Adapting to Change: How Fish Populations Responds to Ecological Shifts

Irmak Kurtul
Ege University

Phillip J. HAUBROCK (✉ philip.haubrock@senckenberg.de)
Senckenberg Research Institute and Natural History Museum Frankfurt

Cuneyt Kaya
Recep Tayyip Erdogan University

Hakan Kaykac
Ege University

Ali Ilhan
Ege University

F. Ozan Duzbastilar
Ege University

Zafer Tosunoglu
Ege University

Hasan Sari
Ege University

Paride Balzani
University of South Bohemia in České Budějovice, South Bohemian Research Centre of Aquaculture and Biodiversity of Hydrocenoses

Ali Serhan Tarkan
Muğla Sıtıkı Koçman University

Article

Keywords:

Posted Date: June 16th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3029244/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.
Abstract

Invasive species are a significant threat to natural biodiversity and human well-being. Despite becoming more commonly considered in the field of biological invasion, studies using long-term time series from Türkiye’s freshwater resources have remained scarce. To fill this gap, we used nine time series from the highly anthropogenically-altered Lake Bafa in Western Anatolia sampled between 1958 and 2019. We investigate how fish populations in Lake Bafa were affected by environmental changes and examined changes in taxonomic and functional diversity of non-native species over time. The analyses revealed an increase in non-native species richness over time. Non-native species did not interfere with native species' niche space, whereas applied models indicate that in this highly altered ecosystem, foremost temperature and salinity shaped the fish community over time, limiting the impacts of non-native species. These results have implications for the fishery of the lake, which include highly valuable catadromous fish species, highlighting the value and importance of long-term data for the study of freshwater ecology to better understand both invasion dynamics and changes in the naturality of ecosystems. These findings further underline the importance of long-term data to create new management strategies for the lake and start restoration processes, thus improving fisheries management.

Introduction

The Anthropocene is characterized by the destruction of habitats, environmental pollution, climate change, the introductions of invasive species, and the overexploitation of natural resources\(^1,2\). These combined have led to a rapid loss of biodiversity, with many species facing extinction\(^3,4\). In low-resilient fish communities, the effects of anthropogenic disturbances are often more pronounced\(^5,6\). Overfishing and destructive fishing practices had devastating effects on fish populations, causing substantial declines in abundance and diversity\(^7\). Additionally, the introduction of non-native fish species and other aquatic organisms disrupted native communities and lead to the displacement of native species\(^8,9\). These factors collectively can lead to the collapse of entire fisheries and the loss of important ecosystem services\(^10,11\), underlining the urgent need to investigate how freshwater communities have changed over time.

Among the many impacts of global change, changes in the taxonomic and functional composition of communities are particularly important, having significant consequences for ecosystem function\(^12\) due to the loss of certain traits and the acquisition of others\(^13,14\). One such aquatic ecosystem is Lake Bafa in Western Anatolia (Turkey). Lake Bafa was formed between 50–300 AD when alluvium carried by the Büyük Menderes River cut the connection of Latmos Bay with the Aegean Sea, separating it from the sea\(^15–17\). Furthermore, drought periods in the Büyük Menderes River basin resulted in the construction of several dams, which exacerbated severe ecological disturbances in Lake Bafa. Lake Bafa’s fish community has shown a dynamic composition over time, reflecting changes in climate conditions, human disturbances (i.e., canal building), and the introduction of non-native species (both intentional and accidental), with direct economic and socio-cultural implications on the livelihood of people\(^18\).
Despite some recent works investigating functional changes in aquatic communities and their consequences on ecosystem functioning\textsuperscript{12,14}, studies investigating drivers of such changes have remained mostly anecdotal. This lack of linking environmental changes to effects on an ecosystem’s provisioning to human wellbeing can facilitate ongoing change due to an underlying ignorance towards needed conservation or management interventions, ultimately exacerbating a possible deterioration of fishery production\textsuperscript{19}. Hence, in this work, we aimed to investigate how the fish community in Lake Bafa responded to environmental changes over time by combining taxonomic information from historical data and recent monitoring with the analysis of species’ functional traits. We hypothesized that (i) community composition has changed substantially over time; (ii) those changes were driven by multiple environmental changes simultaneously; and (iii) they resulted in a complete shift in the occupied functional space and fish community functioning.

**Results**

**Sampling**

In the wet period, (between September 2018 and May 2019) mean values of water temperature, salinity, electrical conductivity, pH, and dissolved oxygen yielded 24.0 °C, 31.7 ppt, 48.6 µS\textsubscript{25}°C/cm, 7.13, and 6.21 mg/l, respectively (Table S2). The study identified 12 taxa (7 sampled by our field effort, 5 sampled from the lakes’ fisherman) belonging to the families Anguillidae, Mugilidae, Atherinidae, Syngnathidae, Cyprinodontidae, Moronidae, Sparidae, Gobiidae, and Poeciliidae (Table S3).

In 2018/2019, our sampling across the 24 sites found the most dominant species to be the non-native *Atherina boyeri*, contributing 94.71% of the overall sampled number of individuals, hence being the most caught species in the lake during the two sampling periods (Table 1). This species was very abundant in the western, southern, and eastern parts of the lake, both in September and May. The second most abundant species was *Gobius niger*, a non-native species without economic value that entered Lake Bafa in the late 1990s, which also occurred in most sites around Lake Bafa. These species are followed in abundance by members of the family Mugilidae, namely *Chelon auratus* (constituting 89% of all Mugilidae), *C. ramada* (7%), and *Mugil cephalus* (3%), which were the most common native species. They however only represented 0.80% of the total caught abundance in September 2018 and 0.05% of the total abundance in May 2019, contributing only 0.27% to the total abundance of fish caught in 2018/2019. *Syngnathus abaster* was found only in the Kapıkırı area of Lake Bafa while *Aphanius fasciatus* was found only in shallow waters with underwater plants near Kapıkırı Village (sites #16–17; Fig. 1). The historical and current fish fauna of the studied sites were listed (Table S4).
Table 1
Abundance of current fish species of Lake Bafa from sampling in 2018 and 2019 (both dry and wet seasons).

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Wet period</th>
<th></th>
<th>Dry period</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%N</td>
<td>N</td>
<td>%N</td>
<td>N</td>
<td>%N</td>
</tr>
<tr>
<td>Atherina boyeri</td>
<td>4824</td>
<td>82.00</td>
<td>14440</td>
<td>99.88</td>
<td>19264</td>
<td>94.705</td>
</tr>
<tr>
<td>Gobius niger</td>
<td>1009</td>
<td>17.15</td>
<td>10</td>
<td>0.07</td>
<td>1019</td>
<td>5.010</td>
</tr>
<tr>
<td>Chelon auratus</td>
<td>42</td>
<td>0.715</td>
<td>7</td>
<td>0.044</td>
<td>49</td>
<td>0.241</td>
</tr>
<tr>
<td>Chelon ramada</td>
<td>3</td>
<td>0.051</td>
<td>1</td>
<td>0.006</td>
<td>4</td>
<td>0.020</td>
</tr>
<tr>
<td>Mugil cephalus</td>
<td>2</td>
<td>0.034</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0.010</td>
</tr>
<tr>
<td>Syngnathus abaster</td>
<td>2</td>
<td>0.030</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0.010</td>
</tr>
<tr>
<td>Aphanius fasciatus</td>
<td>1</td>
<td>0.020</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.005</td>
</tr>
<tr>
<td>Total</td>
<td>5883</td>
<td>100.00</td>
<td>14458</td>
<td>100.00</td>
<td>20341</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Species richness

Between 1958 and 2018, salinity increased from 3.5 to 23.8 ppt following the establishment of 15 impoundments on its tributary, intense irrigation, and sea water inflow. Simultaneously, the number of species increased from 6 known to have occurred in Lake Bafa, to 15 in the years after 2000. From these, non-native contributed 4 species at their peak in 2017. Concomitant to the incline in native and non-native species (Fig. 2a), we found the number of marine species to increase more strongly than the number of freshwater species (Fig. 2b).

Functional diversity

The computed functional metrics showed no significant change across time (p > 0.05 for all). The only identifiable change was in the number of species, increasing from 6 species in 1958 to 15 between 2000 and 2015, before declining to 11 in 2018 (Fig. 3).

The functional space occupied by the fish community in 1958 was relatively small, limited by the number of present species. In the following years, the number of species and hence, the occupied native niche space increased. The first non-native species, Gambusia holbrooki and Atherina boyeri, appeared in 1989 and remaining until 2018, occupied a niche space outside that of native species. In 2015, two further non-native species appeared, L. gibbosus and C. gibelio, this latter overlapping with natives’ niche space, disappearing again in 2018 (Fig. 4).

Community composition
Communities changed substantially in their composition over time. However, non-native species were not drivers of compositional changes, but rather the appearance or disappearance of native species was (Fig. 5a). Concomitantly, trait modalities that were characteristic for changes in the community composition were numerous but not unique to non-native species (Fig. 5b).

**Discussion**

Non-native species introduction rates are projected to increase, showing no signs of amelioration\(^{20,21}\). Also in our work, the analyses confirmed an increase in non-native species richness over time, which however did not interfere with the niche space of native species. We further found that mainly temperature and salinity changes were the most influential factors in restructuring the fish community, simultaneously preventing non-native species’ impacts.

Despite the importance of long-term data, including historic data, a limited number of studies on freshwater fisheries management have relied on them\(^8,22\). This has caused changes in freshwater fish communities to remain hidden, creating ignorance towards drivers of change. Lake Bafa in Turkey is no exception, with previous studies indicating that native fish communities respond to ecological shifts of the lake, despite providing no information on the effects this may have on ecosystem functioning or local population\(^{23}\). Filling this gap, we confirmed that the native fish community of Lake Bafa responded to environmental change, predominantly an increase in salinization, while revealing that the few non-native species played a lesser role, with their arrival probably hindered by environmental filters (i.e., high salinity).

Previous studies have been conducted on the fish fauna of Lake Bafa. Artüz\(^{24}\) was the first to list 6 fish species in the area, while there were 17–20 fish species in the 1980s and 1990s\(^{17,23,25,26}\). Sampling in 2018/2019 combined with reports from local fishermen, however, detected only 12 of the 25 previously reported species. Historical data have to be considered with great care, being aware of differences and limitations of the varying field sampling methods applied over time, with the increase in the number of species resulting from improved sampling techniques and not by the introduction of non-native species, thereby raising concerns about the noted declines after 2015. Contemporary, native species richness fluctuated substantially as some of the species occurring over time belong to the lakes’ native fauna but could not be recorded continuously or in the last year, with 8 species probably being extirpated from the lake. However, it should be noted that *A. anguilla* could not be caught during the sampling studies but was reported by fishermen as present.

We further noted a stronger increase in marine than freshwater species (in terms of total numbers), reflecting the lake’s gradual salinity increase. Salinity has increased by approximately 280% since the first measurement on the lake’s shore until day (Figure S1). There have been many reasons for the increase in salinity in the lake. One of the main reasons is that the delta is deprived of freshwater due to the construction of reservoirs on e.g. the Büyük Menderes River and embankment, which was built with the aim of protecting Serçin Village from floods, resulting in insufficient water supplying the lake from the
Serçin water resources. Likely due to the influence of also other environmental variables, *A. boyeri*, which is not a member of the lake's native fauna, has become the dominant fish species, very abundant in the western, southern, and eastern parts of the lake. This small zooplanktivorous species is widely distributed around the world and known as invasive for lake habitats in Turkey\textsuperscript{27}. Yet, a lack of measured environmental variables with a high spatial-temporal resolution makes inferences of drivers of compositional changes and those facilitating the success of *A. boyeri* difficult. It is however plausible that the increased salinity of the lake caused significant changes, including the disappearance of native species.

The analysis of functional niche space suggests that the ecological character (i.e. functioning) of Lake Bafa's fish community was stable over time, showing no significant change in any regard. This was despite the increase in species richness over the years. We furthermore found that despite the fluctuations of the native fish populations, both *A. boyeri* and *G. holbrooki* occupied positions outside the native niche space. There might be several reasons for this: The main one might be that (i) the resilient niche of native species did not allow any overlap between native and non-native fish species, thereby hindered non-native species in their establishment or the reaching of high abundances\textsuperscript{28} due to competitive interactions—as shown in 2015—and (ii) limited resources that could have been shared with native species\textsuperscript{29}. It is however also plausible that (iii) non-native species were subject to a 'boom' phase in between sampled years, while being in the 'bust' phase during sampled years\textsuperscript{30}. Another reason (iv) why non-native species tend to disappear is the high salinity. Salinity has often been shown to be a deterrent of species migrations, hindering—to some degree—the influx of several well-known invasive species\textsuperscript{26,31}. It is therefore possible that the salinity also affects the competitiveness of some species\textsuperscript{32}, limiting non-native species establishment. As such, it is no surprise that compositional changes were predominantly characterized by native species and their respective traits.

In an environment of increasing salinity, females of brackish marine species can reproduce earlier, despite lower oocyte numbers, while showing stronger swimming ability\textsuperscript{33}. The large predatory species found in Lake Bafa (e.g., *Dicentrarchus labrax*) are however euryoparous (i.e., without strict spawning habitat preferences). The analyses concomitantly showed that stout species that dominated in 2015 do not protect their eggs, whereas among the species evaluated within the scope of this study, limnophilic species had moderate buoyancy and continued to breed at the highest ages (Fig. 5b). Traits like breeding at older ages and lack of egg protection may simply suggest a more stable community or a lack of species that try to steal eggs, supporting current trait results, but could also be an indicator of dominant lake species that are not under threat.

Lake Bafa has lost its natural ecological condition (especially in terms of salinity parameters), as well as almost all its native fish fauna. This is cumbersome, as Lake Bafa's fishery sustains the livelihood of roughly 6,510 people in the lake's surroundings\textsuperscript{34}, yet fishery yield of the lake decreased by 90% from 312,400 kg/year to 31,125 kg/year\textsuperscript{35}. Aside from members of the family Mugilidae, being arguably the most economically important fishes in Lake Bafa, catadromous fish fauna is also very important for
fishing activities of the lake. Yet, catadromous fish entering the lake via the Büyük Menderes River have decreased a lot as a result of the increasing salinity and foremost dam construction.

Our results furthermore suggest that smaller, highly specialized native species, namely *S. fluviatilis*, *A. fasciatus*, and *K. caucasica*, are exposed to the greatest risks (see Fig. 4). Regarding the fisheries over the past years (see Table S5), *A. anguilla*, *C. ramada*, and *M. cephalus* were the most fished species. Due to extensive overfishing, dam construction limiting migration, and invasive species, *A. anguilla* is classified on the IUCN Red List as Critically Endangered, facing substantial local extinction risks. Indeed, Lake Bafa is frequently used for many human activities and this situation likely served as a stepping stone for the introduction of invasive species. *Anguilla anguilla* and mullet species (*C. ramada*, *C. labrosus*, *M. cephalus*) have a high tolerance toward high salinities and can presumably withstand stressors to some degree, having sustained environmental pressures until now, including the threat of sporadically appearing non-native species. Yet, although *A. boyeri* was ubiquitously present in Lake Bafa in 2018/2019, other non-native species like *C. gibelio* — and potential pathogens introduced alongside — can present additional pressure on fishery relevant species. However, the increasing salinity in Lake Bafa may lower this risk, especially considering the absence of *C. gibelio* in the last sampling year (2018). This should nevertheless be confirmed by subsequent studies.

To mitigate the effects of systematic change in Lake Bafa, but also other aquatic ecosystems facing multiple threats, regular biomonitoring should become a requirement. New management strategies need to be implemented, targeting changes throughout time. In the particular case of Lake Bafa, management should be applied before migration periods, improving the migratory ability of catadromous species, and revert Lake Bafa back to a more natural state. This is because excessive irrigation and droughts in the dry season substantially affect the lake ecosystem. We hence suggest the creation of management strategies, i.e., by local research bodies or agencies, to routinely monitor the fish distribution and abundance of Lake Bafa to understand the dispersion and abundance of both saltwater and freshwater fish species to better understand their ecology.

**Materials and Methods**

**Study Area**

Lake Bafa, also known as Çamiçi Lake, is an alluvial barrier lake located in the southeast delta of the Büyük Menderes River in Western Anatolia. Lake Bafa has a rich aquatic habitat diversity due to multiple habitat complexes such as grassy, sandy, and stony places, providing a suitable habitat for various catadromous fish and aquatic birds. The lake is located just 2 m above sea level within the borders of Söke (Aydın) and Milas (Muğla) district in the part of Western Anatolia. It has a length of 16 km in the east-west direction and a width of 7 km in the north-south direction, and an area of approximately 68 km². The average depth of the lake is 3 m, while the maximum depth is 23 m. Livestock, olive cultivation, and fishing are carried out in the settlements around the lake and fishing ranks third among these economic activities. Bafa Lake was a part of the Aegean Sea before it was isolated by the
alluvium carried by the Büyük Menderes River\textsuperscript{15,16}, which cut the connection of Latmos Bay with the Aegean Sea between 50–300 AD\textsuperscript{15,17}. The waters of Lake Bafa show mesohaline\textsuperscript{17} properties with a salinity of about 13‰ and have an anoxic layer at depth of 8–10 m due to temperature stratification in the dry period of the year\textsuperscript{26}. While the eastern part of the Lake Bafa remains in regard of unimpaired, the western basin of the lake is largely impacted by human activities, particularly agriculture and husbandry. Many extinctions have been reported due to non-native species, exploitation of fisheries, and habitat alterations\textsuperscript{42}.

**Sampling**

Sampling was carried out two times (dry and wet periods) in 2018 and 2019. Temperature, pH, salinity, electrical conductivity, and dissolved oxygen were measured in situ using the WTW Multi 3430 measuring device. Standard benthic nets (in accordance with the criteria of "TS-EN 14757 Water Quality-Taking fish samples with dense mesh nets with changing meshes" – 175 m long with each panel 35 m long and 3 m high, node-to-node mesh width 10, 20, 30, 40, 50 mm mesh size) were used, aiming to collect all fish species present in the lake. As the lake has a very wide surface area, 28 different localities were investigated (24 on the shore and 4 in the middle of the lake, which did not render any catches and were ultimately discarded for analyses). In addition, we contacted local fishermen to obtain further specimens of species caught in the lake, which we included in the analysis of functional space and ecosystem functioning.

**Ethical approval for research involving human participants and/or animal**

We are grateful to Republic Of Türkiye Ministry Of Agriculture And Forestry for the legal permission (Number 72784983-488.04-102240). As the care and use of experimental animals were complied with animal welfare international/ national laws, guidelines and policies as approved by the Animal Experiments Local Ethics Committee of Ege University (Number 2018/043). Some fish were obtained from the fishermen with the consent of the fishermen to have used them in academic studies.

**Historic data collection**

Historical environmental data on temperature, salinity, pH, and dissolved oxygen were collected from the available literature (Table S1). Since salinity is the most influential environmental factor, a supporting graph showing its changes over the years is given (Figure S1). To allow for comparability, only data collected during spring were kept\textsuperscript{25,26,39,43–45}. Following the same approach, data on fish community composition were retrieved from the literature\textsuperscript{17,23,25,26,46–48} (Kasparek 1988; Balık and Ustaoğlu, 1989; Sarı et al., 1999a; Sarı et al.,1999b; DSI, 2011; Güçlü et al., 2013; Şaş and Yabanlı, 2015).

**Species richness and functional analyses**

We investigated spatial differences in community composition based on samples obtained in our sampling (2018/2019) and changes in species richness based on information on the species presents
over time (from 1989 to 2019) in Lake Bafa. We distinguished changes in native and non-native species richness as well as changes in the richness of marine and freshwater species.

To infer changes in functional space and ecosystem functioning, we tested for significant correlations (Spearman correlation) between the number of fish species (including catches from fishermen) and the proportions of trait modalities in the fish community across time. We investigated changes in functional metrics to describe changes in the Hutchinsonian niche space (i.e., an $n$-dimensional hypervolume with $n$ axes equivalent to the species-specific requirements), which is referred to as niche differentiation. In this context, different functional niches reflect different community niches expressed over time and are hereafter referred to as niche space. Therefore, we quantified changes in the niche space of the fish community in Lake Bafa, using five metrics: functional divergence ($F_{\text{div}}$; a measure of the variance of the species function, whereby clustering extent indicates niche differentiation, as described by Mason), functional dispersion ($F_{\text{dis}}$; which is the overall convex hull volume occupied by all occurring traits in multidimensional space), functional richness ($F_{\text{ric}}$; which is a descriptor of how much niche space is occupied by the occurring species, measured as the number of unique trait value combinations in each period; Table S2), functional evenness ($F_{\text{eve}}$; a measure of the nearest neighbor distance among species, indicating the regular distribution of species in the occupied niche space, as reported by Schleuter and Villéger), and Rao's Q ($Q_{\text{Rao}}$; a measure of the functional differentiation between multiple groups based on species abundance or presence/absence data). Together, these metrics can depict shifting trends in a community's occupied niche space over time.

Each metric was computed for each year using the $dbFD$ function of the R package FD, after ‘fuzzy coding’ standardization of the traits using the $\text{prep.fuzzy.var.function}$ of the same package. To display changes in native and non-native species’ niche space over time, we used a canonical analysis of principal coordinates (CAP; R package vegan), which was run using all native and non-native species with their respective traits using Gower dissimilarity distance and Jaccard distance for species abundance and occurrence data, respectively.

Community composition

Finally, to investigate species and trait modalities that were characteristic of changes over time, we performed two separate CAPs on the community composition (based on species abundance) and its functional trait composition, pooling native and non-native fish species, and then fitted species and trait modalities with non-linear relationships with the principal coordinates, using forward and backward selection to keep only those significantly correlating with the ordination axes until the minimal Akaike's information criterion (AIC) was reached. All analyses were performed using the software R (v. 4.2; R Core Team 2022).

Declarations

Acknowledgement
We would like to express our appreciation to the Republic of Turkiye Ministry of Agriculture and Forestry for the legal permission for this research, and the Ege University Scientific Research Project Commission, which supported some parts of this study (BAP-Project No: 2018 SAUM 001). Because of that the authors Irmak Kurtul and Ali Serhan Tarkan gave their contributes to this manuscript at the Bournemouth University, we would like to thank to Bournemouth University for providing their facilities, and TÜBİTAK BİDEB (2219 Program) which supported authors Irmak Kurtul and Ali Serhan Tarkan with one-year scholarships during their post-doc research at the United Kingdom.

Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request Supplementary materials.

Author contributions

Irmak KURTUL: Conceptualization, Data curation, Methodology, Writing – review & editing, Formal analysis, Supervision, Writing – original draft, Visualization. Phillip J. HAUBROCK: Conceptualization, Data curation, Methodology, Formal analysis, Supervision, Writing – original draft, Writing – review & editing. Cüneyt KAYA: Writing – review & editing, Formal analysis, Writing – original draft. Hakan KAYKAÇ: Writing – original draft. Ali İLHAN: Writing – original draft. F. Ozan DÜZBASTILAR: Writing – original draft. Zafer TOSUNOĞLU: Writing – original draft. Hasan M. SARI: Funding acquisition, Project administration, Writing – original draft. Paride BALZANI: Writing – review & editing. Ali Serhan TARKAN: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

References


52. Mason 2005


**Figures**
Figure 1

Spatial distribution (presence/absence) of fish species sampled in 2018 and 2019,
Figure 2

Species richness of native (blue) vs non-native (red) species richness over time (a) and freshwater (green) vs marine (blue) species richness over time (b). The respective arrow represents each group’s raw incline.

Figure 3

Trait metrics (a=Functional Richness, FRic; b=Functional Evenness, FEve; c=Functional Divergence, FDiv; d=Function Dispersion, FDis; e=Rao’s Q, RaoQ; f=number of species, # Species) over time.
Figure 4

Canonical analysis of principal coordinates (CAP) on fishes’ functional traits, indicating their occupied functional space (blue: native species; red: non-native species) over time.
Figure 5

Canonical analysis of principal coordinates (CAP) on the fish community composition, showing changes across time and the significant ($p < 0.05$) features (a) species and b) trait modalities) correlating with them.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Occurrence.csv
- SupplementaryAdaptingChanceMSNatureScientificReports.docx
- Traits.csv