Macroinvertebrate Community in Streams on the Canary Islands: Gradient Analysis and Stressors

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ABSTRACT

This study describes the gradient analysis of the freshwater macroinvertebrate assemblages in eight streams of Tenerife and La Gomera (Canary Islands) over a 16-year period. During this period, a total of 75 taxa belonging to 34 taxonomic families were found. Endemism has an important presence in the streams on both islands, especially regarding Trichoptera and Coleoptera. The overall status of freshwater macroinvertebrates is rather uncertain as recent data on these communities are scarce and focused on a limited number of sites. Overexploitation of aquifers and the diversion of natural water flows for irrigation have resulted in the drying up of numerous natural streams, inevitably endangering the fauna that inhabits them. A reduction in number and abundance of endemic and sensitive species was observed in the majority of the sampled streams resulting in a lower ecological rating. Therefore, it is proposed that the protection of streams of high conservation value is essential to conserve freshwater macroinvertebrate fauna native to the Canary Islands.

1. INTRODUCTION

The Canary Islands and other Atlantic islands have never been physically connected to any continental landmass [1]. This has had a significant impact on the islands' flora and fauna. Indeed, the biota of these Atlantic islands is characterized by "high diversity and distinctiveness" [2-4]. Many species are found on only one or two islands, making endemism a significant factor. Furthermore, there is a clear dominance of a few families and the total absence of others [5].

The conservation of streams in the Canary Islands requires a comprehensive approach that integrates both spatial and temporal considerations. Given the differences in species composition between islands such as La Gomera and Tenerife, tailored conservation strategies are essential to address the unique ecological dynamics of each site. Moreover, temporal variability, influenced by shifting environmental conditions, underscores the need for adaptive management practices that account for fluctuating species assemblages [3-5]. Recent studies emphasize the significance of understanding these spatial and temporal nuances in stream ecosystems for effective conservation efforts on the islands [6, 7].

Small freshwater streams on the Canary Islands harbor a disharmonic, yet interesting and surprisingly diverse, fauna [5, 8-10]. In a previous study [11], the conservation status of the macroinvertebrate fauna in the running waters of the Canary Islands was investigated with particular emphasis on endemic species and considering the threats and challenges they face. On oceanic islands, the freshwater fauna is largely represented by insects with taxa occupying a wide range of niches due to the relative absence of competitors for local resources [12].

The degree of endemism exhibited by different groups varies considerably, with the primary determinant being their capacity for dispersal. For example, the Trichoptera are conservative insects, as their capacity to disperse is limited. This makes it difficult for continental populations to reach the islands continuously. This isolation logically promotes endemism. The opposite example can be found for Odonata, where low endemism levels are observed (except for *Sympetrum nigrifemur* (Sélys 1884), which is endemic to Macaronesia). Their dispersal capacity is considerable, with the ability to travel up to 650 km in active flight [13]. The absence of some continental stream dwellers, such as Plecoptera, can also be explained by their low dispersal capacity.

Macaronesian freshwater systems are similarly affected by environmental degradation sharing many of the same characteristics as continental systems such as bank and bed construction, destruction of ecological continuity, and the overuse of the water supply but they are particularly susceptible to degradation because of their high degree of endemicity and inherent fragility of being insular ecosystems (*i.e.*, species impoverishment, disharmony, etc.). In the Canary Islands, the reduction in the number of natural perennial streams means that freshwater macroinvertebrates are among the most threatened fauna due to the disappearance of natural ecosystems and the inability of these species to adapt to new semi-natural or artificial habitats [5]. Barely a dozen permanent streams remain in the archipelago, some of which suffer from seasonal droughts. Between 1933 and 1973, the number of perennial streams in Gran Canaria fell from 285 to just 20 [5], and this number has continued to fall reaching zero in 2017. A similar situation can be observed in Tenerife, where there are currently fewer than ten documented permanent streams. On La Gomera and Tenerife combined, only 15 km of permanent streams with undisturbed hydromorphology remained [11]. However, they still have exceptional conservation value, due to the high number of endemic species found in their aquatic and associated habitats [10, 11, 14]. Threats to freshwater ecosystems include: 1) the loss of forest cover, 2) the use of groundwater and surface water reservoirs for agricultural irrigation (most streams are highly channelized for irrigation) and 3) water pollution from both point and non-point sources. The disappearance and/or increasing channelization of streams can lead to the extinction of such organisms. Thus, it is necessary to consider the conservation status of the endemic species in any assessment approach.

The aim of this study is to present an analysis of the evolution of the lotic macroinvertebrate (MI) fauna over the last 16 years. The focus is on the islands of Tenerife and La Gomera, as the last streams on Gran Canaria have either dried up or become intermittent. Unfortunately, no long-term data were available for the island of La Palma. To perform the analysis, we have used a specific assessment system based on the occurrence and distribution of aquatic macroinvertebrates, which has been enhanced by incorporating hydromorphological parameters [10, 11]. The study was carried out by sampling the remaining streams in Tenerife and La Gomera and by analyzing published data [5, 8, 15]. This assessment approach has also been applied to the island of Madeira [16].

Additionally, we compare the situations of the streams by using diversity and multivariate statistics.

2. MATERIALS AND METHODS

2.1. Study Area

The Canary Islands are located in the NE sector of the Central Atlantic, between 27˚37' and 29˚25' north latitude, and 13°20' and 18°10' west longitude, and are about 100 km from the African coast and 1000 km from the Iberian Peninsula [17]. The archipelago consists of eight oceanic islands (La Graciosa, Lanzarote, Fuerteventura, Gran Canaria, Tenerife, La Gomera, La Palma, and El Hierro), three islets (Lobos north of Fuerteventura, and Montaña Clara and Alegranza north of Lanzarote), and numerous rocks, covering a total emerged area of 7436 km^2 [18]. The Canary Islands are part of one of the 36 global biodiversity hotspots, and its uniqueness stands out [19].

The topography and climate of the islands result in a high altitudinal gradient of vegetation zones in the most mountainous ones [20, 21]. Along the coasts, characterized by high temperatures, insolation, and low rainfall, succulent plant scrublands are found, with few permanent watercourses. At higher altitudes, an open forest of sclerophyllous plants develops, with a scarcity of watercourses due to excessive use for agriculture, livestock, and human population [22]. At an even higher altitude, linked to the presence of moisture-laden clouds, a perennially green forest called Monteverde emerges. This forest, like the pine forest that develops at immediately higher altitudes, retains moisture and allows for the presence of permanent watercourses. However, human activity has significantly altered these watercourses, with some having disappeared completely. Above the pine forest, typical leguminous scrubland of the Canarian high mountains grows, characterized by extreme climate with abrupt temperature variations and low rainfall. This is concentrated in winter, sometimes in the form of hail and snow. The watercourses in this area are mostly seasonal [23]. The present study focuses on streams in Tenerife and La Gomera.

2.2. Sampling Sites and Sampling

Samples were collected from eight streams during several campaigns from November 2006 to February 2023 (**Table 1**). The locations studied were natural running water habitats. All sites were sampled during two periods: autumn and spring.

Table 1. Sampling sites for aquatic macroinvertebrates on La Gomera (LG) and Tenerife (TF) with total number (A), number of endemic (B), % endemic species (C), sensitive species (D), and % sensitive species (E) over the entire study period.

Code Stream	Date	Altitude (m.a.s.l.)	Site characteristics	A	B	C	D	E
LG1 La Laja	2006 2013 2018 2023	590	In Garajonay National Park, pine forest, supplies a reservoir.	52	17	32.7	7	13.5
LG2 El Cedro	2006 2013 2018 2023	910	In Garajonay National Park, laurel forest, with natural morphology for 2.2 km.	53	22	41.5	13	24.5
LG3 Barranco del Agua	2006 2013 2023	410	Influenced by agriculture, water scarcity.	31	11	35.5	5	16.1
LG4 Meriga	2006 2013 2023	970	Small stream in Garajonay National Park, laurel forest; downstream of the site piping of the whole stream.	33	15	45.5	8	24.2

Continued

LG5 El Rejo	2006 2013 2018 2023	650	Small stream in Garajonay National Park, laurel forest.	37 17 45.9 10 27.0
TF1 Afur	2006 2013 2018 2022	300	Influenced by agriculture, low flow rates.	52 14 26.9 5 9.6
TF2 Barranco del Infierno	2006 2013 2018 2022	500	In a nature reserve, natural morphology over a flowing distance of almost 1 km, then total canalization.	59 17 28.8 8 13.6
TF3 Barranco del Río	2006-2013-2022	1300	In a nature reserve.	42 19 45.2 10 23.8

MI were sampled in five streams on La Gomera and three on Tenerife (**Figure 1**). Four sites from La Gomera are especially well preserved. These permanent streams are located in or near the Garajonay National Park, one of the best-preserved remnants of Laurisilva forest worldwide, with undisturbed perennial streams [10]. Two of the three Tenerife sites are also located in nature reserves. These sites are, therefore, not normally affected by intensive human use, but are expected to be affected by large-scale climatic changes. For both islands, macroinvertebrates were sampled using a hand net with a mesh size of 0.5 mm, then separated into a tray and preserved in 70% ethanol. Samples included mineral and dead organic substrates as well as submerged and emergent aquatic plants. The length of the sampling sites was approximately 100 m. The material from captures was obtained through a stratified survey, which involved the identification of different habitats at each sampling station [24]. In the laboratory, the invertebrates were identified to species level (except Chironomidae) using a stereoscopic magnifier, according to [25-33].

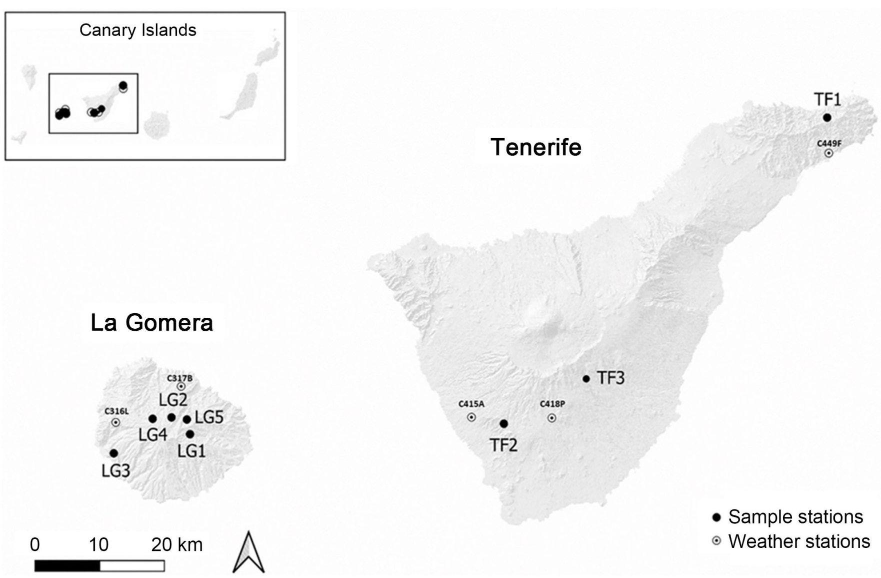


Figure 1. Sampled streams and meteorological stations used for this study. Black dots represent sample stations and circles with point meteorological stations.

2.3. Calculation of Indices and Statistics

A specific assessment system for the streams of the Canary Islands was developed using five different metrics: 1) Water quality is assessed by calculating the Saprobic Index, which indicates organic pollution; 2) Diversity is expressed as the percentage of species collected in a given stream compared to the total number of species living in the same habitat on that island; 3) Degree of naturalness is calculated as the sum of sensitive species (those found only in streams with high water quality and nearly natural hydromorphological conditions); 4) Refuge function is represented by the number of endemic species, and finally, v) Hydromorphology is calculated as the sum of physical characteristics of a water body [10, 11]. Calibration of metrics was carried out with reference to the few undisturbed stream reaches (sampling sites in National parks and nature reserves in 2006 and 2023). Finally, the concept of Ecological Integrity [34, 35] corresponds to the weighted average of the five metrics mentioned above. In terms of conservation, naturalness and endemism play the most important roles. Thus, their weight in the EI calculation is the highest (Equation (1)):

$$EI = (DI \times 2 + NN \times 3 + ES \times 3 + HM \times 1 + SI \times 1)/10. \quad (1)$$

EI: Ecological Integrity; DI: Diversity; NN: Naturalness; ES: Endemic species; HM: Hydromorphology; SI: Saprobic Index.

We calculated species richness per plot as well as the Smith and Wilson evenness index [36]. Species richness of sampled streams for each sampling period was recorded. Smith and Wilson evenness and species richness for different years were compared individually using a two-way distance base permutational-repeated measures ANOVA, with the islands applied as paired factors. Analysis was based on Bray-Curtis distances of the raw data, with p-values obtained by using 9999 permutations of the appropriate exchangeable units [37]. In instances where the permutational analysis of variance (PERMANOVA) indicated significant differences between groups (at the $p < 0.05$ level), pairwise post hoc comparisons were conducted using t-statistics.

Ordination techniques help explain community variation [38] and have been used to assess trends in species composition along different environmental gradients [39]. A detrended correspondence analysis (DCA) was employed to analyze species composition gradient. A polygon was delineated on the plane defined by the DCA axes I and II to enclose the sites of each stream in Tenerife and La Gomera. Furthermore, a second DCA graph was generated from the same analysis, with streams sampled at the same year (independently of La Gomera or Tenerife) enclosed in the same polygon. It is anticipated that the island species composition will be distinguished, as well as the different sampling year of the streams. Permutational repeated measure ANOVAS procedures were performed using the PRIMER v6 and the add-on PERMANOVA+ software [37], while ordination analyses were performed using CANOCO v4.5, Microcomputer Power, Ithaca, NY, USA.

3. RESULTS

A total of 75 taxa belonging to 12 orders and 34 families were collected between 2006 and 2023 (Supplementary material, Annex 1). The number of species recorded on each island was 64 for Tenerife and 61 for La Gomera. The endemic species collected represent 36% of the freshwater invertebrate fauna. **Table 2** shows the distribution of species richness at the sites over the whole sampling period from 2006 to 2023.

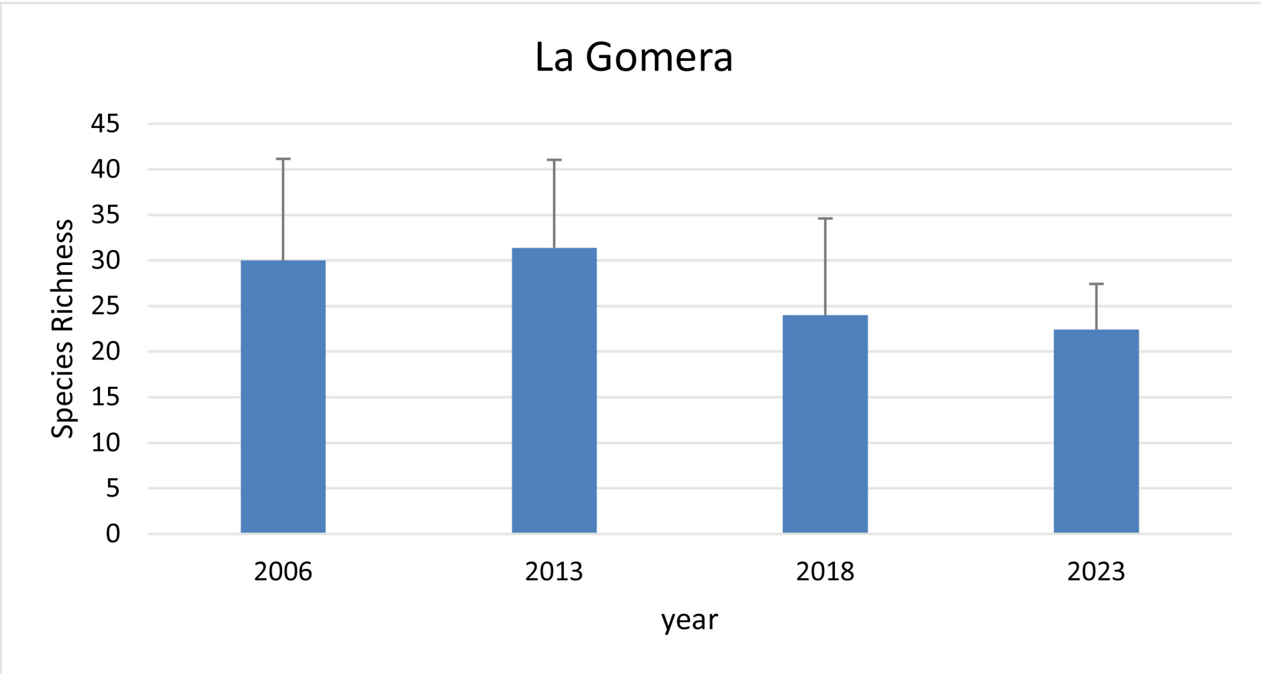
Regarding taxonomic groups, Coleoptera was the richest group (24 species) followed by Trichoptera (10 species), both with high levels of endemicity. The most diverse family was the Dytiscidae (Coleoptera) with 14 species, four of which are endemic. It is noteworthy that the order Crustacea consisted of only two species, although both are endemic, one of which (*Rhipidogammarus gomeranus* Beyer & Stock 1994) has not been reported in recent years.

In 2013, Barranco del Infierno (TF2) and El Cedro (LG2) were found to contain 50 and 47 species respectively, of which 30% and 45% were endemic (**Table 2**). These two streams served as reference sites. The results of this campaign demonstrated that most sites have experienced a significant decline in species diversity, with notable losses among endemic and sensitive ones. It should also be noted that the losses mainly affected stream sites in strictly protected areas (LG2, LG4, LG5, TF2). Moreover, in LG2, LG4 and LG5, the number of endemic species has declined by between 50 and 80% (Table 2). LG4 has lost most of its species and the situation at LG5 is only slightly better. Additionally, more species are endangered and several of them were not recorded in the period from 2018 to 2023, among them: *Lepidostoma tenerifensis* (Malicky 1992), *Ochthebius lapidicola* (Wollaston 1864), and *Rhipidogammarus rheophilus* (Stock & Sánchez 1990). Others, such as *Meladema imbricata* (Wollaston 1871) and *Tinodes canariensis* (McLachlan 1883) have also become scarce.

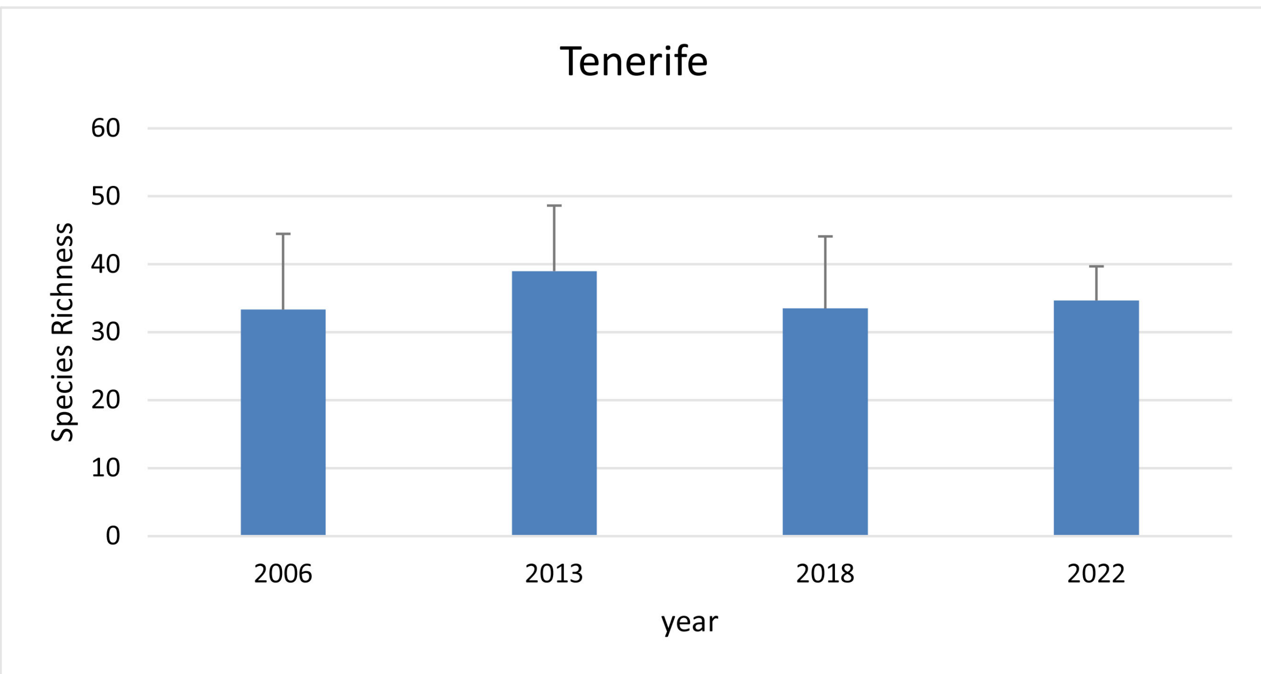
Table 2. Development of the Ecological Integrity, number of macroinvertebrate species, endemics and sensitive species of 8 Canarian streams in La Gomera (LG) and Tenerife (TF).

Code Year	Ecological Integrity	total number of species	number of endemic species	number of sensitive species
LG 1/06	4.3	35	14	3
LG 1/13	4.7	42	16	5
LG 1/18	3.8	27	7	2
LG 1/23	4.0	34	12	3
LG 2/06	4.8	46	21	12
LG 2/13	4.8	47	21	12
LG 2/18	3.9	22	13	8
LG2 /23	4.1	25	12	7
LG 3/06	2.2	16	6	1
LG 3/13	2.5	21	7	1
LG 3/23	4.0	29	11	5
LG 4/06	4.3	28	15	8
LG 4/13	4.0	25	12	6
LG 4/23	1.6	10	3	1
LG 5/06	4.1	25	13	6
LG 5/13	4.1	22	10	6
LG 5/18	4.0	23	14	8
LG 5/23	2.5	14	5	4
TF1/06	2.5	25	4	3
TF1/13	3.0	35	7	2
TF1/18	4.1	40	12	4
TF1/22	3.3	34	8	1
TF2/06	4.7	46	16	8
TF2/13	4.4	50	15	7
TF2/18	4.4	41	13	7
TF2/22	4.1	40	11	5
TF3/06	4.4	29	17	9
TF3/13	4.7	32	17	9
TF3/22	4.6	30	15	7

Several patterns in species richness and composition were identified in the macroinvertebrate communities of Tenerife and La Gomera. A comparison of the average values of species richness reveals that the island of Tenerife exhibits higher values than La Gomera (**Figure 2(a)**, **Figure 2(b)**). In terms of evenness, the variation was relatively small, revealing that for the years in which the richness was lower, evenness values increased (very likely due to a low number of rare species that appeared in some years and disappeared later; **Figure 2(c)**, **Figure 2(d)**).



(a)



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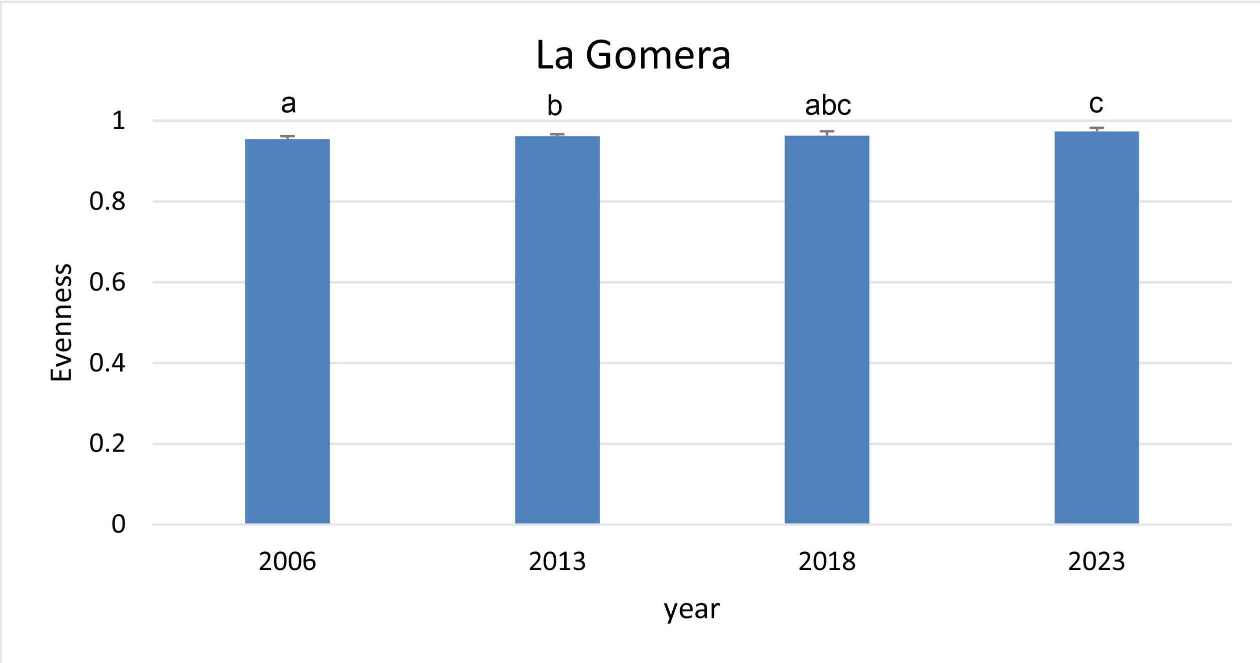
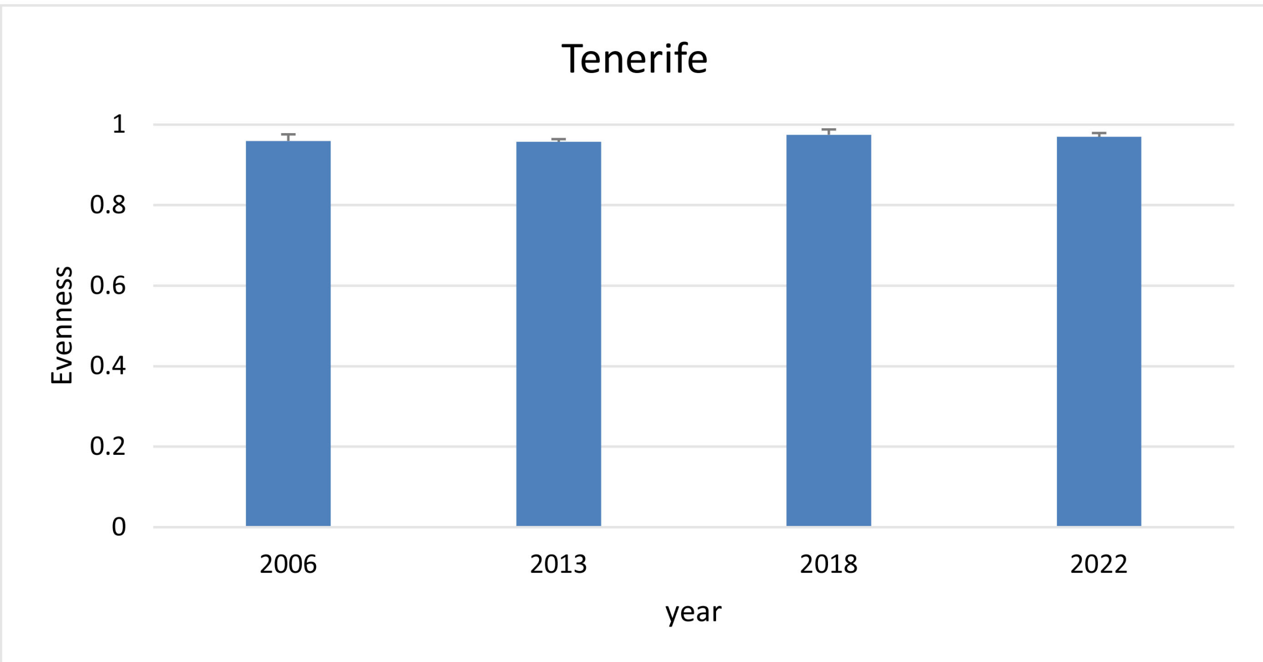


(c)



(d)

Figure 2. Mean values and standard deviation for (a, b) patterns in species richness and evenness index (c, d) of macroinvertebrate community on Tenerife and La Gomera.

In the case of La Gomera, using the island as a paired factor, differences in species richness over the years were not significant (Figure 2(a); Pseudo F3, 14= 0.775, p = 0.121) nor for the island of Tenerife (Figure 2(b); Pseudo F3, 14 = 0.266, p = 0.326). In the case of the Smith and Wilson evenness on La Gomera, the differences over the years were significant (Figure 2(c); Pseudo F3, 14 = 5.061, p = 0.0015), with lower values of evenness at the beginning of the sampling compared to later years. As for Tenerife, evenness did not reveal any significant differences (Figure 2(d); Pseudo $F_{3, 14} = 3.42$, $p = 0.091$).

Additionally, the species composition revealed differences based on the DCA analysis (cumulative explained variation of axis I and II: 26.25, total variation: 1.41).

Figure 3 shows the two-dimensional space of axes I and II of the DCA. In the graph, species coordinates and site coordinates are presented, but for the latter, we have included all the sampling sites of different years on La Gomera and Tenerife in a different polygon. The species composition of the streams of La Gomera and Tenerife can be discriminated, but a small proportion of the polygons overlapping, indicating that species composition does not differs completely among islands. The dominant species detected for La Gomera are the following: *Baetis gomerensis* (Gattolliat & Sartori 2018), *Chaetogammarus chaetocerus* (Beyer & Stock 1994), *Gordius aquaticus* (Linnaeus 1758), *Mesophylax aspersus canariensis* (McLachlan 1882), *Oxyethira spinosella* (McLachlan 1883), *Pisidium casertanum* (Poli 1791), *Rhipidogammarus gomeranus* (Beyer & Stock 1994), and *Wormaldia tagananana* (Enderlein 1929) (these species are located to the left of the two-dimensional space). In the case of Tenerife, the dominant species on the island are *Agabus nebulosus* (Forster 1771), *Anax imperator* (Leach 1815), *Cloeon dipterum* (Linnaeus 1761), *Crocothemis erythraea* (Brullé 1839), *Meladema coriacea* (Laporte 1834), *Notonecta canariensis* (Kirkaldy 1897), and *Physella acuta* (Draparnaud 1805).

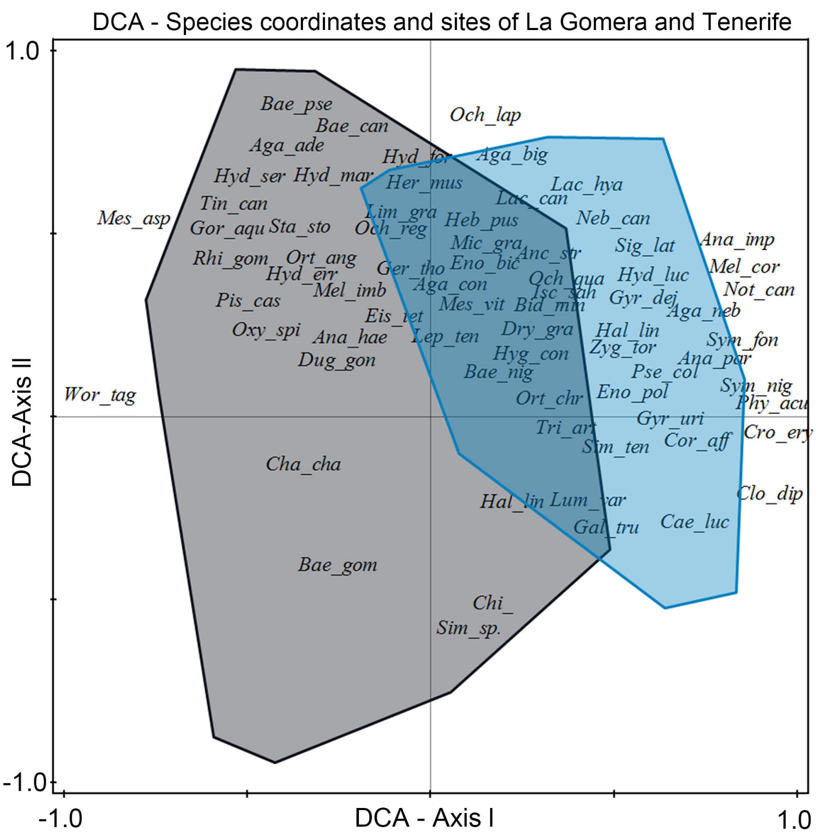


Figure 3. Species scores in the ordination space defined by axis I and axis II of the DCA derived from basal area. Polygons enclose the sampling sites in different years for both island, thick blue shade for Tenerife, and gray shade for La Gomera. Species names are indicated with the first three letters of genus and three first letters of the specific epithet (full names of the species in the Appendix).

The same analysis is presented in Figure 4 but now with discrimination based on the sampling year. In 2023, all the streams sampled were from La Gomera and were highly discriminated from the rest of the years, with a dominance of *Baetis gomerensis*, Chironomidae and Simulium sp. A similar pattern was observed for the island of Tenerife, the only island sampled in 2022, showing a dominance of *Crocothemis erythraea* (Brullé 1839) and *Cloeon dipterum* (Linnaeus 1761). In contrast, for the other years, discrimination was not as pronounced, with a higher variation in species composition observed in 2006 and lower variation in other years, probably related to the lower sampling.

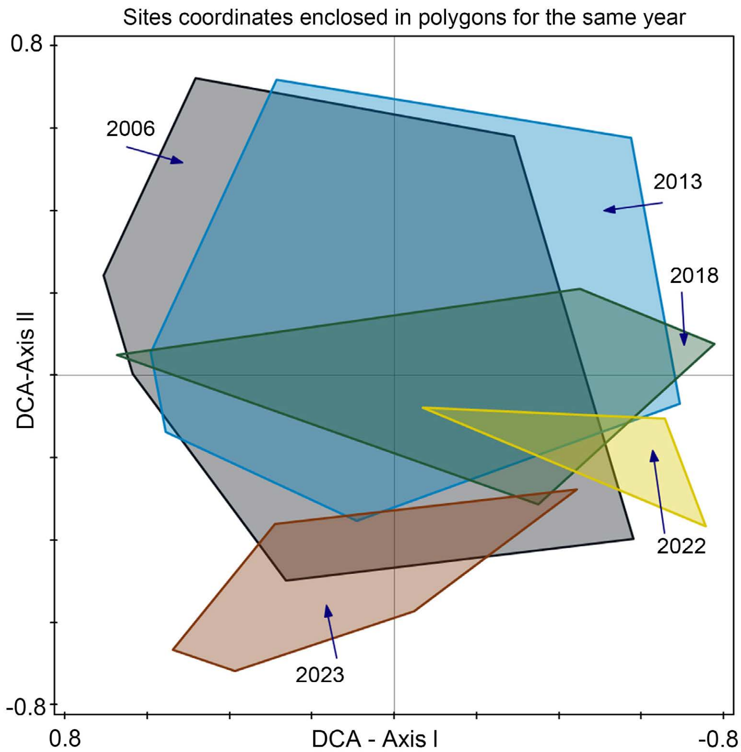


Figure 4. Polygons with different colors enclose the sampling sites for each year for both islands. The year is indicated with an arrow pointing to the polygon.

4. DISCUSSION

The present paper investigates the long-term evolution of aquatic macroinvertebrates in small streams of the Canary Islands. The islands of La Gomera and Tenerife were selected because they both have permanently flowing streams. Consequently, the impact of total desiccation can be disregarded. The majority of the monitoring was conducted in water bodies in strictly protected areas. This allows us to exclude the influence of sewage, hydraulic engineering, and intensive land use. MI were chosen because their species numbers are quite high and their environmental quality requirements are very diverse, so they can be used as premium bioindicators [10, 11, 16]. Other groups of organisms commonly used for aquatic bioindication are either absent, such as freshwater fishes, or present with very few species, such as aquatic macrophytes. An assessment based on MI has been developed [10] and improved [11] for the conditions of island ecosystems.

Ordination techniques help explain community variation as it is a useful tool to evaluate trends over time, as well as space [40]. From the perspective of species composition, the islands of La Gomera and Tenerife exhibit notable distinctions, as observed through the discriminant analysis in multivariate assessments (see Figure 3; DCA). These disparities can be mainly attributed to both islands' long-standing isolation, as well as varying natural histories, alongside environmental and climatic conditions. This evidence highlights the need for the implementation of tailored analyses for each site to extract meaningful insights into species diversity and composition.

Moreover, these spatial discrepancies in species composition are accompanied by temporal variability. Fluctuations in environmental conditions over the years reveal shifts in species composition. Consequently, effective conservation strategies for streams must encompass both spatial and temporal dimensions. By acknowledging the dynamic interplay between environmental factors and species composition, conservation efforts can be more finely tuned to safeguard the delicate balance of aquatic ecosystems. In these studies, the most diverse streams in the Canary Islands were the Barranco del Infierno in Tenerife followed by El Cedro in La Gomera, and were classified as having a "good ecological status" [10]. The highest levels of endemism were found in Meriga (LG 4), within the Garajonay Natural Park, which is one of the best-preserved remnants of laurisilva in the world [41].

Recent trends in limnological biodiversity and freshwater ecosystem quality are characterized by declines in both. Comparing the data from the years 1995 [5] and 1998 [15] with our data collected between the 2006 and 2013, reveals the absence of up to ten endemic species, most of them with lotic preferences, perhaps indicating that some of them have been lost forever [11]. The main reason is the continuous reduction in surface water. In 1860, Tenerife still had 22 perennial streams that flowed into the sea, but today there is not even one left [42]. The remaining natural watercourses on Tenerife and La Gomera are short, isolated and carry very little water even in summer and early fall [11]. Expectations that the situation would improve have not materialized. In the years since 2013, there has been a further deterioration in the status of most of the remaining water bodies. There has also been a significant decline in endemic and sensitive species, both in terms of numbers and abundance. As a result, such species are increasingly being pushed to the brink of extinction. A study on the island of Madeira, which is considerably wetter than the Canary Islands and has more permanent streams, revealed that freshwater endemics are also under significant pressure [16]. They have decreased in number and, probably, also in individual abundance over the last 30 years compared to the results from [13]. This particular insular biodiversity crisis, affecting, in this case, Macaronesian freshwater streams, is not an isolated case; it is part of a wider trend that is collapsing the outstanding island natural heritage worldwide [43]. This crisis is rooted in the unsustainable use that humans make of the islands' resources. It is unfortunate that, in contrast to other endemic Canarian vertebrate species (such as birds, reptiles or bats), the endemic invertebrate species living in these streams are not sufficiently charismatic or known by the local society to be properly valued; this translates into a lack of pressure on public authorities to conserve them. Conversely, the pressure exerted by landowners and farmers, especially those engaged in export-oriented agriculture (such as bananas or flowers, which demand very high supplies of freshwater), is especially intense regarding the use of existing freshwater sources. Consequently, the potential for stream restoration is currently non-existent.

A case in point, is the creek at Meriga (LG 4) in the center of the Garajonay National Park, which provides an illustrative example of poor water management. Due to its limited size and length, the creek has never supported a particularly diverse array of species, although there is a high proportion of endemic and sensitive species. In recent years, however, two pipes (**Figure 5**) have been installed in addition to the existing canal that draw almost all the water from the stream near the source. The result has been a complete collapse of the macroinvertebrate biocoenosis.

It is important to note that not all sites have experienced negative outcomes. A significant proportion of the sampled locations (TF1, TF2, TF3 & LG3) have demonstrated a notable improvement in their ecological condition over the past 15 years, despite the absence of dedicated ecological restoration initiatives. This evidence suggests that these communities possess the capacity for spontaneous recovery when anthropogenic pressure is reduced or eliminated. Thus, despite their decline, Macaronesian freshwater ecosystems still have a high conservation value and should be subject to conservation and restoration measures. In many European territories, the implementation of the Water Framework Directive (WFD) has facilitated the restoration of numerous freshwater bodies. However, management entities have largely neglected the restoration of small water bodies on islands. The conservation of freshwater ecosystems and macroinvertebrates depends on the implementation of specific conservation programs for these habitats. The establishment of a specific eco-region within the WFD for the Macaronesian archipelagos (Azores, Madeira and the Canary

Islands) would serve to highlight the current state of these streams and oblige financial support for conservation or ecological restoration projects for these habitats.

Figure 5. Drainage of Meriga (La Gomera) stream water by means of open canal and pipes (V. Lüderitz).

The identification of reference ecosystems is a fundamental aspect of restoration projects, as it allows for the assessment of optimal hydromorphological, physico-chemical and biological conditions. In protected areas such as the Barranco del Infierno in Tenerife and El Cedro in La Gomera, we identified streams that are very close to their natural state, but even these natural treasures are disappearing. To halt this ongoing degradation, it is essential to achieve reasonable hydromorphology for streams to restore their ecological functions [44, 45]. The scale at which hydromorphological degradation has its greatest impact is on the benthic macroinvertebrate community [10], rendering them ideal bioindicators of stream conditions. While restoring stream morphology is important, another concern is the drying up of the streams due to water abstraction and diversion. It is imperative that measures are taken to prevent, to the greatest extent possible, the abstraction of water from the sources and natural courses of the streams. Similarly, freshwater streams and their associated madicolous habitats are also vulnerable to desiccation. The development of new industrial water production techniques, such as the use of treated water for irrigation or desalinated water for human consumption, opens new possibilities for the recovery of these ecosystems.

5. CONCLUSIONS AND IMPLICATIONS

Biodiversity as the diversity of species, ecological functions, habitats and ecosystems at all is essential for the processes that support all life on Earth, including humans. Without a wide range of animals, plants and microorganisms, we cannot have the healthy ecosystems [46]. The biodiversity and endemicity of freshwater macroinvertebrates found in Canary Island streams are noteworthy, particularly given the relatively small amount of water they contain. However, these species are highly endangered given the poor state of conservation of the streams at present.

The legislation in place for their conservation at both local and international levels is inadequate. It is therefore essential to establish a differentiated eco-region for the Macaronesian archipelagos in the Water Framework Directive, given the different characteristics of the river basins and species assemblages that inhabit them. The protection of the laurisilva forests, which are currently unprotected, should be included in the conservation measures.

The phenomenon of the most protected areas exhibiting the highest levels of endemism and biodiversity is also present in the Canary Islands. It is, therefore, proposed to protect streams in La Gomera and Tenerife by restoring their hydromorphology and eliminating water catchments and diversions from them.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Volker Lüderitz: conceptualization, methodology, validation, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, project administration; José María Fernández-Palacios: validation, writing—review and editing, supervision; Uta Langheinrich: software, data curation, visualization; Cristina González Montelongo: methodology, editing, data curation; Jose Ramon Arevalo: conceptualization, methodology, software, validation, formal analysis, resources, writing—review and editing, visualization. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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SUPPLEMENTARY MATERIALS

The supporting information can be found in **Appendix 1** (abundances of MI-species in streams on La Gomera and Tenerife) and **Appendix 2** (climatograms of La Gomera and Tenerife).

APPENDIX 1. ABUNDANCES OF MACROINVERTEBRATE SPECIES IN STREAMS ON LA GOMERA AND TENERIFE

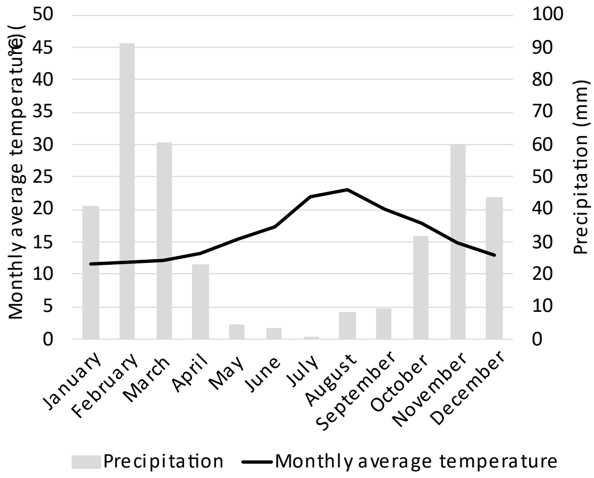
La Gomera	endemic species	sensitive species	LG1 La Laja				LG2 El Cedro				LG3 B.d. Aqua			LG4 Meriga			LG5 El Rejo			
Species / Year			2006	2013	2018	2023	**2006**	**2013**	**2018**	**2023**	2006	2013	2023	**2006**	**2013**	**2023**	2006	2013	2018	2023
Agabus biguttatus				2	2		3	4		3				2	2					
Agabus conspersus				3			3	3										2		
Agabus nebulosus			5	3	3	3		2												
Agapetus adejensis	x	x	4	3	3	3	4	3	4	3				5	3		3	3	4	
Anacaena haemorrhoa	x	x						3	2	3			3	3	3		2	3	3	2
Anax imperator			4	4	4	4	3	4				3	4							
Anax parthenope			4	2	4															
Ancylus fluviatilus striatus	x		4	4	4	3	5	5		3	4	4	3	4	3	3	4	4	3	
Baetis gomerensis	x	x	5	3		4	5	3	5	4			4	3	2		4	2	5	3
Baetis nigrescens					3	3	3	3	4	3	4	4	3	3	2					
Baetis pseudorhodani	x	x	3	3			4	5	4					4	3		3	4	5	
Caenis luctuosa					3				3				3							
Chaetogammarus chaetocerus	x	x					3	3			4	4	6	3						
Chironomidae						4				4			4			4				4
Cloeon dipterum			4	4	5	6			3		5	5	3							
Crocothemis erythrea			3	4	4							2	3							
Dryops gracilis			5	3	4	4	4	3	5		5	5	3	4	4	3	4	3		3
Dugesia gonocephala			4	4	4	4	5	4		4			4	5	4	4	5	4	4	3
Eiseniella tetraedra			3	3	4	4	3	3						3	2	5	3	3	4	4
Enochrus bicolor																	2			
Enochrus politus			3														2			
Galba truncatula					3	4					3	3	3				4	3		
Gerris thoracicus				4			4	4		3	4	5		4	3		3	2		3
Gordius aquaticus							3	2												
Gyrinus dejeani			5	4	4	6	4	4		4	4	3	4	4	4	3			3	
Gyrinus urinator			3	4	4	4	3	3	5	4		3	3			3				
Haliplus lineatocollis suffusus	x		3	3	3	3														
Hebrus pusillus canariensis	x		3	3		3	2	4		3									2	
Herophydrus musicus				3			4	3						3						
Hydraena serricollis	x	x					3	4	3	3				3	3				3	
Hydrometra stagnorum			4	3		3	5	4		3	5	5	4	3	3		4	2		3
Hydroporus errans	x		3	3		3	3	3	3		3	3	3	3	3		3	4		
Hydroporus lucasi		x		2														2		
Hydropsyche maroccana			3	3	4	3	5	5	4	3	2	4	3	4	4		4	3	4	3
Hydroptila fortunata	x		3	3		3	3	4	3					3	3		2		3	
Hygrotus confluens			3				2													
Laccobius canariensis	x		3	4			2	2	3										3	
Laccophilus hyalinus			2	4	4	4	4	3	3					4	3		3	3	3	
Limnobius gracilipes							3	2	2											
Lumbriculus variegatus					4															
Meladema coriacea			2	3		3	3	4												
Meladema imbricata	x	x					2													
Mesophylax aspersus canariensis	x		3	4	4	3	6	5	5	3	3	4	3	6	5		6	4	4	3
Microvelia gracillima				2		3	3	3		3					2					
Nebrioporus canariensis	x		3	4		3	4	5	3	3	3	3	3	3	4		3	3		
Notonecta canariensis	x		4	4	4	4	3	4		3		4	3							
Ochthebius lapidicola	x		3	3			3	3												
Ochthebius quadrifoveolatus			2	3		3														
Ochthebius regulosus				3			3	3	3			3			4				2	
Orthetrum chrysostigma			5	4		4							4				3	3		
Orthotrichia angustella		x					2	3												
Oxyethira spinosella	x	x			3		4	3	3										2	
Physella acuta			4	4	3	4	2	3		4	3	3	3						3	
Pisidium casertanum							4	4			3	4	3	5	3		4	4	3	
Rhipidogammarus gomeranus	x						4	3						3			3			
Sigara lateralis			4	4			3	3						2						
Simulium sp.					3	4				4			5			4			4	4
Stactobia storai	x	x					3	3		3				3						
Sympetrum fonscolombei			3	3	5	4		3												
Sympetrum nigrifemur	x			3	4	4							3							
Tinodes canariensis	x	x					4	3	4								3		3	
Velia lindbergi	x		4	4		5	4	4		5	5	5	4	4	3	3	4	3	3	4
Wormaldia tagananana	x	x		2			5	4	4	3			3	4	2	2	5	4	5	4
Zygonyx torridus		x				3	2	2		3			3							2

Tenerife	**endemic species**	**sensitive species**	**TF1 Afur**				**TF2 B.d. Infierno**				**TF3 B.d. Rio**		
Species / Year			2006	2013	2018	2022	**2006**	**2013**	**2018**	**2022**	2006	2013	2022
Agabus biguttatus					3	2	4	4	3	3	4	4	3
Agabus conspersus			2	3									
Agabus nebulosus			3	3	3			2	3			3	3
Agapetus adejensis	x	x					4	4	3	3	3	4	3
Anacaena haemorrhoa	x	x	3		3	3	3	3	2	3	3	4	3
Anax imperator			4	4	4	4	4	4	4	5	4	5	3
Anax parthenope				4	3	3	3	3	2				
Ancylus fluviatilus striatus	x		4	4	4	4	4	4	4	3	4	4	3
Baetis nigrescens				3	4		3	4	3	3			3
Baetis pseudorhodani	x	x		4			5	5	4		6	5	4
Baetis tenerifiensis	x	x			4		4	4	4	3	5	5	4
Bidessus minutissimus								4					
Caenis luctuosa			3	4	4	4			3	5			
Chironomidae						5			4	5			
Cloeon dipterum			5	5	5	5	4	4	4	5			5
Corixa affinis			2	2	3	2		2					
Crocothemis erythrea			4	5	5	4	3	3	3	4	3	3	3
Dryops gracilis			3	3	3	4	5	4	5	4	4	4	3
Dugesia gonocephala					3	4	4	4	4	3		3	
Eiseniella tetraedra				4	3	4	4	4	4	4	4	4	3
Enochrus bicolor							3	3					
Enochrus politus			3		3			3		3		2	
Galba truncatula			5	5	3	4	4	4		4			
Gerris thoracicus			3	3	4	3	3	3	4	3	4	4	
Gyrinus dejeani			4	4	5	5	4	5	4	4	5	6	4
Gyrinus urinator			4	4	4	4	3	5	3	4			4
Haliplus lineatocollis suffusus	x				4	5	3	3		3			
Hebrus pusillus canariensis	x			2	3						3	3	
Herophydrus musicus								3					
Hydraena serricollis	x	x					3	3	2		3	3	3
Hydrometra gracilenta													4
Hydrometra stagnorum					4	3	4	4	3	4			3
Hydroporus errans	x					3	3		4		3	4	3
Hydroporus lucasi		x	3	4	4		4	2	4	3	4	3	
Hydropsyche maroccana				4	4		5	5	5	3	3	4	
Hydroptila fortunata	x				3			3		3	4	4	3
Hygrotus confluens			5					3					
Ischnura saharensis				2			2	2					
Laccobius canariensis	x				3		3	3	3				3
Laccophilus hyalinus				4	4	5	4	4	5	5	4	3	
Lepidostoma tenerifiensis											2		
Limnobius gracilipes							3						
Lumbriculus variegatus						4							
Meladema coriacea			5	3	3	4	4	4	4	3			
Meladema imbricata	x	x									4	4	4
Mesophylax aspersus canariensis	x				2		3	3	4	4	4	4	5
Mesovelia vittigera							3						
Microvelia gracillima				2			5		3	3			
Nebrioporus canariensis	x		4	5	4	4	4	5	4	4	5	4	4
Notonecta canariensis	x		4	4	5	4	3	5	4	4	4	4	4
Ochthebius lapidicola	x						3	2			3	3	
Ochthebius quadrifoveolatus							3	3					
Ochthebius regulosus				3			3	3					
Orthetrum chrysostigma			5	4	4	5		4	5	4	4	4	4
Physella acuta			5	5	4	4	5	5	5	4			
Pisidium casertanum							3	3	3	3			
Pseudosuccinea columella			2	2		2	2	3					
Sigara lateralis				3	4	3	4	3		4			
Simulium sp.					4	4			4	3			
Simulium teneriferum						4			4	4			4
Stactobia storai	x	x									3	3	
Sympetrum fonscolombei			4	3	4	3		4	3	4		2	
Sympetrum nigrifemur	x			4	4	5	3	3	4	4	3	3	4
Tinodes canariensis	x	x					3				3	3	
Trithemis arteriosa				3									
Velia lindbergi	x			4	4	3	3	4	4	4			3
Zygonyx torridus		x	2		4		5	5	4	2			2

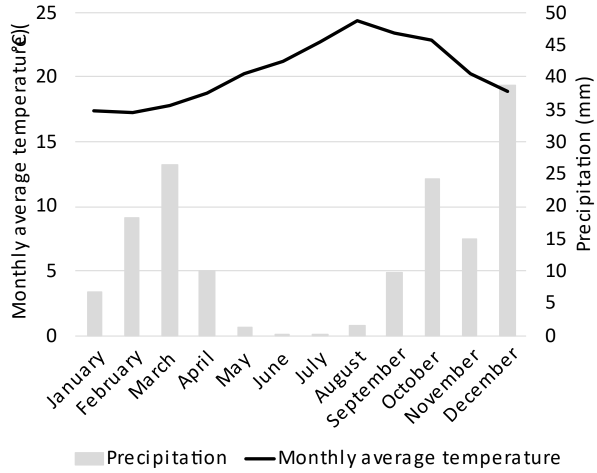
APPENDIX 2. CLIMATOGRAMS OF LA GOMERA AND TENERIFE

TENERIFE

Walter Lieth climate diagram
C415A Weather station
(Santiago del Teide, 990 m a.s.l.)
(climate record: May 2014 - February 2023)

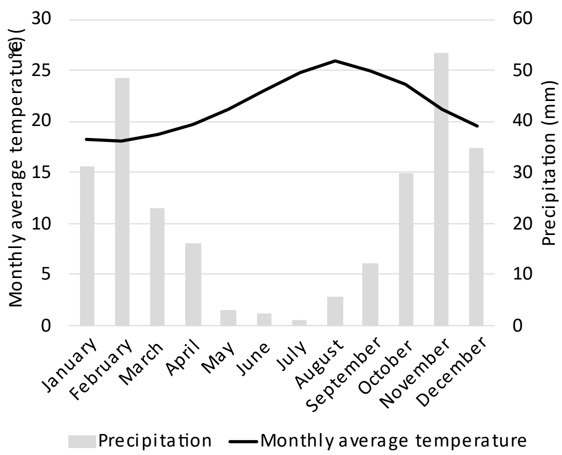


Walter Lieth climate diagram
C418P Weather station
(Adeje, Los menores segunda, 384 m a.s.l.)
(climate record: July 2011 - December 2021)

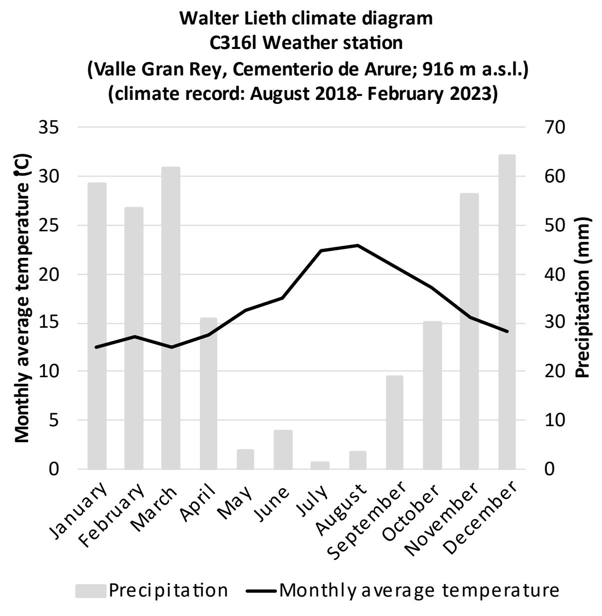


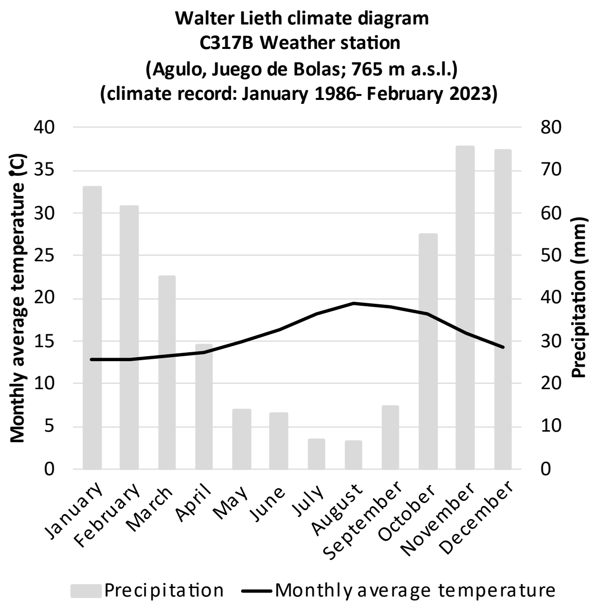
TENERIFE

Walter Lieth climate diagram
C449F Weather station
(Anaga, San Andrés, 19 m a.s.l.)
(climate record: May 2009 - February 2023)



LA GOMERA


Walter Lieth climate diagram
C316I Weather station
(Valle Gran Rey, Cementerio de Arure; 916 m a.s.l.)
(climate record: August 2018- February 2023)
Monthly average temperature (C)
Precipitation (mm)
January
February
March
April
May
June
July
August
September
October
November
December
Precipitation
Monthly average temperature


Walter Lieth climate diagram
C317B Weather station
(Agulo, Juego de Bolas; 765 m a.s.l.)
(climate record: January 1986- February 2023)
Monthly average temperature (C)
Precipitation (mm)
January
February
March
April
May
June
July
August
September
October
November
December
Precipitation
Monthly average temperature