezesi* Ploeg 1991	1 (1)	0
	(On) *Oreochromis niloticus* (Linnaeus 1758)	58 (30)	244 (162)
Crenuchidae	(Cb) *Characidium bimaculatum* Fowler 1941	39 (30)	7 (7)
Curimatidae	(Sn) *Steindachnerina notonota* (Miranda Ribeiro 1937)	86 (30)	251 (144)
Erythrinidae	(Hm) *Hoplias malabaricus* (Bloch 1794)	47 (30)	71 (71)
Loricariidae	(Hy) *Hypostomus* sp.	14 (14)	6 (6)
Poeciliidae	(Pv) *Poecilia vivipara* Bloch and Schneider 1801	2 (2)	57 (57)
Prochilodontidae	(Pb) *Prochilodus brevis* Steindachner 1875	0	8 (8)
Species richness		16	16
Total abundance:		2163	1754

FIGURES CAPTIONS

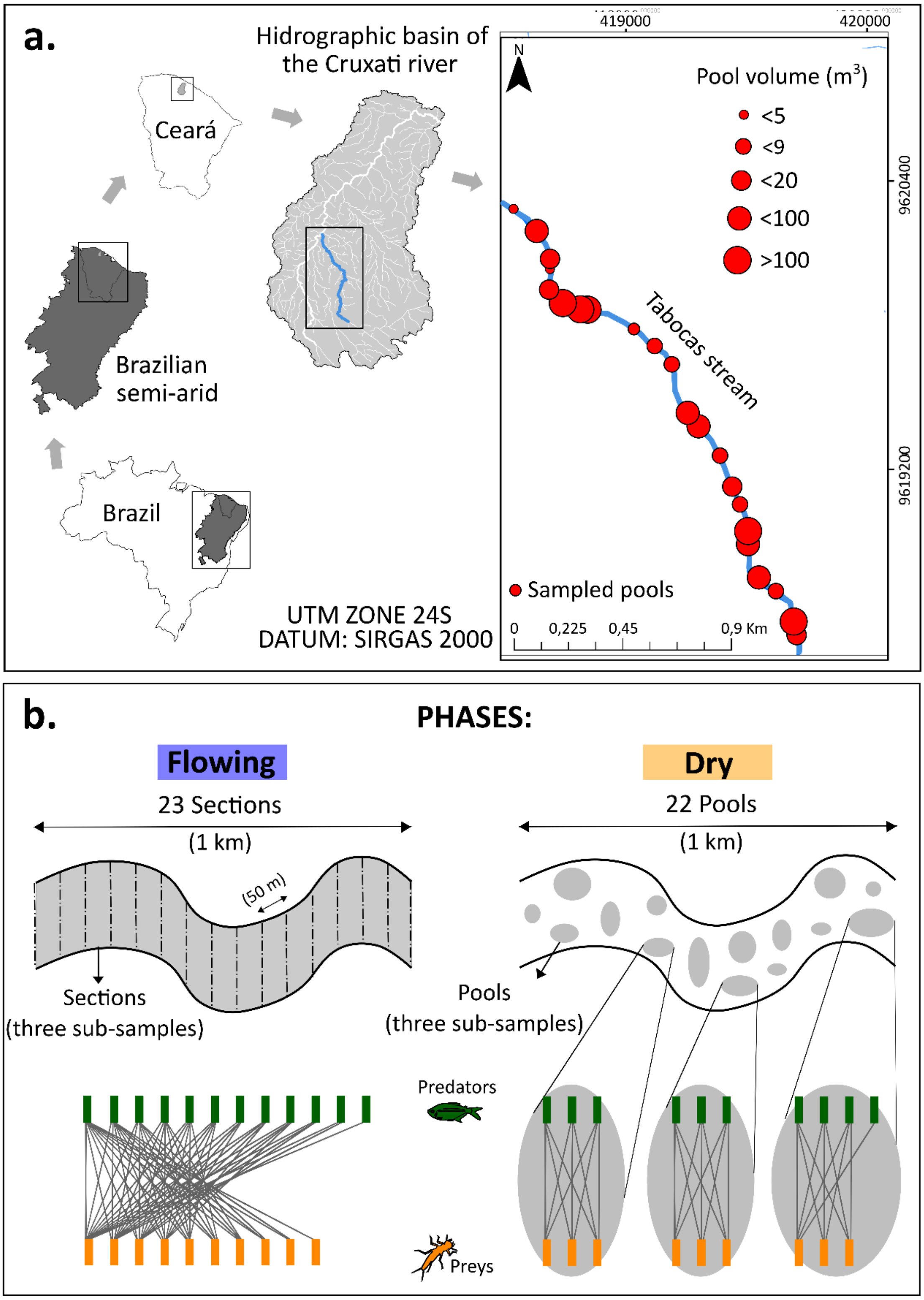

Fig. 1 **a** Schematic representation of the study area highlighting the different sizes of isolated pools. **b** the sampling design for each phase and the hypothetical predator-prey network structure. In fig. b, we illustrated how samplings were conducted over a distance of 1 km during both flowing and dry phases. During the flowing phase, we predicted a food web assembly and during the dry phase we predicted a food web disassembly

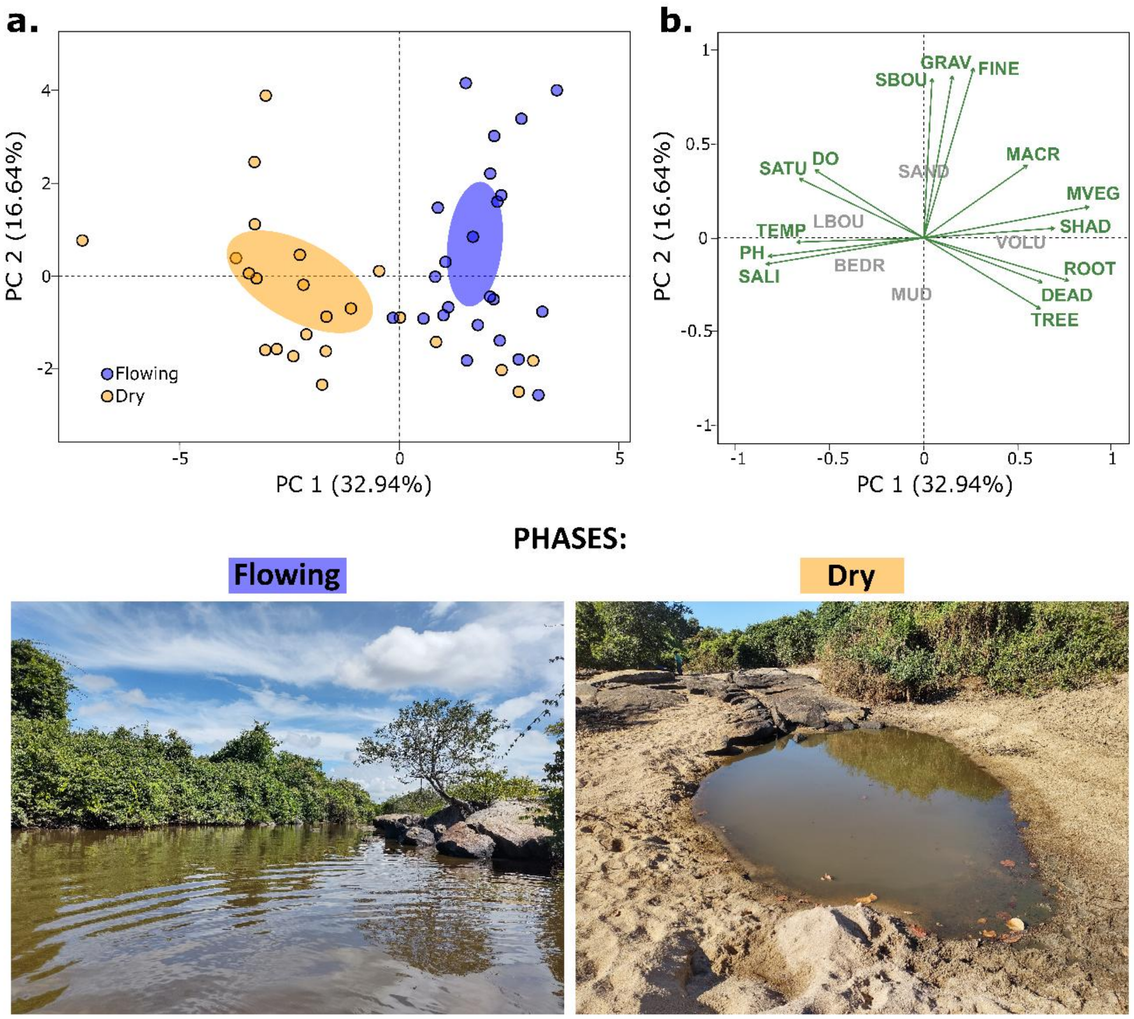

Fig. 2 Principal component analysis of environmental variables during dry and flowing phases of Tabocas' NPR, Ceará, Brazil. **a** Scatter plot of the observed points for the dry phase (isolated pools) and flowing phase (sections). **b** Plot of the environmental variables. The legend abbreviations are as follows: TEMP = Temperature; SATU = Oxygen %; DO = Dissolved oxygen; SALI = Salinity; PH = pH; BEDR = Bedrock; LBOU = Large boulder; SBOU = Small boulder; GRAV = Gravel; FINE = Fine gravel; SAND = Sand; MUD = Mud; VOLU = Water volume; MACR = Macrophyte; TREE = Tree branch; DEAD = Dead wood; ROOT = Root; SHAD = Shading; MVEG = Marginal vegetation.

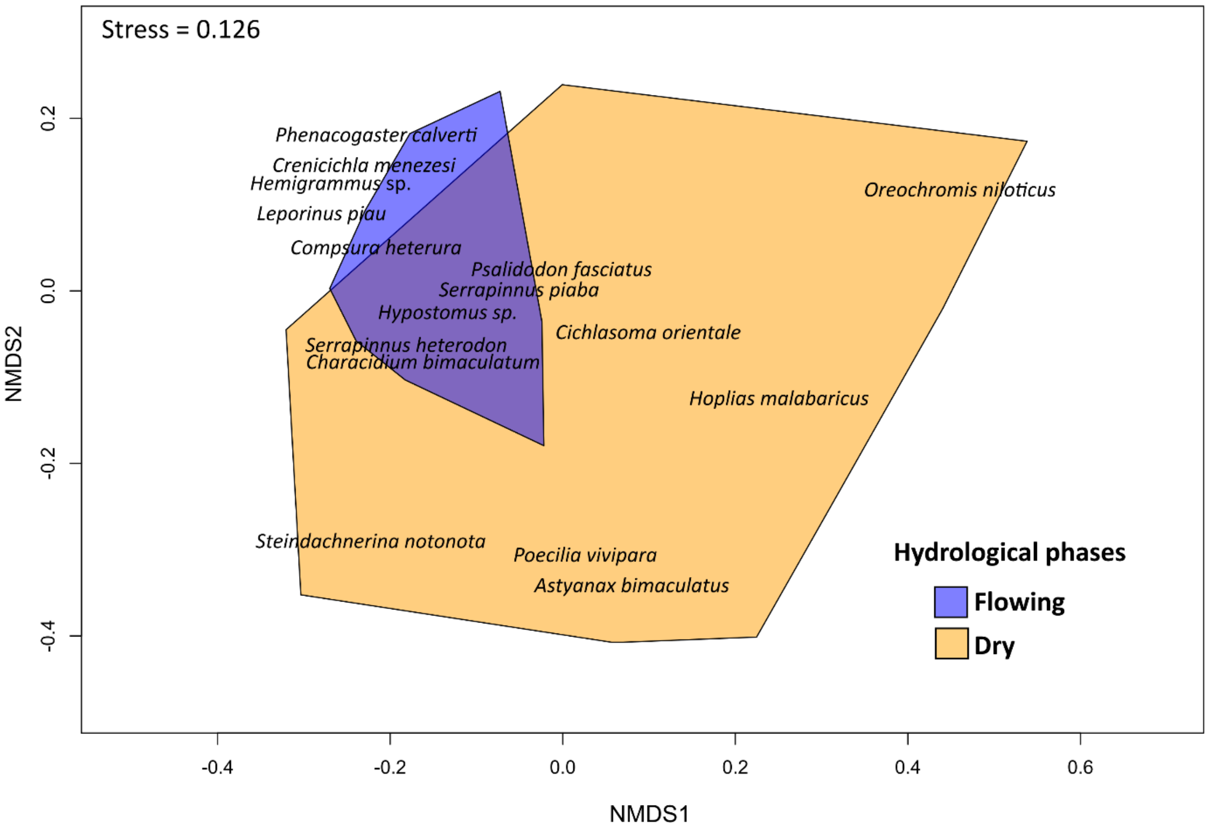

Fig. 3 Non-metric multidimensional scaling (NMDS) plot of predator composition captured during dry and flowing phases of Tabocas' NPR, Ceará, Brazil (Axes 1 and 2)

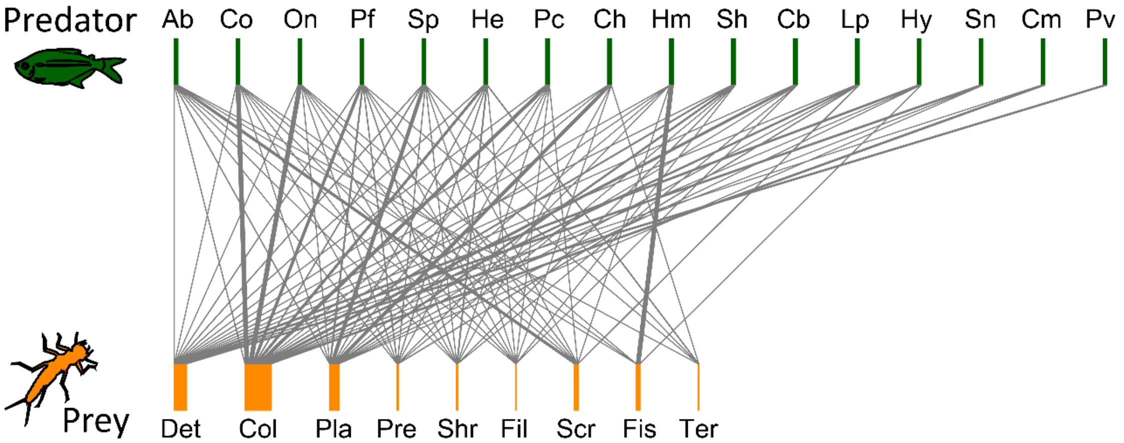

Fig. 4 Bipartite predator-prey interaction network showing a nested pattern during the flowing phase of Tabocas' NPR, Ceará, Brazil. The legend abbreviations are as follows: Prey - Det: organic detritus; Col: collector invertebrate; Pla = plant material; Pre = predators invertebrate; Shr = shredder invertebrate; Fil = filtering invertebrate; Scr = scrapers invertebrate; Fis = fish; Ter = terrestrial invertebrate. Predator - Lp: *Leporinus piau*, Ab: *Astyanax bimaculatus*, Ch: *Compsura heterura*, He: *Hemigrammus* sp., Pc: *Phenacogaster calverti*, Pf: *Psalidodon fasciatus*, Sh: *Serrapinnus heterodon*, Sp: *Serrapinnus piaba*, Co: *Cichlasoma orientale*, On: *Oreochromis niloticus*, Cb: *Characidium bimaculatum*, Sn: *Steindachnerina notonota*, Hm: *Hoplias malabaricus*, Hy: *Hypostomus* sp., Pv: *Poecilia vivipara*

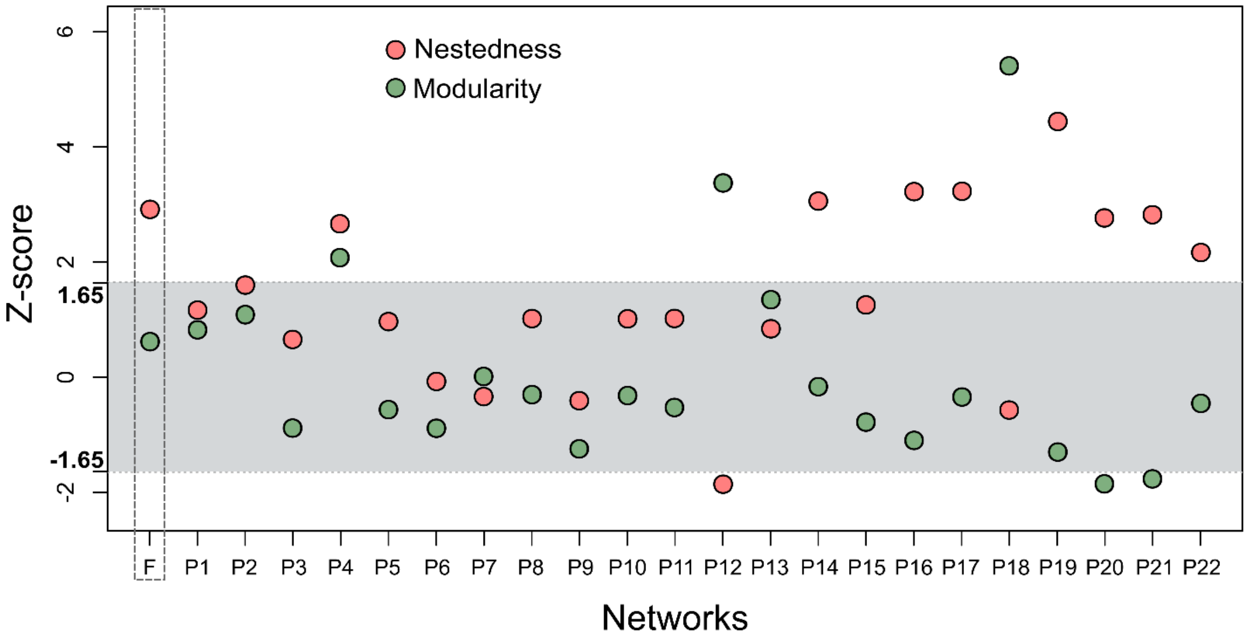

Fig .5 Z-score values for nestedness (light salmon) and modularity (green) for the network structure during flowing (F) and dry phases (each pool is analysed separately: P1 - P22) of Tabocas' NPR, Ceará, Brazil. The grey shaded area represents the interval expected by chance, ranging from -1.65 to +1.65 of Z-score (random). Data points located outside this range indicate networks that exhibit higher levels of modularity or nestedness compared to what is expected by the null model (with the *vaznull* method)

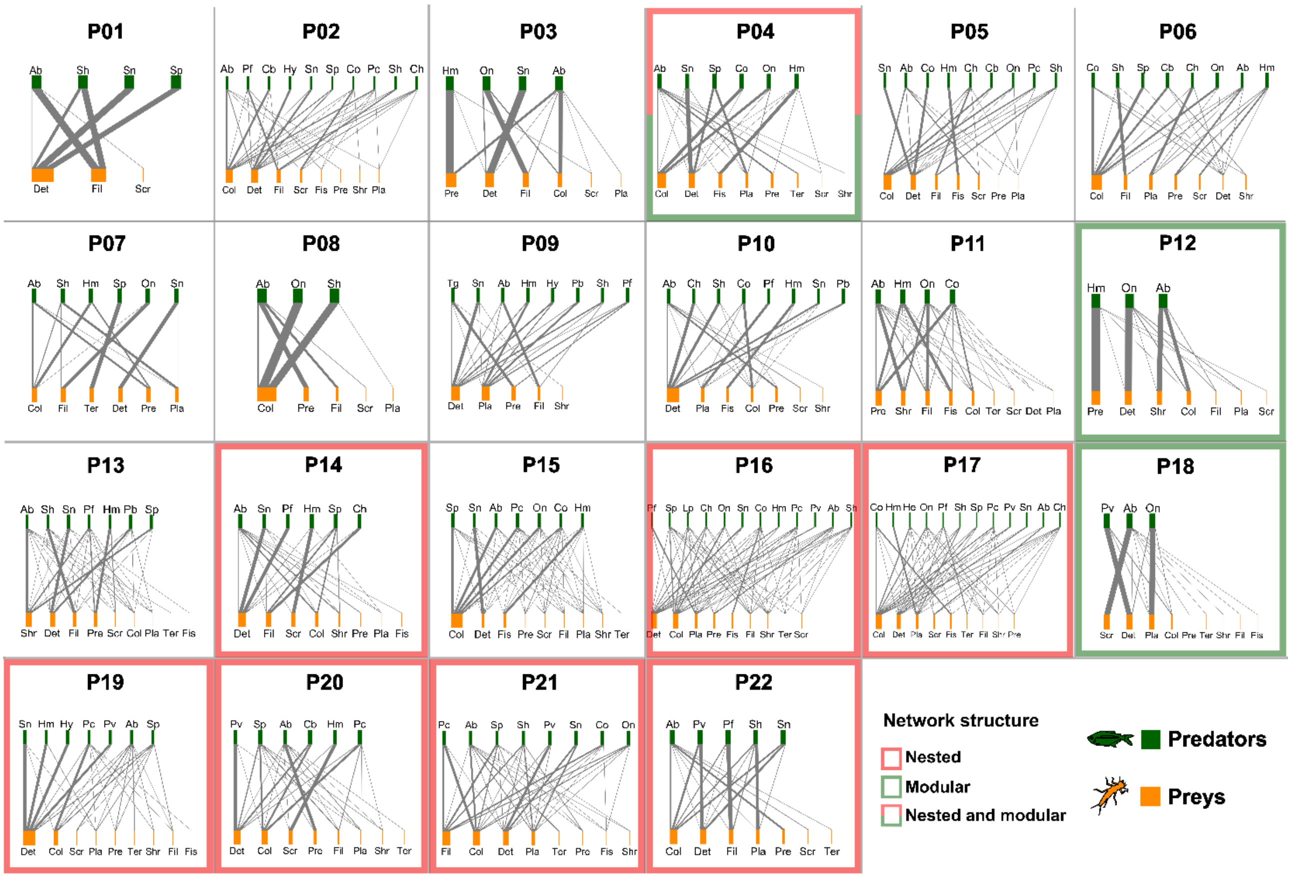

Fig. 6 Bipartite predator-prey interaction networks corresponding to each pool (dry phase), arranged in consecutive sampling order in the Tabocas' NPR, Ceará, Brazil. The networks are highlighted to show nested (light salmon) and modular (green) structures when compared to the null model - '*vaznull*' method. The legend abbreviations are as follows: Prey - Det: organic detritus; Col: collector invertebrate; Pla = plant material; Pre = predators invertebrate; Shr = shredder invertebrate; Fil = filtering invertebrate; Scr = scrapers invertebrate; Fis = fish; Ter = terrestrial invertebrate. Predator - Lp: *Leporinus piau*, Ab: *Astyanax bimaculatus*, Ch: *Compsura heterura*, He: *Hemigrammus* sp., Pc: *Phenacogaster calverti*, Pf: *Psalidodon fasciatus*, Sh: *Serrapinnus heterodon*, Sp: *Serrapinnus piaba*, Co: *Cichlasoma orientale*, On: *Oreochromis niloticus*, Cb: *Characidium bimaculatum*, Sn: *Steindachnerina notonota*, Hm: *Hoplias malabaricus*, Hy: *Hypostomus* sp., Pv: *Poecilia vivipara*

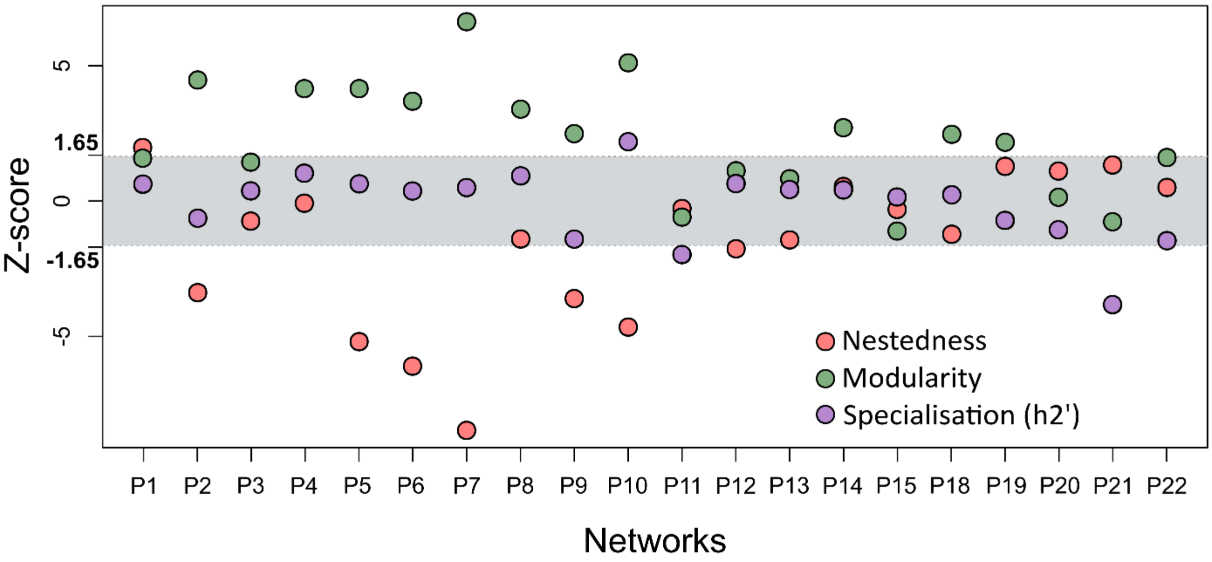

Fig .7 Z-score values for nestedness (light salmon), modularity (green) and specialisation (light purple) network structures for all isolated pools separately (P1-P22) were obtained when compared to what is expected by the theoretical model based on predator richness. The grey colour range represents the interval expected by chance (-1.65 to +1.65), while data points outside this range indicate networks with higher or lower levels of nestedness, modularity, or specialisation (h2'). Due to the high correlation between the variables of isolated pools P16 and P17, it was not possible to calculate the Z-score

Hydrological fluctuations determine predator-prey interactions in a semi-arid non-perennial river

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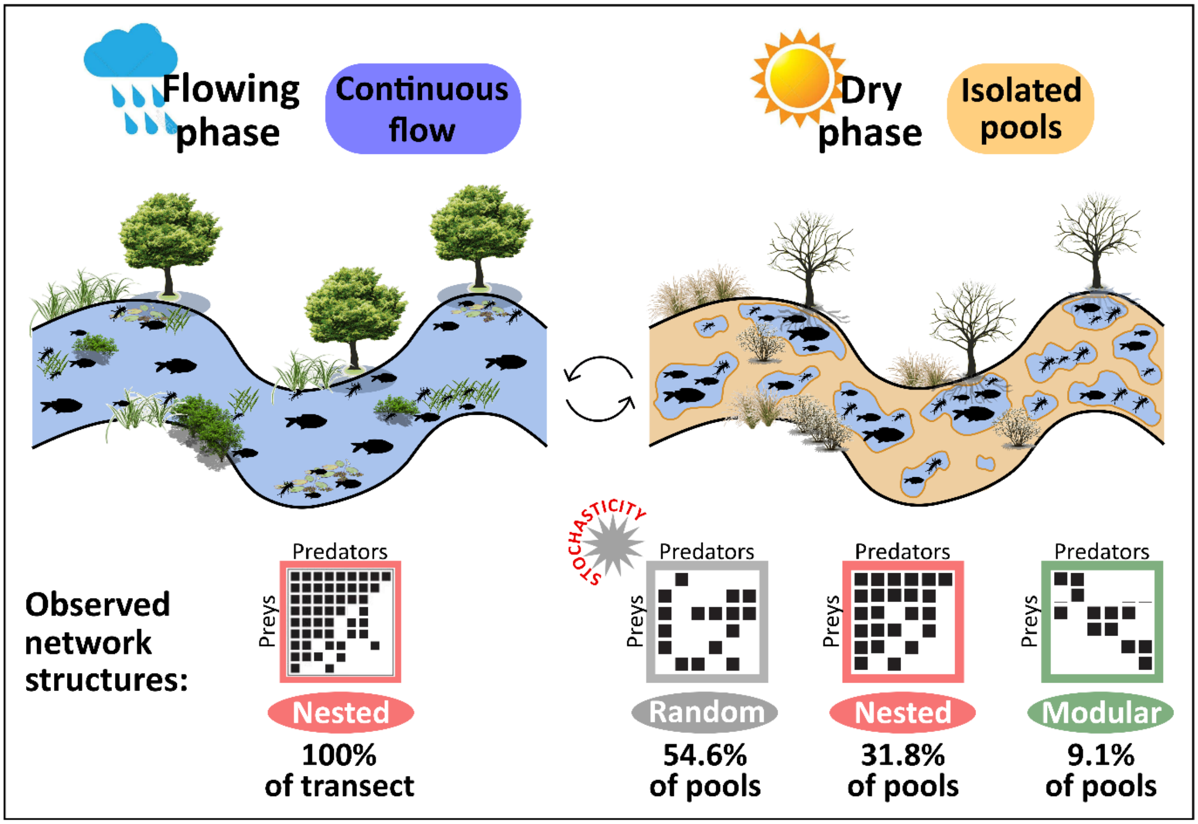
HYDROBIOLOGIA

Supplementary Information



Graphical abstract According to the transition of flowing to dry phase in the Tabocas' NPR, the structure of predator-prey interaction networks shifts from being nested and consistent to being random in most pools. The low number of predator-prey links in these random networks shows a decrease in the use of the trophic resource by fish (predators) as an adjustment to the survival in these limiting environments.

Table S1 Ecological categories used in the analysis and the food items included in each one of Tabocas' NPR, Ceará, Brazil. The classification based on the functional feeding group was obtained from Cummins et al. (2005).

Taxonomic group	Food items	Ecological categories	Code
KINGDOM ANIMALIA			
Phylum Arthropoda			
Class Arachnida			
Order Araneae	Araneae	Terrestrial invertebrates	Ter
Suborder Oribatida	Oribatida	Collectors invertebrates	Col
Order Trombidiformes			
Family Hydrachnidae	Hydrachnidae	Predators invertebrates	Pre
Class Branchiopoda			
Order Cladocera	Cladocera	Filtering invertebrates	Fil
Class Insecta			
Order Isoptera	Isoptera	Terrestrial invertebrates	Ter
Order Coleoptera	Coleoptera terrestrial	Terrestrial invertebrates	Ter
	Coleoptera larvae	Shredders invertebrates	Shr
	Coleoptera adult	Predators invertebrates	Pre
Order Diptera	Diptera adult	Terrestrial invertebrates	Ter
	Diptera larvae	Collectors invertebrates	Col
	Diptera pupa	Collectors invertebrates	Col
Order Ephemeroptera	Ephemeroptera nymph	Collectors invertebrates	Col
Order Hemiptera	Hemiptera adult	Scrapers invertebrates	Scr
	Hemiptera nymph	Scrapers invertebrates	Scr
Order Hymenoptera			
Family Formicidae	Formicidae	Terrestrial invertebrates	Ter
Order Lepidoptera	Lepidoptera adult	Terrestrial invertebrates	Ter
	Lepidoptera larvae	Scrapers invertebrates	Scr
Order Odonata	Odonata nymph	Predators invertebrates	Pre
Order Orthoptera	Orthoptera nymph	Collectors invertebrates	Col
Order Trichoptera	Trichoptera cocoon	Shredders invertebrates	Shr
	Trichoptera_larvae	Shredders invertebrates	Shr
Class Malacostraca			
Order Amphipoda	Amphipoda	Shredders invertebrates	Shr
Class Maxillopoda			
Order Copepoda	Copepoda	Filtering invertebrates	Fil
Class Ostracoda	Ostracoda	Collectors invertebrates	Col
Phylum Chordata			

Class Actinopterygii	Scales	Fish	Fish
	Fish	Fish	Fish
Phylum Mollusca			
Class Bivalvia	Bivalvia	Filtering invertebrates	Fil
Class Gastropoda	Gastropoda	Scrapers invertebrates	Scr
KINGDOM PROTISTA	Fitoplancton	Plant material	Plant
	Filamentous algae	Plant material	Plant
Class Rhizopoda	Amoeba	Collectors invertebrates	Col
KINGDOM PLANTAE	Plant material	Plant material	Plant
	Seed	Plant material	Plant
	Organic detritos	Organic detritos	Det

Table S2 Values of prey/predator richness and network metrics (nestedness, modularity and specialisation h2') with their respective Z-scores for the flowing phase and for each isolated pool in the dry phase of Tabocas' NPR, Ceará, Brazil. Nes = Nestedness; Mod = Modularity; Spe = Specialisation; Z = Z-score.

	Preys	Predators	Interactions	Nes	Z	Mod	Z	Spe	Z
Flow	9	16	93	0.86	2.91	0.11	0.63	0.77	91.99
P01	3	4	7	0.89	1.16	0.22	0.81	0.92	10.31
P02	8	10	35	0.73	1.61	0.22	1.09	0.75	17.76
P03	6	4	13	0.67	0.66	0.22	-0.9	0.88	12.12
P04	8	6	23	0.79	2.65	0.28	2.06	0.92	15.43
P05	7	9	26	0.62	0.96	0.24	-0.57	0.83	10.86
P06	7	8	26	0.54	-0.08	0.22	-0.88	0.81	13.42
P07	6	6	13	0.29	-0.33	0.38	0.02	0.86	7.25
P08	5	3	7	0.50	1.03	0.36	-0.3	0.99	2.29
P09	4	7	22	0.59	-0.42	0.13	-1.24	0.58	7.79
P10	7	8	22	0.60	1.03	0.28	-0.33	0.98	13.07
P11	9	4	27	0.70	1.02	0.09	-0.53	0.52	55.65
P12	7	3	13	0.47	-1.87	0.26	3.38	0.95	12.39
P13	9	7	37	0.74	0.84	0.16	1.35	0.84	41.41
P14	8	6	23	0.83	3.04	0.23	-0.17	0.85	15.2
P15	9	7	45	0.80	1.26	0.09	-0.8	0.80	111.19
P16	9	11	62	0.86	3.23	0.13	-1.1	0.64	31.3
P17	9	12	51	0.81	3.21	0.18	-0.34	0.71	19.22
P18	9	3	15	0.51	-0.6	0.30	5.41	0.88	16.04
P19	9	7	29	0.89	4.45	0.20	-1.3	0.72	15.41
P20	8	6	27	0.87	2.78	0.14	-1.87	0.68	14.83
P21	8	8	38	0.89	2.81	0.11	-1.75	0.46	18.04
P22	7	5	19	0.81	2.14	0.20	-0.45	0.61	8.28

Table S3 Principal component analysis (PCA) loadings of environmental variables of Tabocas' NPR, Ceará, Brazil.

VARIABLE	Abbreviation	PC1	PC2
Physical and chemical			
Temperature	TEMP	-0.68	-0.02
Oxygen %	SATU	-0.66	0.32
Dissolved oxygen	DO	-0.58	0.36
Salinity	SALI	-0.84	-0.14
pH	PH	-0.83	-0.13
Substratum			
Bedrock (particles > 100 cm)	BEDR	-0.39	-0.14
Large boulder (particles 30 cm to 100 cm)	LBOU	-0.45	0.12
Small boulder (particles 15 to 30 cm)	SBOU	0.05	0.85
Gravel (particles 3 to 15 cm)	GRAV	0.15	0.86
Fine gravel (particles 1 to 3 cm)	FINE	0.19	0.92
Sand (particles 0.2 to 1 cm)	SAND	-0.03	0.29
Mud (particles < 0.2 cm and subject to suspension)	MUD	0.002	-0.26
Site structure			
Water volume	VOLU	0.46	-0.03
Macrophyte	MACR	0.55	0.39
Tree branch	TREE	0.67	-0.32
Dead wood	DEAD	0.63	-0.24
Root	ROOT	0.77	-0.23
Shading	SHAD	0.70	0.05
Marginal vegetation	MVEG	0.88	0.17
Variance explained by components		32.94%	16.64%
Percentage of total variance explained		32.94%	49.58%

Table S4 Distance (m) between pools/sections and physical-chemical variables (temperature °C, oxygen saturation, dissolved oxygen mg/l, salinity ppm and pH) and volume (m^3) corresponding to each isolated pool (Dry) and sections (Flowing) sampled in the Tabocas' NPR, Ceará, Brazil.

Samples	Distance	Volume	Temperature	Sat_O2	DO	Salinity	pH
Pools - Dry							
P01	0	14.94	26.9	74.8	5.39	0.32	9.28
P02	12.46	117.17	26.7	72.6	5.29	0.30	9.56
P03	64.68	8.98	27.6	52.9	3.43	0.33	8.38
P04	28.6	22.03	25.8	19.3	1.19	0.25	7.86
P05	35.7	36.22	29.1	94.8	7.05	0.22	8.29
P06	17.62	131.85	27.7	67.5	5.06	0.23	8.11
P07	24.56	8.37	33.4	124.2	8.39	0.26	8.90
P08	23.62	9.75	33.8	141	9.94	0.36	9.11

P09	64.96	7.34	32.3	24.1	1.51	0.31	8.50
P10	63.45	78.70	31.9	132.4	9.39	0.24	9.23
P11	44.95	28.19	32.8	125.6	8.72	0.28	9.13
P12	88.57	6.75	24.5	131.1	10.52	0.35	7.42
P13	49.3	5.14	26.2	98.4	7.93	0.32	7.68
P14	48.2	9.02	28	105.4	7.47	0.35	8.66
P15	97.25	1560.9	27.8	96	7.27	0.23	8.13
P16	27.9	174.16	28.3	106	8.28	0.23	8.45
P17	72.7	182.23	27.2	72.3	5	0.21	7.11
P18	79.7	15.41	31.8	156.1	11.37	0.30	8.95
P19	46.7	4.56	31.8	109.1	7.39	0.28	8.62
P20	13.55	11.53	30.6	123.7	9.79	0.26	8.84
P21	53.6	58.78	31	135.1	9.84	0.28	9.04
P22	136.5	2.42	36	207.9	14.53	0.54	10.21
Sections - Flowing							
T01	50	8339.9	25.2	91.8	7.3	0.12	7.6
T02	50	5207.7	25.5	94.1	7.4	0.12	7.6
T03	50	18076.3	26.6	89.5	6.9	0.12	7.6
T04	50	14594.1	28.3	87.2	6.6	0.12	7.5
T05	50	5879.6	27.7	86.5	6.5	0.12	7.5
T06	50	12547.5	28.3	83.1	6.3	0.12	7.5
T07	50	5979.6	24.2	103.5	8.4	0.12	7.8
T08	50	4151.1	25.4	77.9	6.3	0.12	7.3
T09	50	11881.9	25.6	73.4	6	0.12	7.7
T10	50	10285.5	27.1	82.6	6.4	0.12	8.6
T11	50	59251.2	28.5	85.8	6.6	0.12	8.6
T12	50	8589.2	28.7	88.3	6.6	0.12	8.5
T13	50	25779.2	28.1	84.4	6.39	0.12	8.3
T14	50	33888.7	27.3	92.5	7	0.12	7.9
T15	50	9583.5	27.8	82.6	6.4	0.12	7.9
T16	50	30176.6	27.6	74.4	5.8	0.12	7.9
T17	50	12056.7	29.5	85.6	6.3	0.12	8.2
T18	50	44307.2	30.4	81.4	6.1	0.12	8.4
T19	50	26682.2	30	76.8	5.7	0.12	8.1
T20	50	16380.3	30.1	78	5.7	0.12	8.1
T21	50	14455.2	27.1	103.2	8.1	0.13	7.9
T22	50	4023.9	27.1	89.5	7	0.13	8
T23	50	8972.8	27	83.2	6.5	0.13	8.1

Fig. S1 Representation of the 22 isolated pools from the dry phase sampled in the Tabocas' NPR, Ceará, Brazil. The colours of the circles represent the network structure for each pool (grey = random; green = modular; and light salmon= nested)

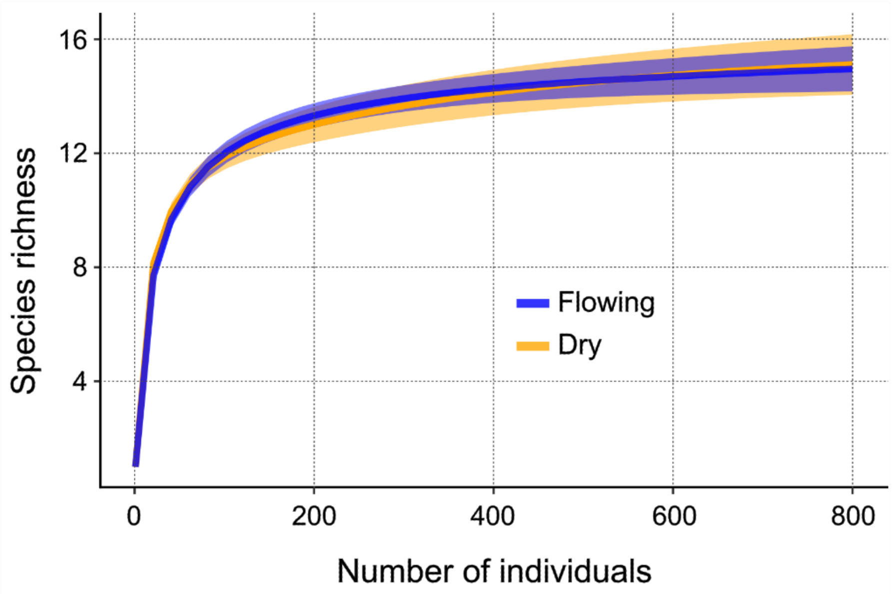


Fig. S2 Rarefaction curves with 95% confidence intervals for each phase of Tabocas' NPR, Ceará, Brazil

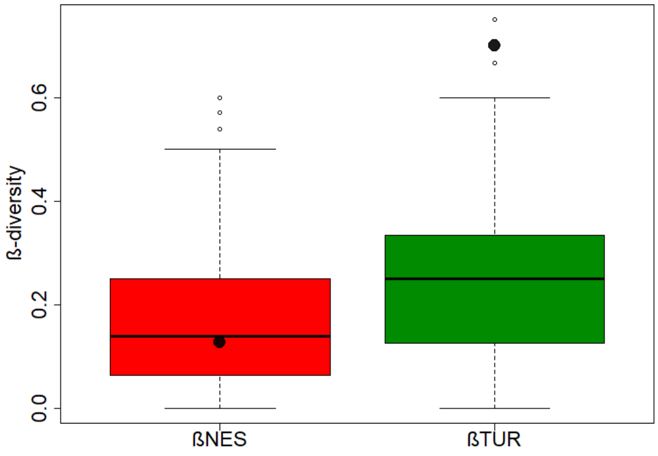


Fig. S3 Observed and simulated values of total and partitioned beta-diversity (β) calculated for species composition among the pools of Tabocas' NPR, Ceará, Brazil. The black dots represent the observed values, and the boxplots depict the distributions of 1000 randomly simulated samples. The red box represents the nestedness component (β NES), and the green box represents the turnover (β TUR) component. Smaller black dots correspond to outliers, and the bars indicate the standard error

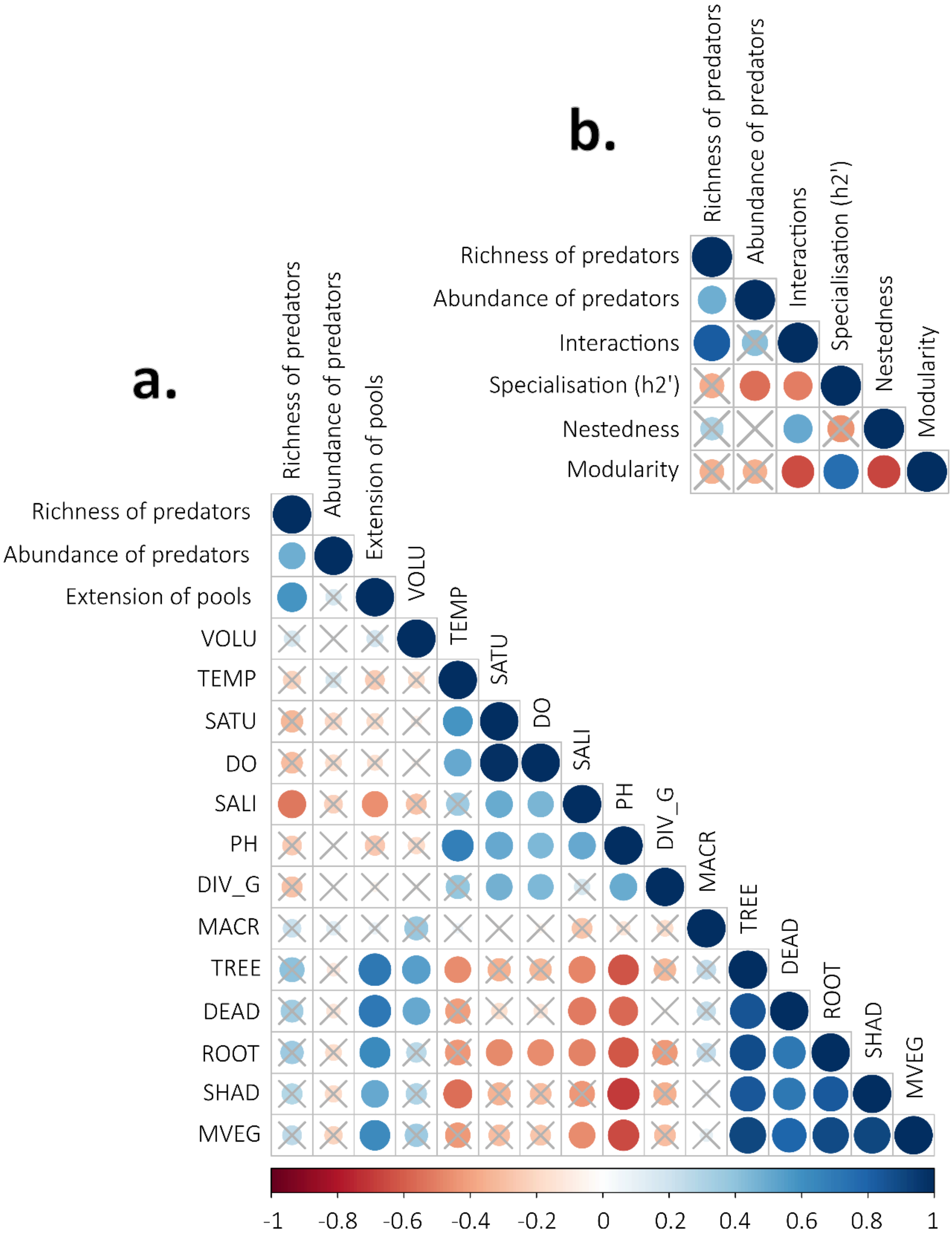


Fig. S4 a Pearson's correlation analysis among pools during the dry phase between environmental variables and predator richness and abundance of Tabocas' NPR, Ceará, Brazil. **b** Network metrics (specialisation h2', nestedness and modularity), number of interactions and predator richness and abundance. Spaces without the X represent significant correlation at $p < 0.05$. Blue circles indicate positive correlation and red circles negative correlation

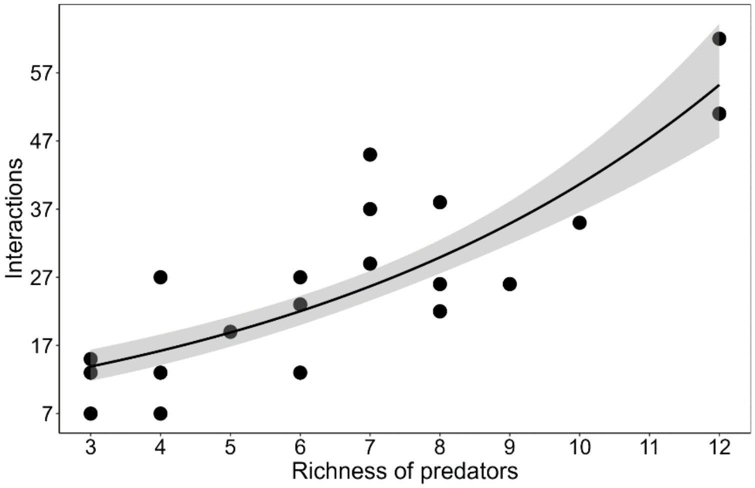


Fig. S4.1 Pearson's correlation analysis (cor: 0.831, p = <0.0001) and generalized linear model (GLM: β1=0.153, SE = 0.015, df = 21, z = 10.10, p = <0.0001, AIC = 164.9) between predator richness and interactions among pools during the dry phase of Tabocas' NPR, Ceará, Brazil. See more details here: https://anonymous.4open.science/r/IntermittentDynamicsNetworks_2024-0E5E/

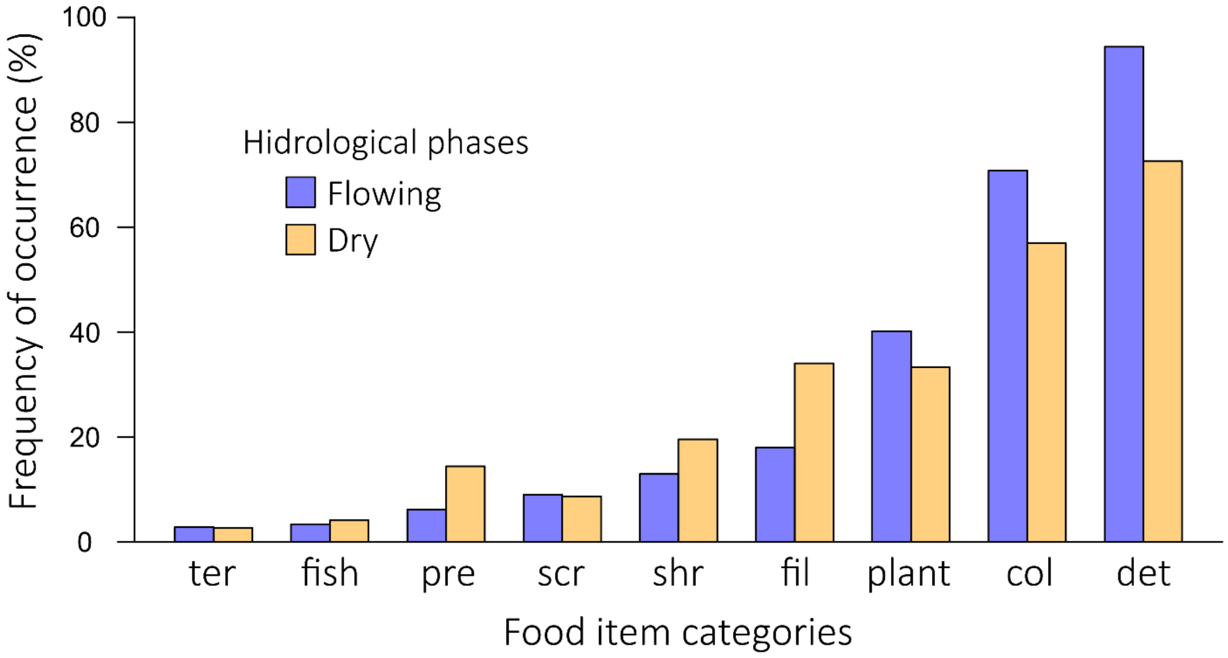


Fig. S5 Frequency of occurrence of food item categories during both flowing and dry phases (all pools combined) of Tabocas' NPR, Ceará, Brazil. The legend abbreviations are as follows: ter = terrestrial invertebrate; shr = shredder invertebrate; fil = filtering invertebrate; col = collector invertebrate; scr = scraper invertebrate; pre = predator invertebrate; fish = fish; plant = plant material, and det = organic detritus

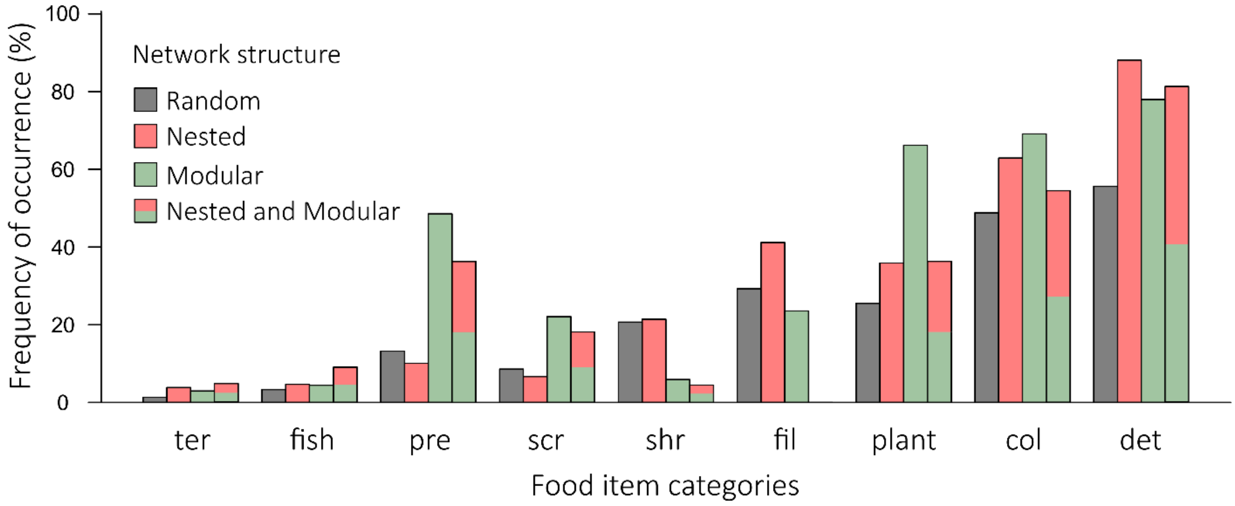


Fig. S6 Frequency of occurrence of food item categories for each observed network pattern or structure corresponding to isolated pools of Tabocas' NPR, Ceará, Brazil. ter = terrestrial invertebrates; shr = shredders invertebrates; fil = filtering invertebrates; col = collectors invertebrates; scr = scrapers invertebrates; pre = predators invertebrates; fish = fish; plant = plant material, det = organic detritus. The colours represent the network structure (grey = random; green = modular; and light salmon= nested)

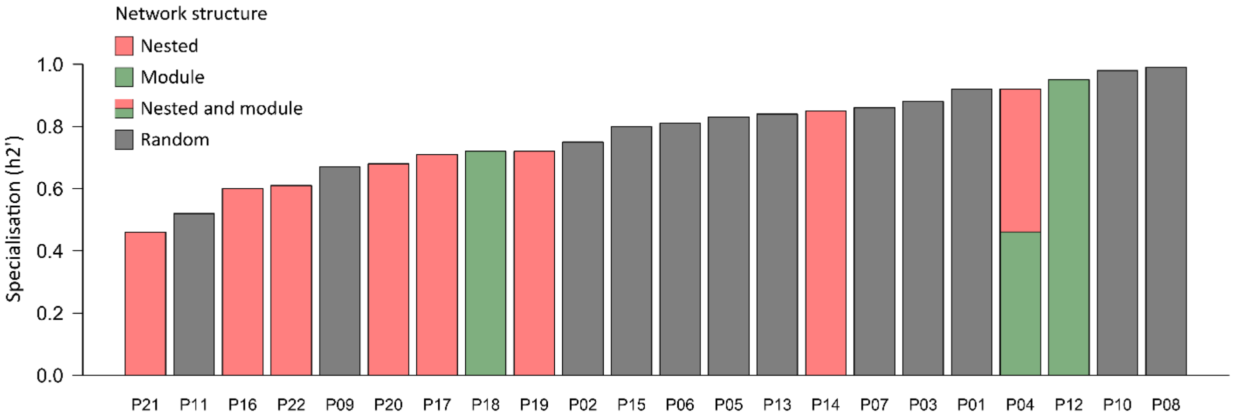


Fig. S7 Level of specialisation (h2') among interacting species in the ecological network from each pool during the dry phase of Tabocas' NPR, Ceará, Brazil. The pools are arranged in ascending order of level of specialisation. The colours represent the network structure (grey = random; green = modular; light salmon= nested)

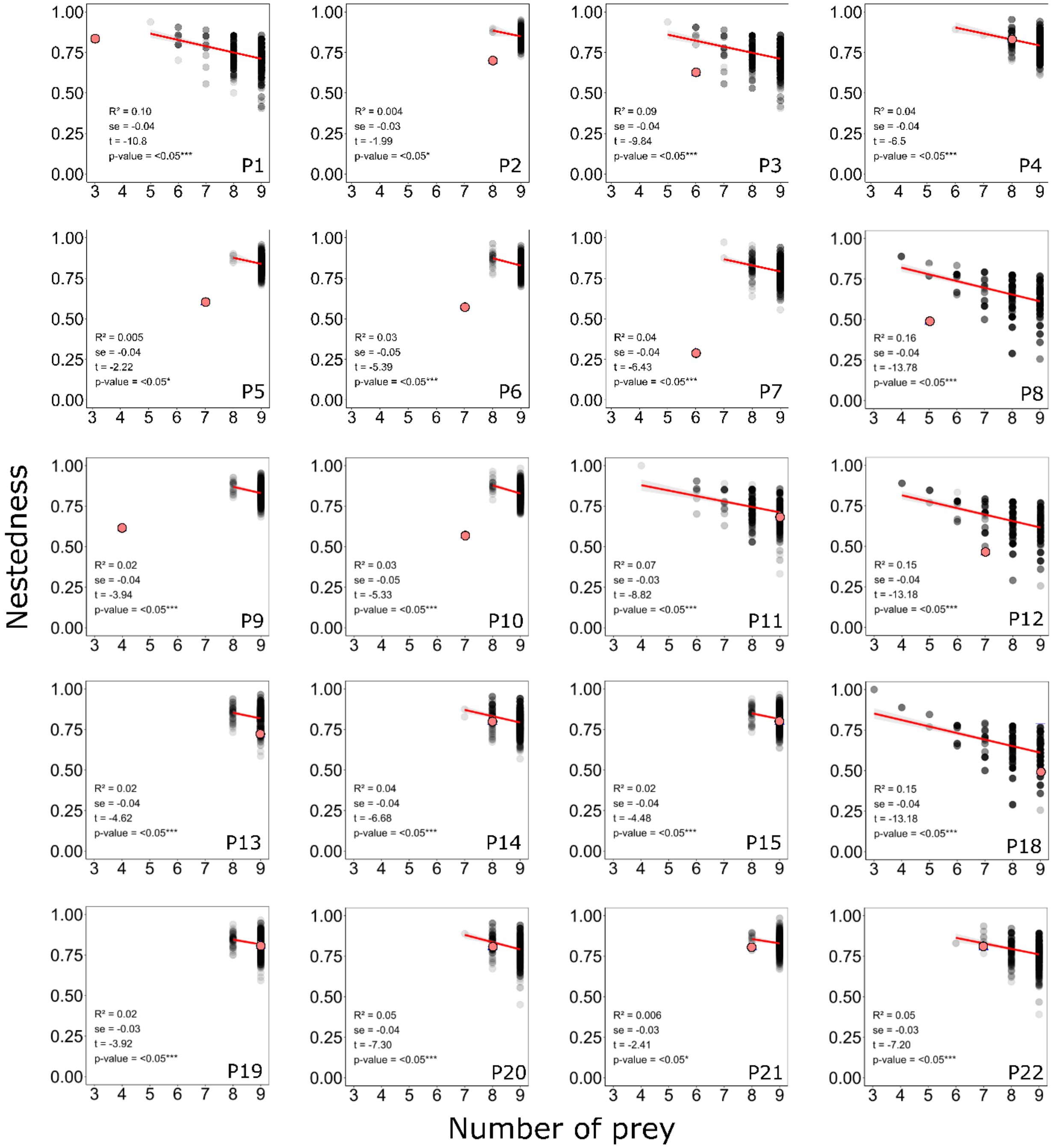


Fig. S8 Nestedness values according to the number of prey of the theoretical model based on predator richness (black dots) and the observed network (light salmon dots) of Tabocas' NPR, Ceará, Brazil. The red lines represent linear regression. The variables from pools P16 and P17 are highly correlated and therefore it was not possible to calculate linear regression

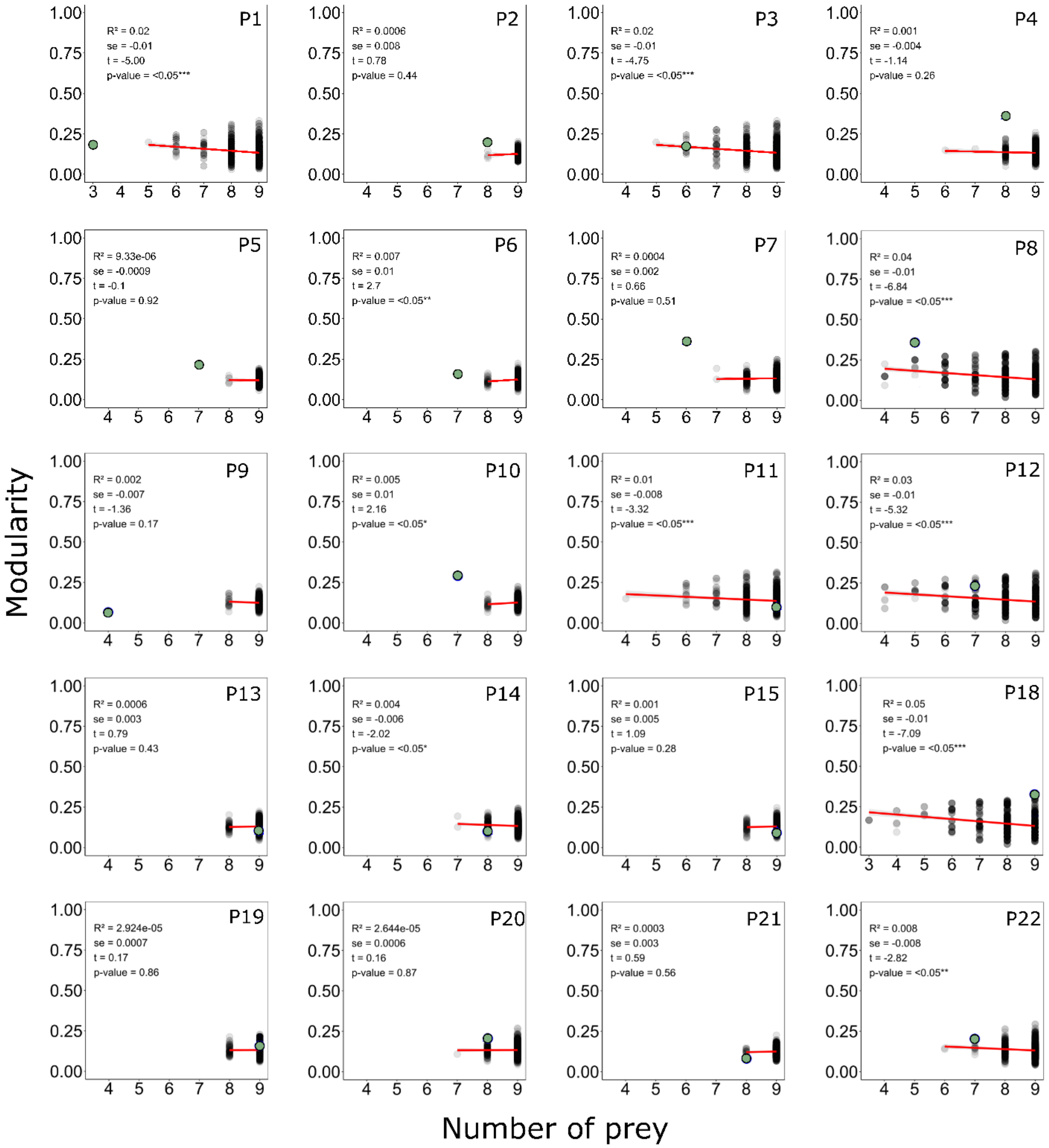


Fig. S9 Modularity values according to the number of prey of the theoretical model based on predator richness (black dots) and the observed network (green dots) of Tabocas' NPR, Ceará, Brazil. The red lines represent linear regression. The variables from pools P16 and P17 are highly correlated and therefore it was not possible to calculate linear regression

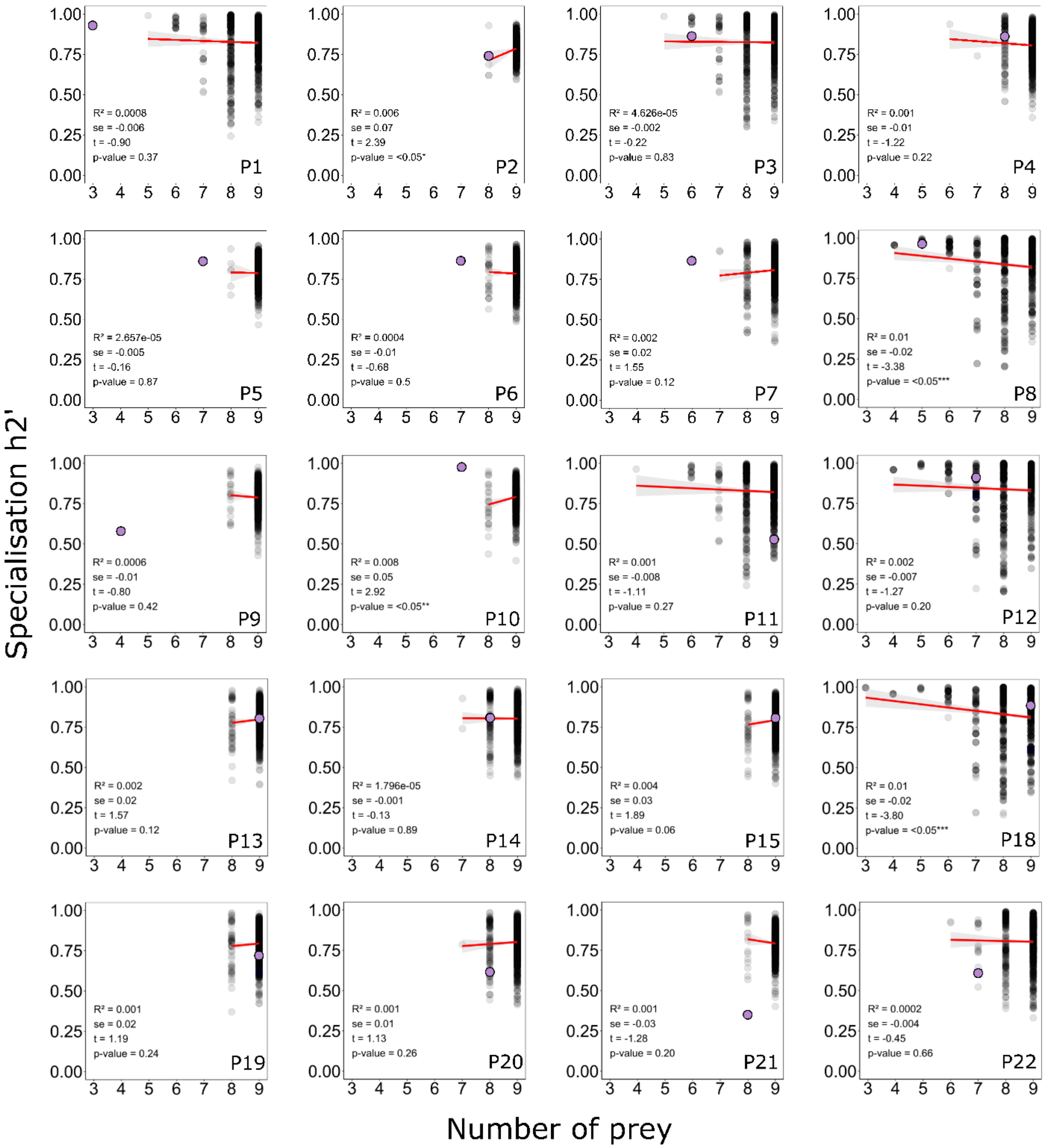


Fig. S10 Specialisation h2' values according to the number of prey of the theoretical model based on predator richness (black dots) and the observed network (light purple dots) of Tabocas' NPR, Ceará, Brazil. The red lines represent linear regression. The variables from pools P16 and P17 are highly correlated and therefore it was not possible to calculate linear regression