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# Using low-cost water presence-absence sensors to assess the regime of headwater streams relevant to the development of aquatic life in the Canary Islands

Francesc Gallart[a,*], Jérôme Latron[a], Miriam Salguero-Sandoval[a,1], Raúl Acosta[a], José María Fernández-Calero[b], Núria Cid[c], Miguel Cañedo-Argüelles[a,2], Pilar Llorens[a]

[a] SHE2 (Surface Hydrology, Ecology and Erosion Group), Institute of Environmental Assessment and Water Research (IDAEA, CSIC), Jordi Girona 18-26, E-08034 Barcelona, Catalonia, Spain

[b] FEHM-Lab (Freshwater Ecology, Hydrology and Management), Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Facultat de Biologia, Institut de Recerca de la Biodiversitat (IRBio), Universitat de Barcelona (UB), Diagonal 643, E-08028 Barcelona, Catalonia, Spain

[c] IRTA Marine and Continental Waters Programme, Carretera de Poble Nou, Km 5.5, E-43540 La Ràpita, Tarragona, Catalonia, Spain

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A B S T R A C T

The streams of the Canary Islands are highly vulnerable habitats with the potential to harbour a rich biodiversity, including endemic and endangered species. However, they remain poorly studied because they are commonly perceived as mostly dry and having a low conservation value. This study is the first to characterize the hydrological regime of these water bodies, shedding light on their potential as key habitats for aquatic organisms, as a first step within two projects that study aquatic life in these streams. Temperature and light intensity HOBO Pendant sensors modified for estimating the electrical conductivity of water were installed in 32 remote small stream reaches on the islands of Tenerife, La Palma, and La Gomera. In most of the reaches, one sensor was installed in a riffle and another at the bottom of a pool, in order to distinguish the condition of the reach between the three aquatic phases that control the occurrence of aquatic habitats: *flow, disconnected pools* and *dry riverbed*. Some of the sensors could not be recovered or suffered other problems, resulting in 22 reaches with valid records spanning different temporal gradients (from 2 to 12 months). Both relative electrical conductivity and daily variance of temperature were used to determine the daily presence-absence of water. The data served to obtain metrics describing the relative frequencies of the three aquatic phases and report the changes in stream aquatic habitats relevant for aquatic organisms between sampling visits.

Eleven reaches showed perennial regimes, four showed regimes dominated by flow sometimes switched to disconnected pools, other four showed regimes rotating between the three phases and the remaining three were dry during all the monitoring periods. These results point to more favourable conditions to the development of aquatic life in these islands than previously expected because, from available data, 50% of the monitored reaches showed continuous flow phase and 73% of them showed permanence of surface water as either *flow* or *disconnected pools* phases during >90% of time. These results also demonstrate the value of recording the *disconnected pools* phase when aquatic life is the focus: if perennial and permanently dry reaches are discarded (eight remaining points), the averaged flow permanence was only 61% of time, while the averaged permanence of surface water increased to 90%. Given the potential of these streams to harbour endemic and endangered species within the context of a global freshwater biodiversity crisis, we call for further efforts to monitor and protect small streams in oceanic islands.

* Corresponding author.
*E-mail address:* francesc.gallart@idaea.csic.es (F. Gallart).

[1] Present address at the Department of Earth and Environmental Sciences, University of Texas at Arlington, Geoscience Building, Room 107, 500 Yates St., Arlington, Texas 76019, USA

[2] Since 16 April 2025, Miguel Cañedo-Argüelles has been seconded to the European Research Council (ERC) Executive Agency (ERCEA), European Commission, COV 2, B-1049 Bruxelles/Brussel, Belgium. The views expressed in this paper are purely those of the author. They do not necessarily reflect the views or official positions of the European Commission, the ERC Executive Agency or the ERC Scientific Council.

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## 1. Introduction

Colour should be used for all figures and the table

We are facing a global freshwater biodiversity crisis, with species disappearing at alarming rates (Dudgeon et al., 2025). Yet streams in oceanic islands remain poorly studied, even when they are subjected to strong water stress derived from a combination of human demands for water and climate warming (Fernández-Palacios and Whittaker, 2008; Nogué et al., 2021; Vidaña, 2020). Within this context, the hydrological characterisation of these habitats is a crucial first step towards the conservation of aquatic biodiversity, because hydrological conditions determine habitat availability and the structure of biological communities (Datry et al., 2017; Magand et al., 2020).

When aquatic life is the main focus, the characterization of the hydrological regime of potentially temporary water courses (those that cease to flow recurrently, including both intermittent and ephemeral ones) must primarily take into account the presence-absence of surface water (Arscott et al., 2010; Boulton, 1989; Fernández-Calero et al., 2025; Uys and O'Keeffe, 1997). Therefore, it is not enough to obtain data on the flow and zero flow periods, but it is also necessary to characterize the relative frequency (permanence) of disconnected pools after the cessation of flow (Bonada et al., 2020; Gallart et al., 2012; Pineda et al., 2022). Even when aquatic life is not the study focus, rigorous analysis of stream network dynamics may require attention to the phase of disconnected pools as it may play a role in water storage and subsurface flow (Assendelft and van Meerveld, 2025; Eastman et al., 2021; Sefton et al., 2019).

As temporary headwater streams are usually ungauged and the few available gauging stations rarely provide reliable information when flow is close to zero (Zimmer et al., 2020), several alternative methods are used to gather information on their regime. These methods include i) onsite observations periodically made either by professionals (Godsey and Kirchner, 2014; ONDE network (www.onde.eaufrance.fr/); Eastman et al., 2021; Sefton et al., 2019) or trained citizens (Allen et al., 2019), ii) onsite occasional observations made by citizens (www.crowdwater.ch; www.dryver.eu), iii) series of aerial or ground photographs (Gallart et al., 2016; Turner and Richter, 2011 and 2017), iv) remote sensing (Maswanganye et al., 2022), v) interviews (Gallart et al., 2016 and 2017), vi) time-lapse photography (Costigan et al., 2017; Straka et al., 2019), vi) water presence sensors (Blasch et al., 2002; Chapin et al., 2014 among others), and vii) pairing water presence and water flow sensors (Bhamjee et al., 2016; Assendelft and van Meerveld, 2025). In a recent study, Mimeau et al., 2025 used most of these methods to develop a modelling approach for anticipating flow intermittency in a set of European river networks.

There are several examples where the information on the relative frequency (permanence) of the three phases gathered from flow records, interviews and series of direct or photographic observations were converted into metrics that allowed the characterisation of stream regimes for surveying or management purposes, sometimes including aquatic life concerns (de Girolamo et al., 2022; Gallart et al., 2017; Munné et al., 2021; Nabih et al., 2021). In contrast, the continuous water presence sensors accompanied by flow sensors have been used primarily for research purposes in physical hydrology, such as the expansion and contraction dynamics of stream networks (Jaeger and Olden, 2012; van Meerveld et al., 2019; Kelly and Bruckerhoff, 2024; Assendelft and van Meerveld, 2025). In spite of the hydrological and ecological relevance of the presence of disconnected pools after the cessation of flow and the

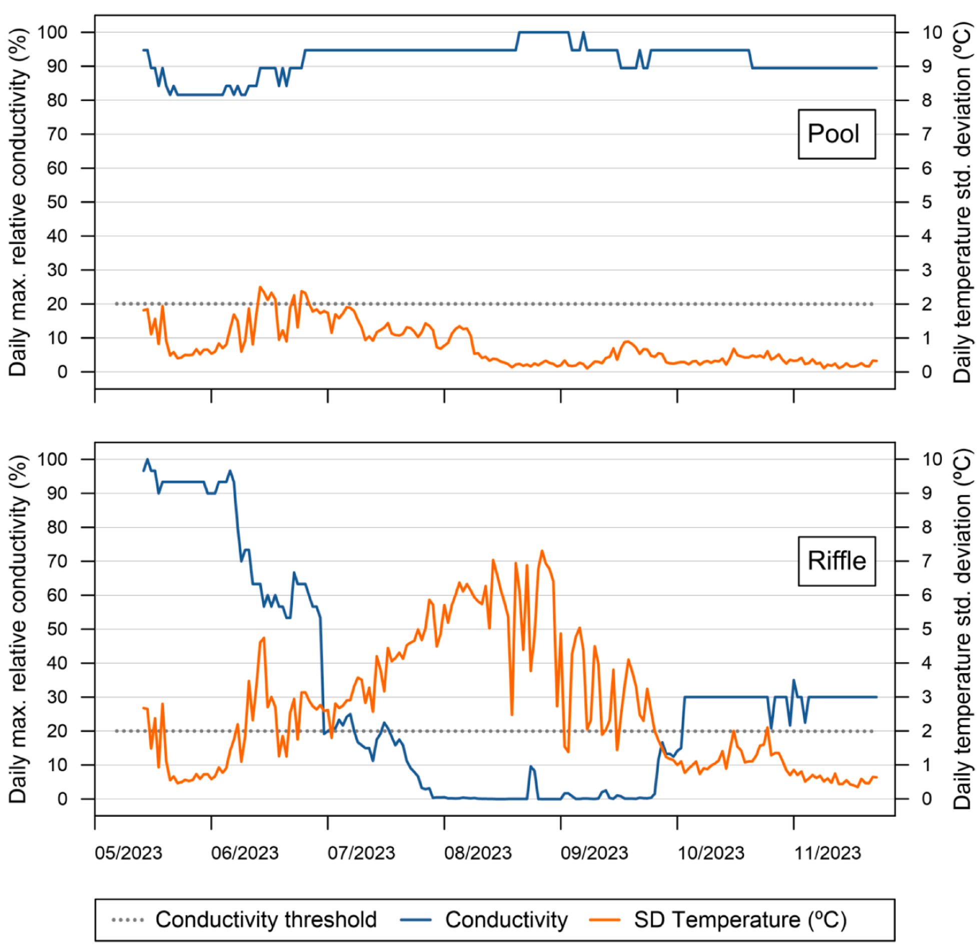


**Fig. 1.** Elaborated responses of the sensors installed at the CT2 site.

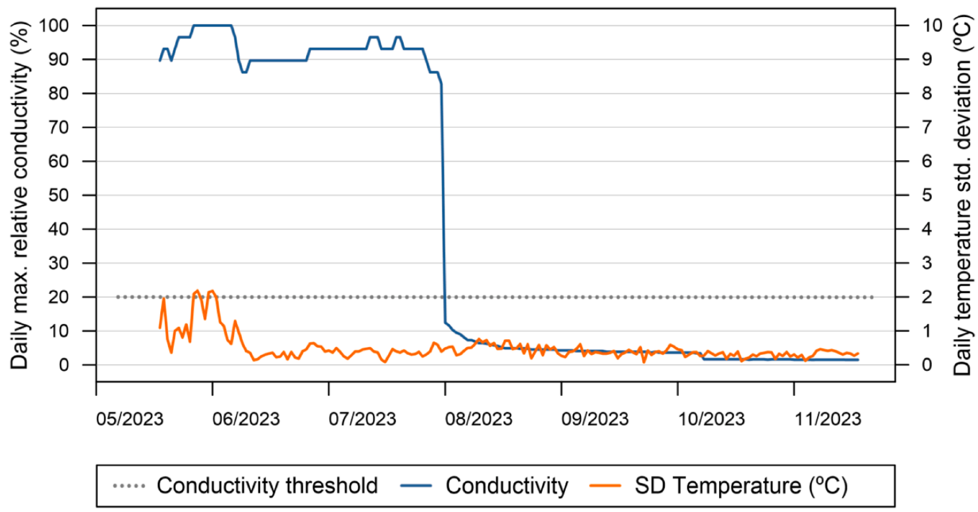


**Fig. 2.** Elaborated response of the sensor installed at the BP5 site.

**Table 1**
Summary of the results obtained at the instrumented reaches. The first letter of the site refers to the funding project: the B refers to BIOACUANA and the C refers to CONACAN. The second letter refers to the island: the T refers to Tenerife, the P to La Palma and the G to La Gomera. Mf, Mp and Md represent the permanencies of the flow, disconnected pools and dry phases respectively. The regime letters and colours correspond to those shown in Figure 3. The sensor performances (last column) show in bold the reasons that caused the total loss of information at the site. The occurrence of flash floods is presumed to be the cause of sensor loss rather than vandalism.

| Site | N (degrees) | W (degrees) | Local name | Mf | Mp | Md | Regime | Valid days | Valid share | Sensor performance |
|---|---|---|---|---|---|---|---|---|---|---|
| BT01 | 28.56095 | -16.25290 | Barranco de Afur | 1 | 0 | 0 | P | 193 | 49% | Not recovered |
| BT02 | 28.55833 | -16.25095 | Barranco de Afur | 0.71 | 0.29 | 0 | FS | 92 | 23% | Out of active channel |
| BT03 | 28.56027 | -16.16529 | Barranco de Iljuana | - | - | - | - | 0 | 0% | **Not recovered** |
| BT04 | 28.56279 | -16.16369 | Barranco de Anosma | 0.62 | 0.35 | 0.03 | FS | 393 | 100% | OK |
| BT05 | 28.54482 | -16.16402 | Barranco de Igueste | 0.32 | 0.28 | 0.4 | AI | 393 | 100% | OK |
| BT06 | 28.54695 | -16.16781 | Barranco de Igueste | 0.65 | 0.23 | 0.12 | AF | 392 | 100% | OK |
| CT01 | 28.19322 | -16.59543 | Barranco de las Vegas | 1 | 0 | 0 | P | 189 | 100% | OK |
| CT02 | 28.19583 | -16.573889 | Barranco del río | 0.54 | 0.46 | 0 | FS | 196 | 100% | OK |
| CT03 | 28.20086 | -16.58119 | Cascada Barranco del Río | 0.79 | 0.21 | 0 | FS | 195 | 100% | OK |
| CT04 | 28.20137 | -16.57702 | Barranco el Fuerte | 0.72 | 0 | 0.28 | AF | 195 | 100% | OK |
| CT05 | 28.17885 | -16.59247 | Barranco de las Aguas | 0 | 0 | 1 | Ep | 189 | 100% | OK |
| CT06 | 28.18319 | -16.59161 | Barranco de las Vegas | 0 | 0 | 1 | Ep | 194 | 100% | OK |
| CT07 | 28.21808 | -16.55597 | Barranco de la Grieta | 0 | 0 | 1 | Ep | 199 | 100% | OK |
| BP01 | 28.72060 | -17.89633 | Barranco de las Traves | 1 | 0 | 0 | P | 187 | 49% | Not recovered |
| BP02 | 28.73117 | -17.87079 | Barranco Verduras Alfonso | - | - | - | - | 0 | 0% | **Not recovered** |
| BP03 | 28.72452 | -17.87586 | Playa de Taburiente | - | - | - | - | 0 | 0% | **Not recovered** |
| BP04 | 28.74107 | -17.87999 | Barranco del Hoyo Verde | 1 | 0 | 0 | P | 186 | 49% | Not recovered |
| BP05 | 28.70976 | -17.87709 | Cascada de Colores | 1 | 0 | 0 | P | 76 | 20% | Not recovered/buried |
| BP06 | 28.70686 | -17.88359 | Barranco de las Angustias | - | - | - | - | 0 | 0% | **Not recovered** |
| CP01 | 28.70670 | -17.85142 | Barranco de Aridane | 1 | 0 | 0 | P | 183 | 100% | OK |
| CP02 | 28.69737 | -17.86064 | Barranco Huanahuao | 1 | 0 | 0 | P | 60 | 33% | Data lost |
| CP03 | 28.72594 | -17.88388 | Barranco Risco Liso | - | - | - | - | 0 | 0% | **Data lost** |
| BG01 | 28.12453 | -17.21853 | Barranco Reventón Oscuro | 1 | 0 | 0 | P | 376 | 100% | OK |
| BG02 | 28.12435 | -17.22305 | Barranco del Cedro | 1 | 0 | 0 | P | 376 | 100% | OK |
| BG03 | 28.13329 | -17.20491 | Barranco de Monteforte | 0.52 | 0.48 | 0 | FS | 376 | 100% | OK |
| BG04 | 28.13943 | -17.21267 | Barranco del Cedro | - | - | - | - | 0 | 0% | **Data lost** |
| BG05 | 28.11832 | -17.32450 | Barranco de Arure | 1 | 0 | 0 | P | 201 | 53% | Not recovered |
| CG01 | 28.11577 | -17.19912 | Barranco de las Lajas | - | - | - | - | 0 | 0% | **Data lost** |
| CG02 | 28.11663 | -17.19788 | Barranco la Selechera | 1 | 0 | 0 | P | 172 | 100% | Out of active channel |
| CG03 | 28.14705 | -17.24078 | Barranco Sobreagulo | - | - | - | - | 0 | 0% | **Not recovered** |
| CG04 | 28.15352 | -17.23686 | Barranco Sobreagulo | - | - | - | - | 0 | 0% | **Not recovered** |

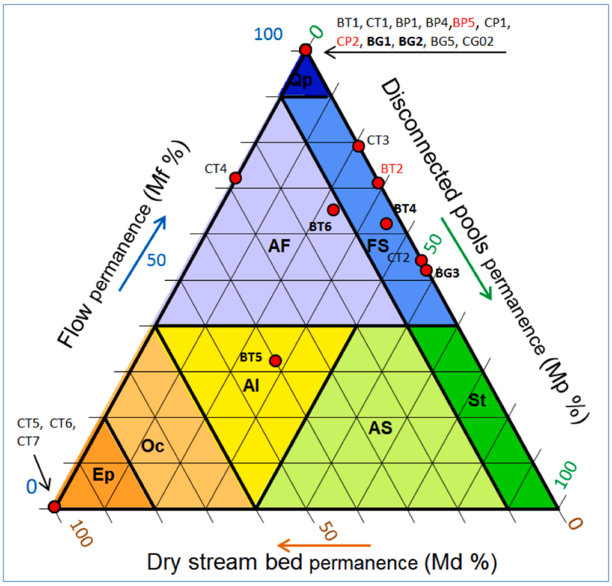


**Fig. 3.** Triangular plot and classification of site regimes.

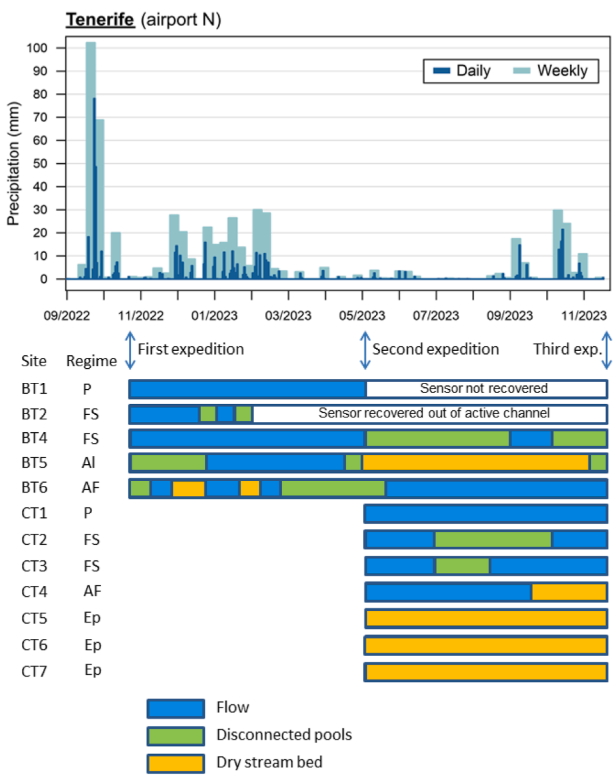


**Fig. 4.** Timelines of the precipitation and aquatic phases recorded on the island of Tenerife. The upper and lower graphs are synchronous. The regimes are those shown in Fig. 3.

increasing availability of its detection, among the 17 worldwide classifications of the regime of temporary streams inventoried by Fritz et al. (2020), only the triangular classification designed for the TREHS software (Gallart et al., 2017; TREHS herein) takes into account the relative permanence of the disconnected pools phase.

The hydrological characterization of surface water bodies is especially relevant in the Canary Islands because they: 1) have been poorly studied; 2) are not monitored even if some are protected; 3) have a great potential to harbour a rich biodiversity, including endemic species (Fernández-Palacios et al., 2021; Malmqvist et al., 1995; Nilsson et al., 1998); 4) are subjected to intense human pressure due to a combination of water withdrawal and pollution (Fernández-Palacios and Whittaker, 2008; Vidaña, 2020) and; 5) are expected to experience flow regime changes (or even become completely dry) under climate change scenarios (CEDEX, 2017; Expósito et al., 2015; García-Herrera et al., 2003; Máyer et al., 2015).

The aim of this study, which is part of two research projects aimed at studying the hydrology and biodiversity of the Canary Islands (https://conacuana.es), was to analyse the relative frequency of the three main aquatic phases (i.e. *flow, disconnected pools* and *dry riverbed*) in 32 remote small stream reaches on three of the Canary Islands (Tenerife, La Palma, and La Gomera) using one pair of low-cost water presence (conductivity and temperature) sensors per stream reach. By doing this, we wanted to offer a simple, cheap and operative method to characterize the regime of small streams in remote areas, most of them covered with dense forest, and where the possibility of using other methods is very limited and lacks spatial resolution. The operational objectives were to 1) record the hydrological conditions that can determine the establishment of aquatic life, particularly between project samplings, and 2) support other types of information for the upcoming assessment of the longer-term hydrological regimes of stream reaches using the TREHS method. Although the temporal extension of the records obtained (between 2 and 12 months) was not adequate for a complete characterisation of the hydrological regimes, the results presented here represent a first preliminary catalogue of the hydrological regimes of a representative group of streams on these islands.

## 2. Materials and methods

### 2.1. Study site

The Canary Islands are an archipelago in the Atlantic Ocean, located 100 km to the northwest of the African continent, at an average latitude of 28° 30′. The archipelago is made up of a group of 8 volcanic islands and 4 islets, covering a total area of about 7500 km$^2$. It is part of the biogeographic region of Macaronesia, together with the Azores, Madeira, Cape Verde and Savage Islands, sharing geographical, environmental and historical conditions that have resulted in floristic and faunal similarities. The climate of the Canary Islands is subtropical oceanic dominated by the semi-permanent Azores anticyclone, the north-easterly trade winds and the ocean Canary Currents, inducing a precipitation equitably distributed throughout the year, but with large local variations due to the rugged topography and varied exposure (Cropper, 2013; Cropper and Hanna, 2014). Annual rainfall on the coasts is about 300 mm, while it can reach 1200 mm on the main peaks. The north-eastern faces of the mountains benefit from occult precipitation (fog drip) due to the condensation of air humidity in canopies driven by the sustained trade winds (García-Santos et al., 2004).

The recent temporal evolution of the climate in the Islands shows a sustained tendency to drier conditions during the last twelve years. The 24-months SPEI index (standardized precipitation evapotranspiration index, Vicente-Serrano et al., 2010) for the three studied islands show values between −1 and −2 during this period (https://monitordesequia.aemet.es), that correspond to exceeded dryness recurrences between 6.3 and 44 years in the long record (60 years), respectively. Climate models project an increase of duration and severity of droughts, particularly in the higher elevations that are the main source of water resources (Carrillo et al., 2023).

The geology of the Canary Islands is characterized by a diversity of volcanic formations developed from 15 Ma ago to the present in some localities. Most of the rocks are tephra and fragmented lava flows that induce high infiltration rates, but the superposition of layers of low porosity such as palaeosols generates a large number of perched aquifers and hanging springs, locally named *nacientes*. Groundwater resources are intensely exploited through numerous wells and underground

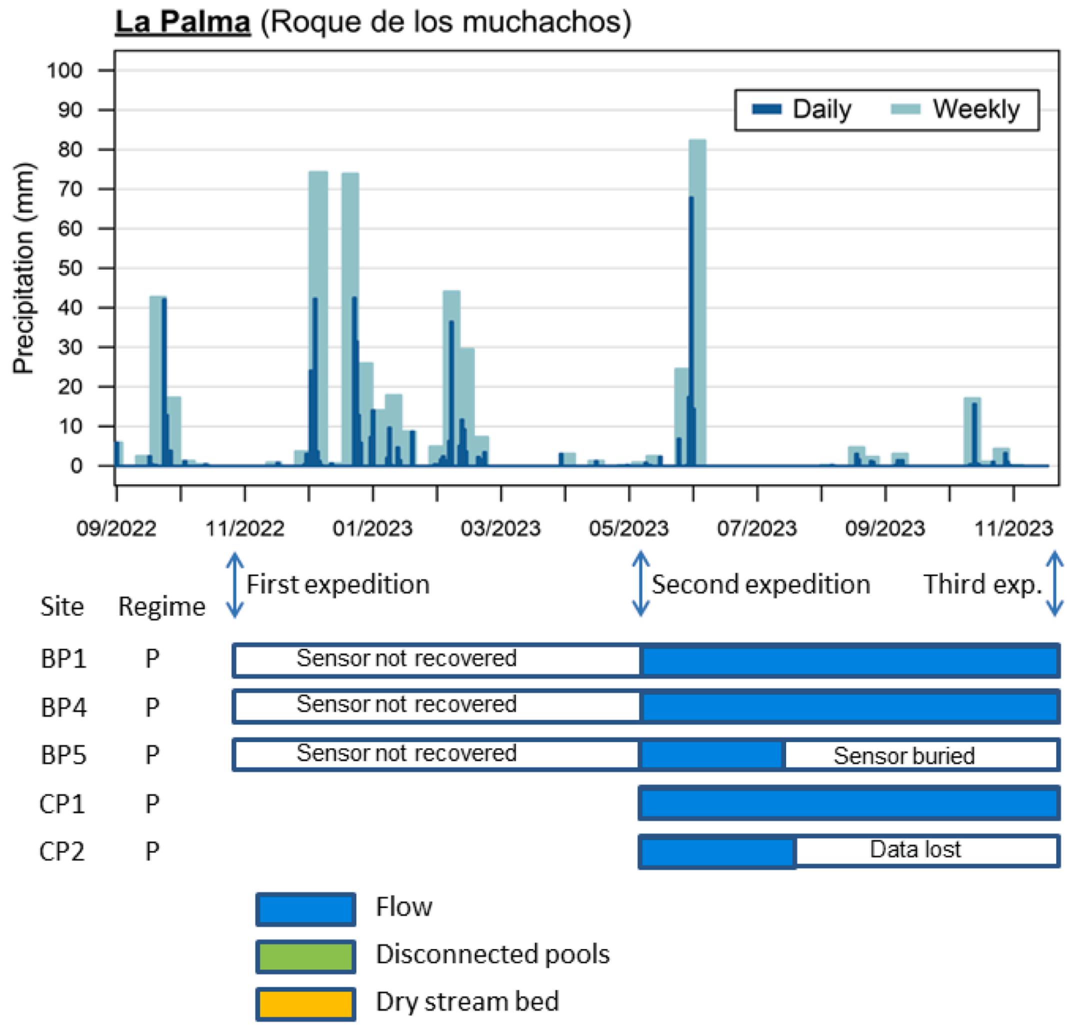


**Fig. 5.** Timelines of the precipitation and aquatic phases recorded on the island of La Palma. The upper and lower graphs are synchronous. The regimes are those shown in Fig. 3.

galleries and many of the springs are channelled for exploitation, thereby reducing or annulling the flow of the natural drainage network (Cabrera and Custodio, 2013; Poncela et al., 2022).

A few water courses are known to be perennial, for example, the Barranco de Las Angustias in La Palma and the Barranco El Cedro in La Gomera, but water courses in most of the ravines are temporary. During heavy rainfall events they can convey flash floods (López Díez et al., 2019), while during rainy seasons they can convey some flow that commonly disappears downstream due to of high transmission losses or its use through intake works or reservoirs (Malmqvist et al., 1993; Santamarta, 2013). Many of the residents we spoke to deemed that most streams show a tendency to dry up, an opinion previously recorded in Tenerife by Malmqvist et al., 1993. However, given the complexity of the surface and groundwater exploitation systems, it is extremely difficult to know the degree of hydrological alteration of the recorded regimes.

The water authorities of the concerned islands (Tenerife, La Palma, and La Gomera) do not recognize any continental surface water bodies in application of the European Water Framework Directive (European Commission, 2000), due to the insufficient extent of the existing rivers and lakes (CIAG, 2023; CIAP, 2025; CIAT, 2023).

### 2.2. Instrumentation and data collection

One-hundred and ten light and temperature sensors (Onset HOBO UA-002–64 Pendant) were modified for semi-quantitative sensing water electrical conductivity instead of light intensity, following the method proposed by Chapin et al. (2014). Eighty two of these sensors were installed during one or two time periods in 32 stream reaches or wet spots below waterfalls and seeping stone walls in Tenerife, La Palma, and La Gomera islands.

These sites were selected as expected locations favourable for aquatic life according to previous scientific studies (Malmqvist et al., 1995; Nilsson et al., 1998; Gutiérrez et al., 2014; Lüderitz et al., 2016; Vidaña, 2020) and technical documents from the respective River Basin District authorities (CIAG, 2023; CIAP, 2025; CIAT, 2023). Three fieldwork expeditions were carried out for the installation and maintenance of sensors: the first one from the 28th October to the 5th November 2022, the second one from the 10th to the 26th May 2023 and the third one from the 14th to the 28th November 2023. This was done simultaneously with the biological sampling (macroinvertebrates, diatoms and DNA).

Where the configuration of the selected reach showed pool forms, one sensor was installed at the bottom of the pool and another in a riffle or a location where water was present only when flow was active; where pool shapes were lacking, only one sensor was installed. The sensors were introduced in plastic pipes for protection and fastened to the bedrock or large stones with thin stainless-steel cables. The logging frequency was set to 5-minute intervals.

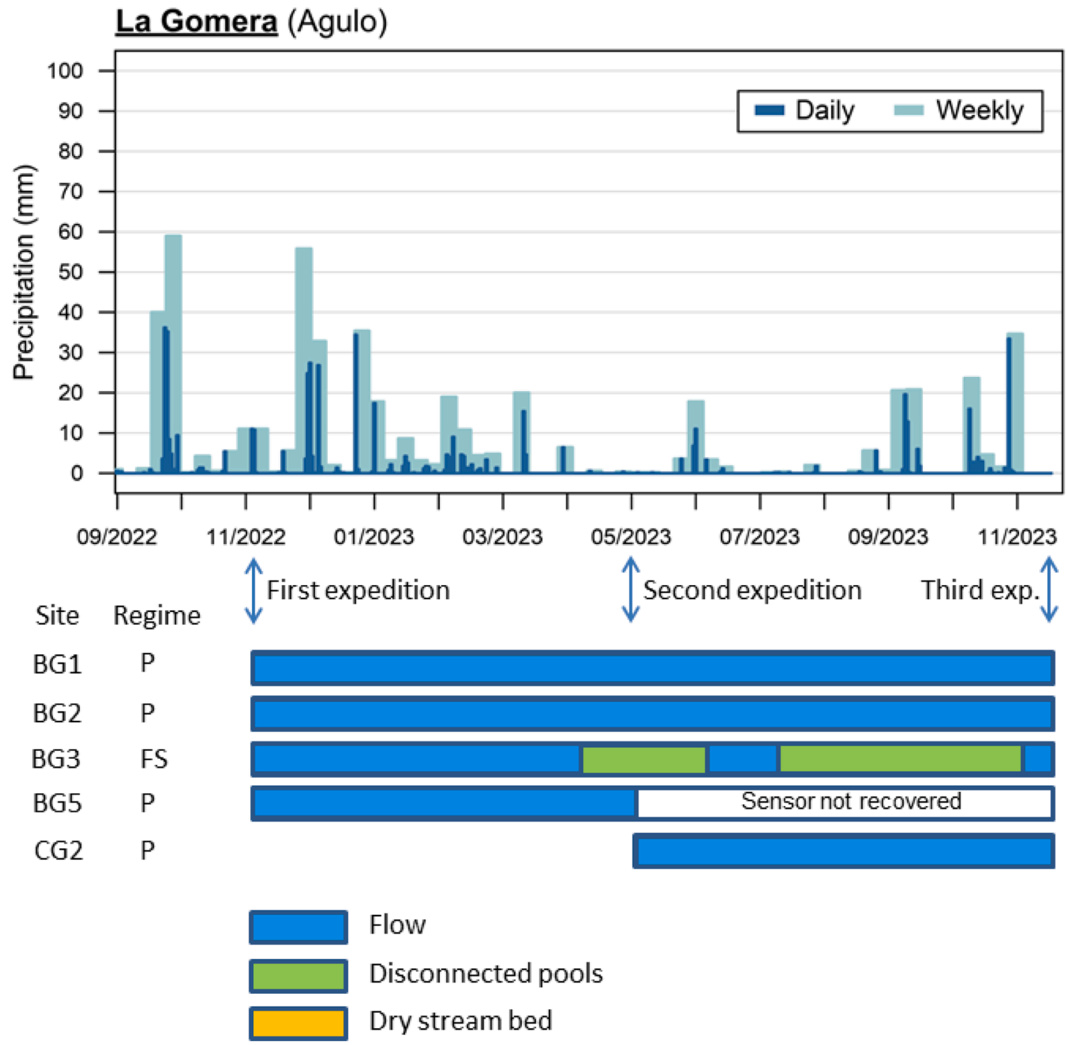


**Fig. 6.** Timelines of the precipitation and aquatic phases recorded on the island of La Gomera. The upper and lower graphs are synchronous. The regimes are those shown in Fig. 3.

### 2.3. Data analyses

Following the recommendations made by Chapin et al. (2014), the conductivity readings were rescaled from 0 to 100 % using, for each sensor, the reading obtained when dry and the maximum reading logged when wet. The conductivity readings were not corrected with temperature because the relationships between conductivity and temperature were very weak. The time resolution of the records was aggregated to one day selecting the maximum daily value of relative conductivity, in order to avoid the effect of electronic noise.

Since it was only possible to validate the wet or dry state of the sensors upon their installation and retrieval, the daily standard deviation of the recorded temperature was used as a secondary criterion. A wet sensor state was decided when the daily maximum relative conductivity exceeded the 20 % threshold, and the standard deviation of temperature showed a rather low value. A temperature threshold value could not be selected due to the dependence of temperature on insolation and the more or less sunny location of the sensor.

The daily sensor states at every instrumented reach were converted into one of the three *aquatic phases* defined by Gallart et al. (2017) for TREHS: *flow (*riffle sensor wet*), disconnected pools (*riffle sensor dry and pool sensor wet*)*, and *dry riverbed (*both sensors dry*)*. Where only one sensor was installed, only either the *flow* or *dry riverbed* phases was considered.

The second objective was approached in two different ways. First, daily data were aggregated to biweekly values taking the more frequent phase in order to obtain a time scale compatible with other sources of data managed by the TREHS software. Secondly, the complementary relative frequencies of occurrence (permanencies herein) of the three phases were expressed as TREHS metrics, Mf (*flow* permanence), Mp (*disconnected pools* permanence) and Md (*dry riverbed* permanence). These metrics were displayed in a triangular graph and used to classify the observed regimes into one of the 9 TREHS classes presumably relevant to the development of aquatic life: Perennial (P), Quasi-perennial (Qp), Alternate-Fluent (AF), Fluent- Stagnant (FS), Stagnant (St), Alternate-Stagnant (AS), Alternate (Al), Occasional (Oc) and Episodic (Ep).

## 3. Results and discussion

### 3.1. Response of the sensors

From the 82 sensors installed, 52 (63 %) were fully operational, 18 could not be recovered, three were retrieved out of the active channel, one was retrieved buried in the sediments and the remaining eight did not deliver valid data. At the reach scale, valid data were obtained for 22 sites of the 32 sites instrumented: six covering 12 months (corresponding to two consecutive fieldwork expeditions), 14 covering six months

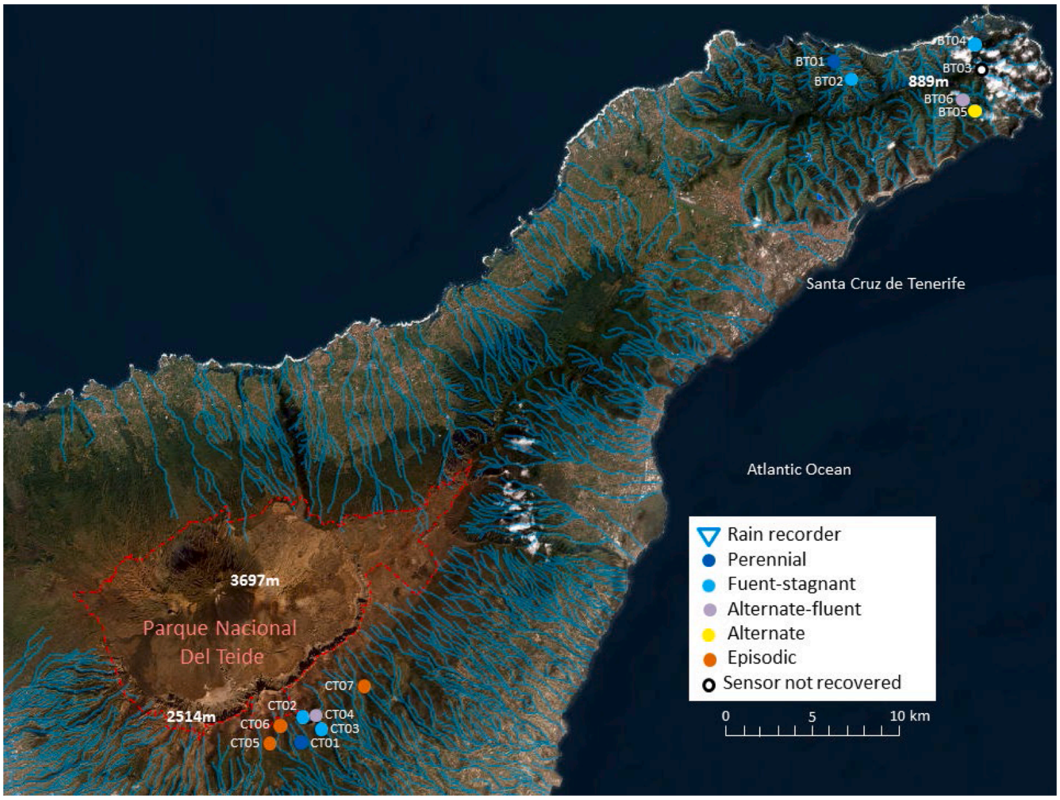


**Fig. 7.** Map of the instrumented reaches in Tenerife.

(one fieldwork expedition) and other two covering two and three months, respectively. This is a modest outcome compared to Chapin et al. (2014) but similar to previous experiences in temporary streams where flash floods recurrently occur (Pineda et al., 2022; Zanetti et al., 2021).

CT2 site is an example where sensors were effective, and the data was easily processed. When the sensors were installed in the reach with flowing water, both denoted wet conditions (high electrical conductivity and low daily temperature variation, Fig. 1). As time passed, wet conditions were only continuously recorded by the pool sensor. In contrast, the riffle sensor showed a period with low relative conductivity and high standard deviation of daily temperature that was attributed to a dry condition. The sequence of aquatic phases determined at this stream reach was therefore *flow* at the beginning, *disconnected pools* between the 9th July and the 5th October and the resumption to *flow* from this date to the end of the record (the *flow* phase was corroborated at the time of sensor recovery).

BP5 site is an example of complex and challenging data processing of the sensors. Only one sensor was installed at this site. When data started to be recorded on the 9th of July the relative conductivity was high but dropped on the 2nd of August, although the standard deviation of temperature remained very low during all this period (Fig. 2). At retrieval, the sensor was found buried into the alluvium below surface flow, a condition that can explain the data patterns. Although flow likely continued near the sensor after its burial, we discarded the data after the drop in relative conductivity for reasons of rigour.

### 3.2. Hydrological characterization of the streams

The characteristics of the sites and the overall results are shown in Table 1. Valid information was recovered in all reaches in Tenerife except one, while data was lost at several reaches in La Palma and La Gomera.

The permanencies of the three phases obtained at reaches with valid data are depicted in a triangular plot, along with the corresponding provisional TREHS regime classification (Fig. 3). Except three reaches at Tenerife that were instrumented in dry channels, all locations show rather wet conditions, with permanencies of the *dry river bed* phase (Md) smaller than 50 %. The reaches in La Palma and La Gomera were the wettest ones, since surface water was detected in all of them as flow or pools >85 % of the recorded time. As a summary, eleven reaches showed *perennial* regimes (P), five showed regimes dominated by flow sometimes switched to disconnected pools (*Fluent-Stagnant*, FS), other three showed regimes rotating between the three phases (*Alternate-Fluent*, AF and *Alternate*, Al) and the remaining three were dry during all the monitoring periods (*Episodic*, Ep).

In Tenerife, the sensor at BT1 was not recovered but the reach was in *disconnected pools* phase at the time of visit. The sensor at BT2 was recovered in the *flow* phase but outside the channel with flowing water. Except for the reaches CT5 to CT7, which were instrumented on dry channels, and BT5, which showed a prolonged dry period, most of the reaches showed enduring *flow* or *disconnected pools* phases favourable to the development of aquatic life (Fig. 4). In summary, the conditions in Tenerife were more diverse than in the other two islands. Malmqvist et al. (1993) in a detailed study of the macroinvertebrate communities in Tenerife, indicated that, although the Barranco Igueste (BT05 and BT06) and the Barranco del Río (CT02) tended to disappear in some part of the section either due to underground flow or water intakes, all the other reaches appeared to have a permanent regime.

In La Palma, the occurrence of large rainfall episodes with associated flood events between the two first fieldwork expeditions led to the generalised loss of sensors. For that reason, we deem that all the reaches underwent *flow* phases during this period, either in *eurheic* (full flow) or *hyperheic* (flood) states, *sensu* Gallart et al. (2012). The sensor buried at BP5 was found in *flow* phase whereas the reach CP2 was found in *disconnected pools* phase at the time of the last visit. We can conclude that the hydrological conditions in all the instrumented reaches in La Palma were very favourable to the development of aquatic life (Fig. 5).

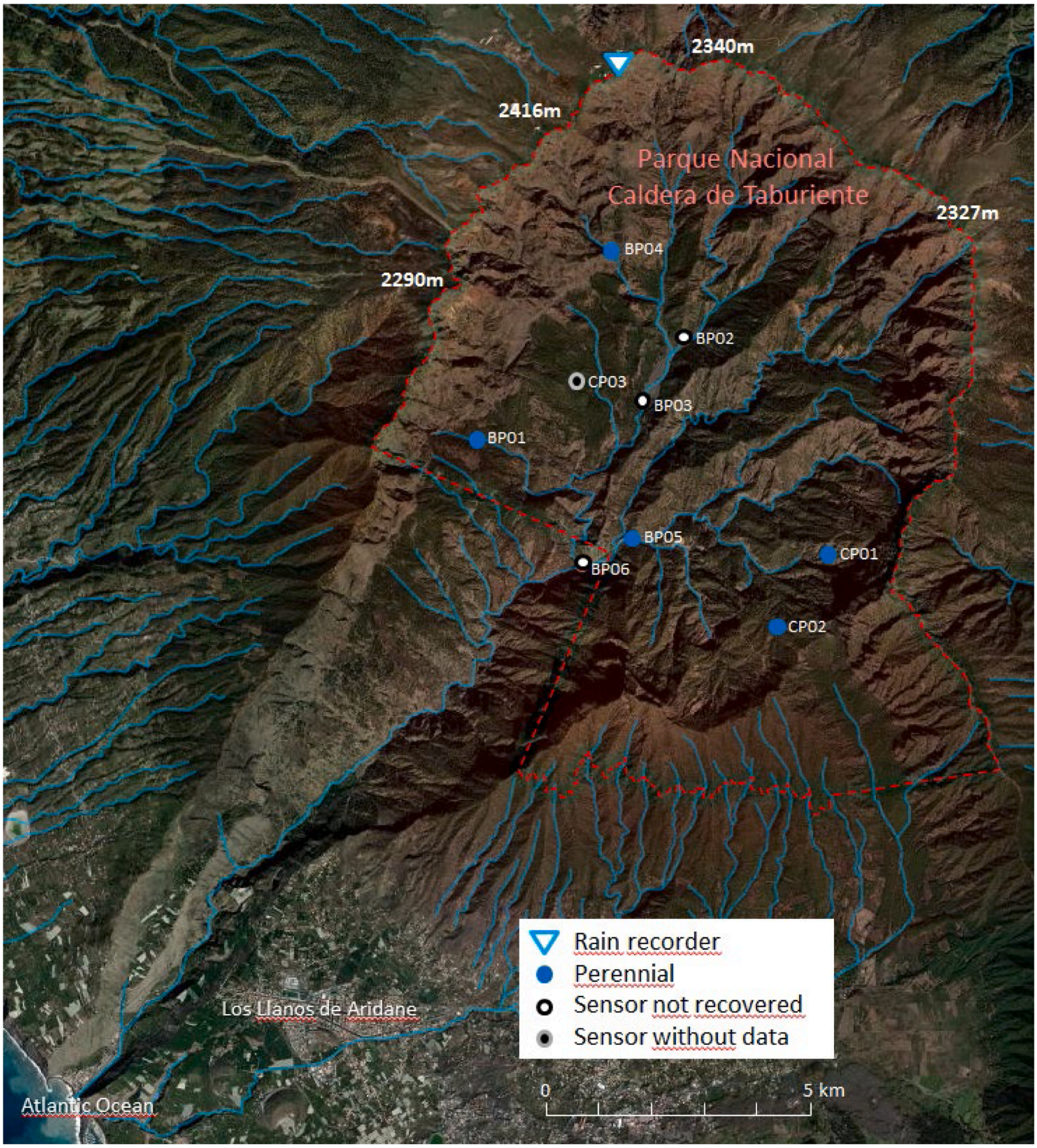


**Fig. 8.** Map of the instrumented reaches in La Palma.

Similarly to La Palma, in La Gomera the conditions in all the instrumented reaches were very favourable to the development of aquatic life (Fig. 6).

Finally, the maps of the instrumented reaches together with the regimes observed are shown in Figs. 7-9 for the Tenerife, La Palma and La Gomera Islands respectively. These maps help to spatially visualize the results shown in Table 1 and Fig. 3, but the regimes cannot be understood without taking into account that, as stated in the methods section, most of the reaches were chosen as presumably favourable for aquatic life using prior information.

Tenerife is the largest island, and the main attention was paid to both the north-eastern edge (mainly in the Anaga Massif Biosphere Reserve) and the south-eastern surroundings of the El Teide National Park. The first cluster is located in a mountainous area of intermediate annual precipitation (500–700 mm), formed by basalt rocks without wells or water intakes (CIAT, 2023), conditions that may justify the high occurrence of surface waters. The second cluster is located on the flank of the Teide volcano that receives smaller annual precipitation (300–500 mm) and is formed by varied volcanic rocks where groundwater is exploited by several wells and galleries (CIAT, 2023), offering irregular conditions for the occurrence of surface waters.

In La Palma, all the reaches were instrumented in the Caldera de Taburiente, because this basin was known to offer good opportunities for the development of aquatic life and also the interest of the Caldera de Taburiente National Park in terms of biodiversity conservation. The Caldera is a deep hollow with abrupt flanks carved into complex volcanic sequences whose summits receive high annual precipitation (>1000 mm). This structure gives rise to countless water sources (*nacientes*) although the number of wells, galleries and water intakes is also very high (CIAP, 2025). The results obtained demonstrate that, in spite of the high degree of exploitation of the waters, there are still good conditions for the development of aquatic life that are the best among the three studied islands.

In La Gomera almost all the reaches were selected within or close to

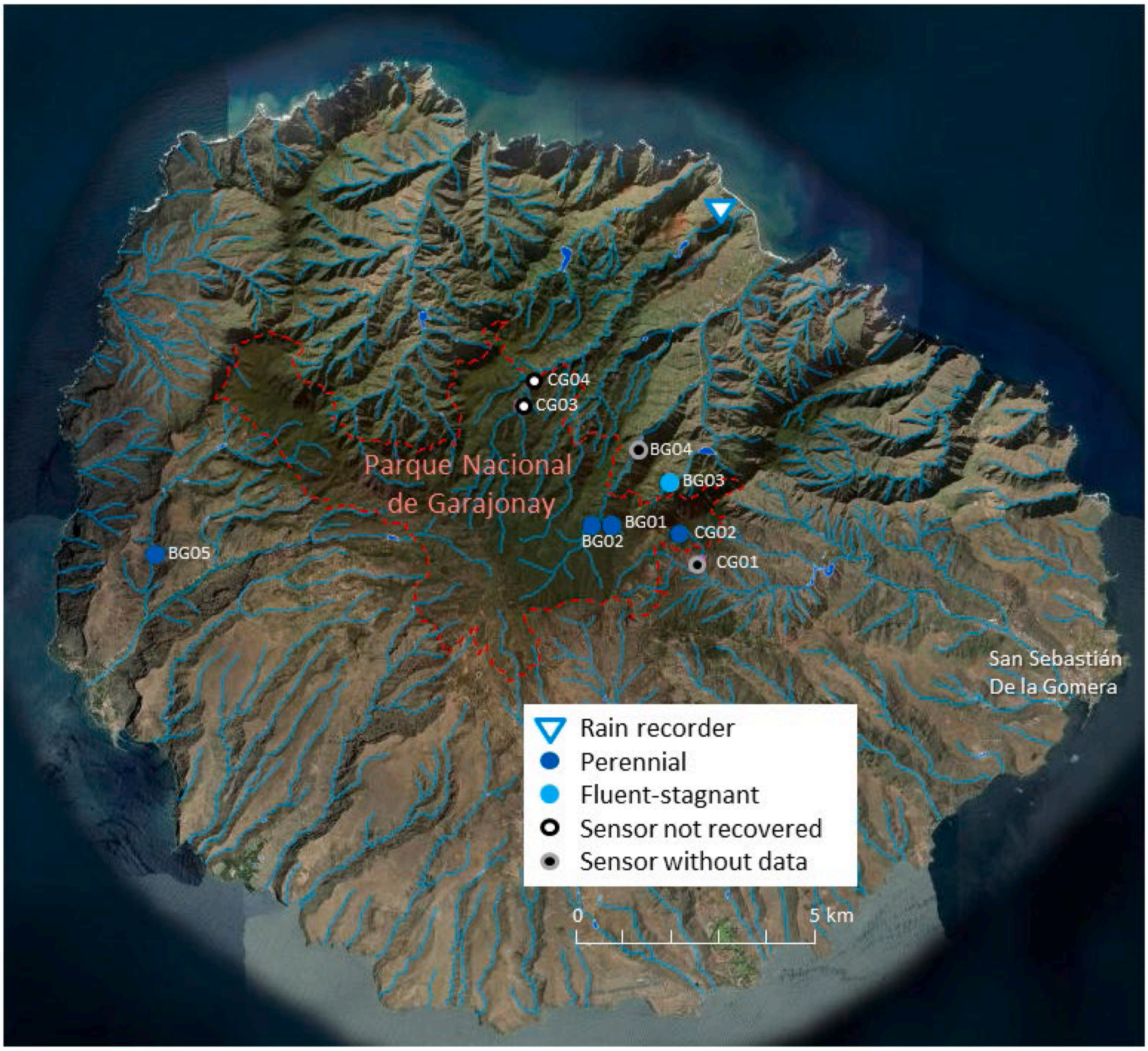


**Fig. 9.** Map of the instrumented reaches in La Gomera.

the Garajonay National Park for similar reasons. These points are located in relatively high annual precipitation areas (700–900 mm) built of succession of basaltic and pyroclastic rocks. There are several water springs and few underground water intakes.

## 4. Conclusions

The use of temperature and light intensity HOBO Pendant sensors, modified for estimating the electrical conductivity of water, provided valuable new information on the hydrological regimes of several remote stream reaches in Tenerife, La Palma and La Gomera Islands. The sensors are low-cost, the installation is uncomplicated, and the data management and interpretation are relatively easy and present few doubts. On the other hand, several sensors installed in torrential reaches were lost or recovered out of the active channel and a few did not deliver valid data. Therefore, information for many sites does no cover the whole year, failing to capture some seasonal hydrological dynamics. We acknowledge that this is a limitation of the current study, which we intend to address with the results obtained through various sources of information (interviews, direct observations, ground and aerial photographs, ect.) managed by the TREHS software. Future studies could also explore other types of sensors such as time-lapse cameras, which might be more efficient in torrential reaches because they are not vulnerable to floods or channel changes, although they are more expensive and vulnerable to vandalism.

This study is the first to characterize the hydrological regime of headwater water bodies in these three Canary Islands, shedding light on their potential as key habitats for aquatic organisms. We successfully identified hydrological conditions favourable to the development of aquatic life in most of the instrumented reaches. Furthermore, the instrumentation focused to the identification of the three aquatic phases was particularly valuable for the main purpose of the project, because if perennial and permanently dry reaches are discarded (8 remaining points), the averaged flow permanence was only 61 %, while the averaged permanence of surface water increased to 90 %. If the disconnected pools phase were not considered, the conditions for the development of aquatic life would be clearly underestimated.

Given the documented potential of these streams to harbour endemic and endangered species within the context of a global freshwater biodiversity crisis (this study as well as Fernández-Palacios et al., 2021; Malmqvist et al., 1995; Nilsson et al., 1998), we call for further efforts to investigate, monitor and protect small streams in oceanic islands.

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### CRediT authorship contribution statement

**Francesc Gallart:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Jérôme Latron:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Miriam Salguero-Sandoval:** Data curation, Visualization, Writing – review & editing. **Raúl Acosta:** Formal analysis, Investigation, Project administration, Writing – review & editing. **José María Fernández-Calero:** Conceptualization, Writing – review & editing. **Núria Cid:** Conceptualization, Investigation, Writing – review & editing. **Miguel Cañedo-Argüelles:** Formal analysis, Investigation, Writing – review & editing. **Pilar Llorens:** Writing – review & editing, Supervision, Methodology, Formal analysis.

### Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### References

Allen, D.C., Kopp, D.A., Costigan, K.H., Datry, T., Hugueny, B., Turner, D.S., Bodner, G. S., Flood, T.J., 2019. Citizen scientists document long-term streamflow declines in intermittent rivers of the desert southwest. USA. Freshwater Sci. 38, 244–256. https://doi.org/10.1086/701483.

Arscott, D.B., Larned, S., Scarsbrook, M.R., Lambert, P., 2010. Aquatic invertebrate community structure along an intermittence gradient: selwyn River, New Zealand. J. North Am. Benthol. Soc. 29, 530–545. http://www.bioone.org/doi/full/10.1899/08-124.1.

Assendelft, R.S., van Meerveld, I., 2025. Spatial and temporal variation in the three main hydrological states of temporary streams in a Swiss pre-alpine catchment. Hydrol. Process. 39 (3), e70018. https://doi.org/10.1002/hyp.70018.

Bhamjee, R., Lindsay, J.B., Cockburn, J., 2016. Monitoring ephemeral headwater streams: a paired-sensor approach. Hydrol. Process. 30 (6), 888–898. https://doi.org/10.1002/hyp.10677.

Blasch, K.W., Ferré, T.P., Christensen, A.H., Hoffmann, J.P., 2002. New field method to determine streamflow timing using electrical resistance sensors. Vadose Zone J. 1 (2), 289–299. https://doi.org/10.2136/vzj2002.2890.

Bonada, N., Cañedo-Argüelles, M., Gallart, F., von Schiller, D., Fortuño, P., Latron, J., Llorens, P., Murria, C., Soria, M., Viñoles, D., Cid, N., 2020. Conservation and management of isolated pools in temporary rivers. Water. (Basel) 12 (10), 2870. https://doi.org/10.3390/w12102870.

Boulton, A.J., 1989. Over-summering refuges of aquatic macroinvertebrates in two intermittent streams in central Victoria, Transac. Royal Soc. South Australia, 31, 23–34.

CIAG. Cabildo Insular de Aguas de La Gomera, 2023. Plan Hidrológico Insular de la Demarcación Hidrográfica de La Gomera 3 ciclo. https://sede.gobiernodecanarias.org/boc/boc-a-2023-122-2035.pdf.

CIAP. Cabildo Insular de Aguas de La Palma, 2025. Plan Hidrológico Insular de la Demarcación Hidrográfica de La Palma tercer ciclo. https://sede.gobiernodecanarias.org/boc/boc-a-2025-038-719.pdf.

CIAT. Cabildo Insular de Aguas de Tenerife, 2023. Plan Hidrológico Insular De La Demarcación Hidrográfica De Tenerife, Tercer Ciclo. https://sede.gobiernodecanarias.org/boc/boc-a-2023-191-3191.pdf.

Cabrera Santana, M.D.C., Custodio Gimena, E., 2013. Hidrogeología y terrenos volcánicos. COIM, ULPCC. https://accedacris.ulpgc.es/handle/10553/56893.

Carrillo, J., Hernández-Barrera, S., Expósito, F.J., Díaz, J.P., González, A., Pérez, J.C., 2023. The uneven impact of climate change on drought with elevation in the Canary Islands. Climate Atmosph. Sci. 6, 31. https://doi.org/10.1038/s41612-023-00358-7.

CEDEX., 2017. Evaluación del impacto del cambio climático en los recursos hídricos y sequías en España. Ministerio de Fomento, Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente. Gobierno de España. 346pp. https://ceh.cedex.es/web/documentos/CAMREC/2017_07_424150001_Evaluaci%C3%B3n_cambio_clim%C3%A1tico_recu.pdf.

Chapin, T.P., Todd, A.S., Zeigler, M.P., 2014. Robust, low-cost data loggers for stream temperature, flow intermittency, and relative conductivity monitoring. Water. Resour. Res. 50 (8), 6542–6548. https://doi.org/10.1002/2013WR015158.

Costigan, K.H., Kennard, M.J., Leigh, C., Sauquet, E., Datry, T., Boulton, A.J., 2017. Flow regimes, in: Datry, T., Bonada, N., Boulton, A. (Eds), Intermittent Rivers and Ephemeral Streams. Academic Press, pp. 51–78.

Cropper, T., 2013. The weather and climate of Macaronesia: past, present and future. Weather 68 (11), 300–307. https://doi.org/10.1002/wea.2155.

Cropper, T.E., Hanna, E., 2014. An analysis of the climate of Macaronesia, 1865–2012. Int. J. Climatol. 34 (3), 604–622. https://doi.org/10.1002/joc.3710.

Datry, T., Bonada, N., Boulton, A. (Eds.), 2017. Intermittent Rivers and Ephemeral streams, Ecology and Management. Academic Press, https://doi.org/10.1016/C2015-0-00459-2.

Dudgeon, D., Strayer, D.L., 2025a. Bending the curve of global freshwater biodiversity loss: what are the prospects? Biolog. Rev. 100 (1), 205–226. https://doi.org/10.1111/brv.13137, 2025.

De Girolamo, A.M., Drouiche, A., Ricci, G.F., Parete, G., Gentile, F., Debieche, T.H., 2022. Characterising flow regimes in a semi-arid region with limited data availability: the Nil Wadi case study (Algeria). J. Hydrol. 41, 101062. https://doi.org/10.1016/j.ejrh.2022.101062.

Eastman, M., Parry, S., Sefton, C., Park, J., England, J., 2021. Reconstructing spatiotemporal dynamics in hydrological state along intermittent rivers. Water. (Basel) 13 (4), 493. https://doi.org/10.3390/w13040493.

European Commission, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Off. J. Eur. Communities. http://eur-lex.europa.eu/legalcontent/en/TXT/?uri=CELEX:32000L0060.

Expósito, F.J., González, A., Pérez, J.C., Díaz, J.P., Taima, D., 2015. High-resolution future projections of temperature and precipitation in the Canary Islands. J. Clim. 28 (19), 7846–7856. https://doi.org/10.1175/JCLI-D-15-0030.1.

Fernández-Calero, J.M., von Schiller, D., Quevedo-Ortiz, G., Pifarré, A.T., Cid, N., Cañedo-Argüelles, M., Bonada, N., 2025. Assessing aerial dispersal in temporary rivers using stable isotopes. Freshw. Biol. 70 (10), e70108. https://doi.org/10.1111/fwb.70108.

Fernández-Palacios, J.M., Whittaker, R.J., 2008. The Canaries: an important biogeographical meeting place. J. Biogeogr. 35 (3), 379–387. https://doi.org/10.1111/j.1365-2699.2008.01890.x.

Fernández-Palacios, J.M., Kreft, H., Irl, S.D.H., Norder, S., Ah-Peng, C., Borges, P.A.V., Burns, K.C., De Nascimento, L., Meyer, J.-Y., Montes, E., Drake, D.R., 2021. Scientists' warning – The outstanding biodiversity of islands is in peril. Glob. Ecol. Conserv. 31, e01847. https://doi.org/10.1016/j.gecco.2021.e01847.

Fritz, K.M., Nadeau, T.L., Kelso, J.E., Beck, W.S., Mazor, R.D., Harrington, R.A., Topping, B.J., 2020. Classifying streamflow duration: the scientific basis and an operational framework for method development. Water. (Basel) 12 (9), 2545. https://doi.org/10.3390/w12092545.

Gallart, F., Prat, N., García-Roger, E.M., Latron, J., Rieradevall, M., Llorens, P., Barberá, G.G., Brito, D., De Girolamo, A.M., Lo Porto, A., Buffagni, A., Erba, S., Neves, R., Nikolaidis, N.P., Perrin, J.L., Querner, E.P., Quiñonero, J.M., Tournoud, M.G., Tzoraki, O., Skoulikidis, N., Gómez, R., Sánchez-Montoya, M.M., Froebrich, J., 2012. A novel approach to analysing the regimes of temporary streams in relation to their controls on the composition and structure of aquatic biota. Hydrol. Earth. Syst. Sci. 16 (9), 3165–3182. https://doi.org/10.5194/hess-16-3165-2012.

Gallart, F., Llorens, P., Latron, J., Cid, N., Rieradevall, M., Prat, N., 2016. Validating alternative methodologies to estimate the regime of temporary rivers when flow data are unavailable. Sci. Total Environ. 565, 1001–1010. https://doi.org/10.1016/j.scitotenv.2016.05.116.

Gallart, F., Cid, N., Latron, J., Llorens, P., Bonada, N., Jeuffroy, J., Jiménez-Argudo, S.M., Vega, R.M., Solà, C., Soria, M., Bardina, M., Hernández-Casahuga, A.J., Fidalgo, A., Estrela, T., Munné, A., Prat, N., 2017. TREHS: an open-access software tool for investigating and evaluating temporary river regimes as a first step for their ecological status assessment. Sci. Total Environ. 607, 519–540. https://doi.org/10.1016/j.scitotenv.2017.06.209.

García-Herrera, R., Gallego, D., Hernández, E., Gimeno, L., Ribera, P., Calvo, N., 2003. Precipitation trends in the Canary Islands. Int. J, Climatol. 23 (2), 235–241. https://doi.org/10.1002/joc.870.

García-Santos, G., Marzol, M.V., Aschan, G., 2004. Water dynamics in a laurel montane cloud forest in the Garajonay National Park (Canary Islands, Spain). Hydrol. Earth. Syst. Sci. 8 (6), 1065–1075. https://doi.org/10.5194/hess-8-1065-2004.

Godsey, S.E., Kirchner, J.W., 2014. Dynamic, discontinuous stream networks: hydrologically driven variations in active drainage density, flowing channels and stream order. Hydrol. Process. 28 (23), 5791–5803. https://doi.org/10.1002/hyp.10310.

Gutiérrez Álvarez, J., Santamaría Fierro, A., Regil Cueto, J.A., 2014. Catálogo de los coleópteros acuáticos (Coleoptera: adephaga & Polyphaga) de las islas Canarias. Boletín de la Sociedad Entomológica Aragonesa , 55, 117–130. http://sea-entomologia.org/Publicaciones/Boletines/Boletin55/Boletin55/117130BSEA55ColeopterosAcuaticosCanarias.pdf.

Jaeger, K.L., Olden, J.D., 2012. Electrical resistance sensor arrays as a means to quantify longitudinal connectivity of rivers. River Res. Applic. 28, 1843–1852. https://doi.org/10.1002/rra.1554.

Kelly, B.T., Bruckerhoff, L.A., 2024. Dry, drier, driest: differentiating flow patterns across a gradient of intermittency. River. Res. Appl. 40 (7), 1273–1285. https://doi.org/10.1002/rra.4289.

López Díez, A., Máyer Suárez, P., Díaz Pacheco, J., Dorta Antequera, P., 2019. Rainfall and flooding in coastal tourist areas of the Canary Islands (Spain). Atmosphere (Basel) 10 (12), 809. https://doi.org/10.3390/atmos10120809.

Lüderitz, V., Arévalo, J.R., Fernández-Palacios, J.M., Fernández-Lugo, S., Eller, K., Langheinrich, U., 2016. Freshwater endemic species and the ecological status of streams in the Canary Islands. J. Mediterranean Ecol. 14, 45–54. http://riull.ull.es/xmlui/handle/915/18750.

Magand, C., Alves, M.H., Calleja, E., Datry, T., Dörflinger, G., England, J., Gallart, F., Gomez, R., Jorda-Capdevila, D., Marti, E., Munné, A., Pastor, A.V., Stubbington, R., Tziortzis, I., Von Schiller, D., 2020. Intermittent rivers and ephemeral streams: what water managers need to know. Europ. Cooper. Sci. Technol. https://doi.org/10.5281/zenodo.3888474.

Malmqvist, B., Nilsson, A.N., Baez, M., Armitage, P.D., Blackburn, J., 1993. Stream macroinvertebrate communities in the island of Tenerife. Archiv für Hydrobiologie 128 (2), 209–235. https://www.ephemeroptera-galactica.com/pubs/pub_m/pubmalmqvistb1993p209.pdf.

Malmqvist, B., Nilsson, A.N., Baez, M., 1995. Tenerife's freshwater macroinvertebrates: status and threats (Canary Islands, Spain). Aquat. Conserv. 5 (1), 1–24. https://doi.org/10.1002/aqc.3270050103.

Maswanganye, S.E., Dube, T., Mazvimavi, D., Jovanovic, N., 2022. Remotely sensed applications in monitoring the spatio-temporal dynamics of pools and flows along non-perennial rivers: a review. South African Geograph. J. 104 (4), 427–445. https://doi.org/10.1080/03736245.2021.1967774.

Máyer, P., Marzol, M., Parreño, J., 2015. Tendencias De La Precipitación en Canarias, in: Estudio, Aprovechamiento y Gestión Del Agua En Terrenos e Islas volcánicas, (II Workshop), Mª. C. Cabrera, T. Cruz-Fuentes, V. Mendoza-Grimón y Ma P. Palacios-Díaz (Eds.), Instituto Geológico y Minero de España y Asociación Internacional de Hidrogeólogos, Las Palmas de Gran Canaria. 223–230. https://accedacris.ulpgc.es/handle/10553/114825.

Mimeau, L., Künne, A., Devers, A., Branger, F., Kralisch, S., Lauvernet, C., Datry, T., 2025. Projections of streamflow intermittence under climate change in European drying river networks. Hydrol. Earth. Syst. Sci. 29 (6), 1615–1636. https://doi.org/10.5194/hess-29-1615-2025.

Munné, A., Bonada, N., Cid, N., Gallart, F., Solà, C., Bardina, M., Rovira, A., Sierra, C., Soria, M., Fortuño, P., Llorens, P., Latron, J., Estrela, T., Fidalgo, A., Serrano, I., Jiménez, S., Vega, R., Prat, N., 2021. A proposal to classify and assess ecological status in Mediterranean temporary rivers: research insights to solve management needs. Water. (Basel) 13 (6), 767. https://doi.org/10.3390/w13060767.

Nabih, S., Tzoraki, O., Zanis, P., Tsikerdekis, T., Akritidis, D., Kontogeorgos, I., Benaabidate, L., 2021. Alteration of the ecohydrological status of the intermittent flow rivers and ephemeral streams due to the climate change impact (Case study: tsiknias river). Hydrology 8 (1), 43. https://doi.org/10.3390/hydrology8010043.

Nilsson, A.N., Malmqvist, B., Báez, M., Blackburn, J.H., Armitage, P.D., 1998. Stream insects and gastropods in the island of Gran Canaria (Spain). Annales de Limnologie - Int. J. Limnol. 34 (4), 413–435. https://doi.org/10.1051/limn/1998033.

Nogué, S., Santos, A.M.C., Birks, H.J.B., Björck, S., Castilla-Beltrán, A., Connor, S., De Boer, E.J., De Nascimento, L., Felde, V.A., Fernández-Palacios, J.M., Froyd, C.A., Haberle, S.G., Hooghiemstra, H., Ljung, K., Norder, S.J., Peñuelas, J., Prebble, M., Stevenson, J., Whittaker, R.J., Steinbauer, M.J., 2021. The human dimension of biodiversity changes on islands. Science (1979) 372 (6541), 488–491. https://doi.org/10.1126/science.abd6706.

Pineda-Morante, D., Fernández-Calero, J.M., Pölsterl, S., Cunillera-Montcusí, D., Bonada, N., Cañedo-Argüelles, M., 2022. Local hydrological conditions and spatial connectivity shape invertebrate communities after rewetting in temporary rivers. Hydrobiologia 849 (6), 1511–1530. https://doi.org/10.1007/s10750-022-04799-8(0123456789 (.,-volV(0123458697(.,-volV).

Poncela, R., Santamarta, J.C., García-Gil, A., Cruz-Pérez, N., Skupien, E., Garcia-Barba, J., 2022. Hydrogeological characterization of heterogeneous volcanic aquifers in the Canary Islands using recession analysis of deep water gallery discharge. J. Hydrol. 610, 127975. https://doi.org/10.1016/j.jhydrol.2022.127975.

Santamarta J.C., 2013. Hidrología y Recursos Hídricos En Islas y Terrenos volcánicos. Colegio de Ingenieros de Montes, Tenerife. https://oa.upm.es/19965/1/Libro_digital_AGUAS.pdf.

Sefton, C.E., Parry, S., England, J., Angell, G., 2019. Visualising and quantifying the variability of hydrological state in intermittent rivers. Fundament. Appl. Limnol. 193/1, 21–38. https://doi.org/10.1127/fal/2019/1149.

Straka, M., Polášek, M., Syrovátka, V., Stubbington, R., Zahrádková, S., Němejcová, D., Šikulová, L., Řezníčková, P., Opatřilová, L., Datry, T., Pařil, P., 2019. Recognition of stream drying based on benthic macroinvertebrates: a new tool in Central Europe. Ecol. Indic. 106, 105486. https://doi.org/10.1016/j.ecolind.2019.105486.

Turner, D.S., Richter, H.E., 2011. Wet/dry mapping: using citizen scientists to monitor the extent of perennial surface flow in dryland regions. Environ. Manage 47 (3), 497–505. https://doi.org/10.1007/s00267-010-9607-y.

Uys, M.C., O'Keeffe, J.H., 1997. Simple words and fuzzy zones: early directions for temporary river research in South Africa. Environ. Manage 21, 517–531. https://link.springer.com/content/pdf/10.1007/s002679900047.pdf.

van Meerveld, H.I., Kirchner, J.W., Vis, M.J., Assendelft, R.S., Seibert, J., 2019. Expansion and contraction of the flowing stream network alter hillslope flowpath lengths and the shape of the travel time distribution. Hydrol. Earth. Syst. Sci. 23 (11), 4825–4834. https://doi.org/10.5194/hess-23-4825-2019.

Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J. Clim. 23 (7), 1696–1718. https://doi.org/10.1175/2009JCLI2909.1.

Vidaña, A.E., 2020. Macroinvertebrates Assemblages in the Canary Islands and Madeira. Universidad de La Laguna, Tenerife. Tesis Máster. https://riull.ull.es/xmlui/bitstream/handle/915/19525/name.pdf?sequence=1&isAllowed=y.

Zanetti, F., Durighetto, N., Vingiani, F., Botter, G., 2022. Analyzing river network dynamics and the active length–discharge relationship using water presence sensors. Hydrol. Earth. Syst. Sci. 26 (13), 3497–3516. https://doi.org/10.5194/hess-26-3497-2022.

Zimmer, M.A., Kaiser, K.E., Blaszczak, J.R., Zipper, S.C., Hammond, J.C., Fritz, K.M., Allen, D.C., 2020. Zero or not? Causes and consequences of zero-flow stream gage readings. Wiley Interdisciplin. Rev. 7 (3), e1436. https://doi.org/10.1002/wat2.1436.