Intermittent Rivers and Ephemeral Streams: A Unique Biome With Important Contributions to Biodiversity and Ecosystem Services

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Abstract

The majority of flowing waterbodies throughout the world can be considered intermittent rivers or ephemeral streams (IRES) because at some point in time and space they stop flowing or dry. Despite their global abundance, less is known about this biome compared to perennial—permanently flowing—rivers. However, a recent surge in research has dramatically improved our understanding of how IRES function and what types of biodiversity and ecosystem services they support. A cycle of terrestrial-aquatic habitat conditions caused by the periodic drying and rewetting creates a high temporal dynamic in the biogeochemistry, biodiversity, and ecosystem services of IRES. Vast amounts of accumulated sediment, organic matter and organisms can be transported from IRES downstream to larger rivers or lakes, contributing to the global C cycle. The mosaic of aquatic and terrestrial habitats along IRES hosts high biodiversity including microorganisms, plants, invertebrates, reptiles, and mammals, with specialized strategies to resist to or recover from changes in habitat conditions. Although IRES provide a broad range of ecosystem services including provision of fresh water and cultural enrichment, there is a continued struggle to protect this dynamic and threatened biome.

What Are Intermittent Rivers and Ephemeral Streams?

Hydrologically Diverse and Globally Abundant

Intermittent rivers and ephemeral streams (IRES) refer to all flowing waters that cease flow and/or dry completely at some point along their course (Datry et al., 2017, Fig. 1). Arguably the world's most widespread type of flowing water (Larned et al., 2010; Datry et al., 2018a), IRES range from small ephemeral streams that flow for a few days after heavy rain to large intermittent rivers that recede to isolated pools but might not dry completely. Many local names for IRES exist throughout the world such as temporary rivers, winterbournes, wadis, arroyos and ramblas (e.g., Steward et al., 2012), highlighting the diversity and cultural importance of this biome to people living in their catchments.

IRES occur on all continents, including Antarctica (Larned et al., 2010; Steward et al., 2012). IRES are dominant features of hyper-arid, arid, semi-arid, and dry-subhumid regions, which represent a third to half of the Earth's land surfaces (Tooth, 2000; Whitford, 2002; Millenial Ecosystem Assessement, 2005, Fig. 1). As examples of their abundance, 70% of rivers are classified as intermittent in Australia (Sheldon et al., 2010), 66–94% of river lengths in Southwestern United States (i.e., Arizona, New Mexico, Utah, Nevada, Colorado, California; Levick et al., 2008) are IRES, and they are found across Mediterranean, temperate, humid, boreal, alpine and polar regions (Sabater and Tockner, 2009; Bonada and Resh, 2013; Leigh et al., 2015). Virtually every river network includes IRES, notably because the dense network of headwaters, which can make up >70% of the total river network length, is typically intermittent (Lowe and Likens, 2005; Meyer et al., 2007; Fritz et al., 2013; Grill et al., 2019).

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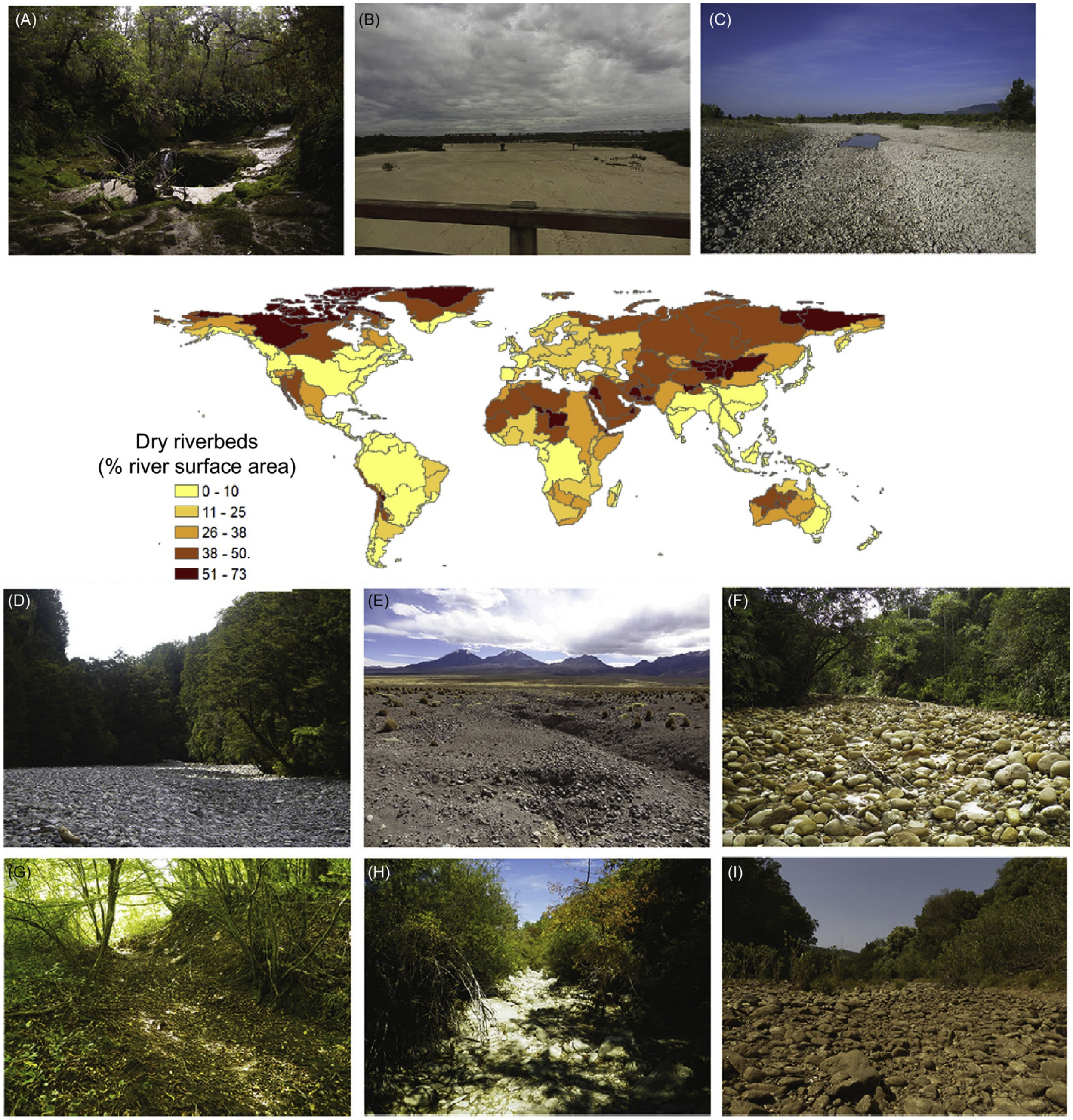

Fig. 1 Different types of IRES from across the world: (A) unnamed karstic stream, West Coast, South Island, New Zealand, (B) Río Seco, Chaco, Bolivia, (C) Asse River, Provence, France, (D) unnamed gravel-bed stream, West Coast, South Island, New Zealand, (E) unnamed stream, Altiplano, Bolivia, (F) Chaki Mayu, Amazonia, Bolivia, (G) Clauge, Jura, France, (H) Calavon River, Provence, France, and (I) Hozgarganta River, Andalucía, Spain. The map represents five categories of the percentage of dry riverbeds over the total river surface per COSCAT (a global segmentation scheme of coasts and river catchments; Meybeck et al., 2006). Dry riverbeds have been estimated as the river surface area dry all year long from models developed in Raymond et al. (2013). These estimates represent the only available global estimates and may over-represent dry riverbeds at higher latitudes. Photo credits: Thibault Datry (A–F), Bertrand Launay (G and H), and Núria Bonada (I).

Three-in-One: IRES Contribute to Lotic, Lentic, and Terrestrial Dynamics

IRES are dynamic shifting habitat mosaics of flowing, non-flowing and dry patches (Fig. 2), the extent and connectivity of which constantly vary across drainage basins in response to river discharge and groundwater levels (Stanley et al., 1997; Jaeger et al., 2014; Datry et al., 2016a). To account for this dynamism in habitat types, concepts from lotic (aquatic flowing), lentic (aquatic non-flowing) and terrestrial ecology are used to understand these ecosystems (Datry et al., 2014b). In general, river networks are an aquatic continuum in a terrestrial matrix and therefore meta-ecosystems linked by lateral (terrestrial to aquatic), vertical (from the surface to the subsurface) and longitudinal (from upstream to downstream) flow of matter and energy (Battin et al., 2009). In IRES,

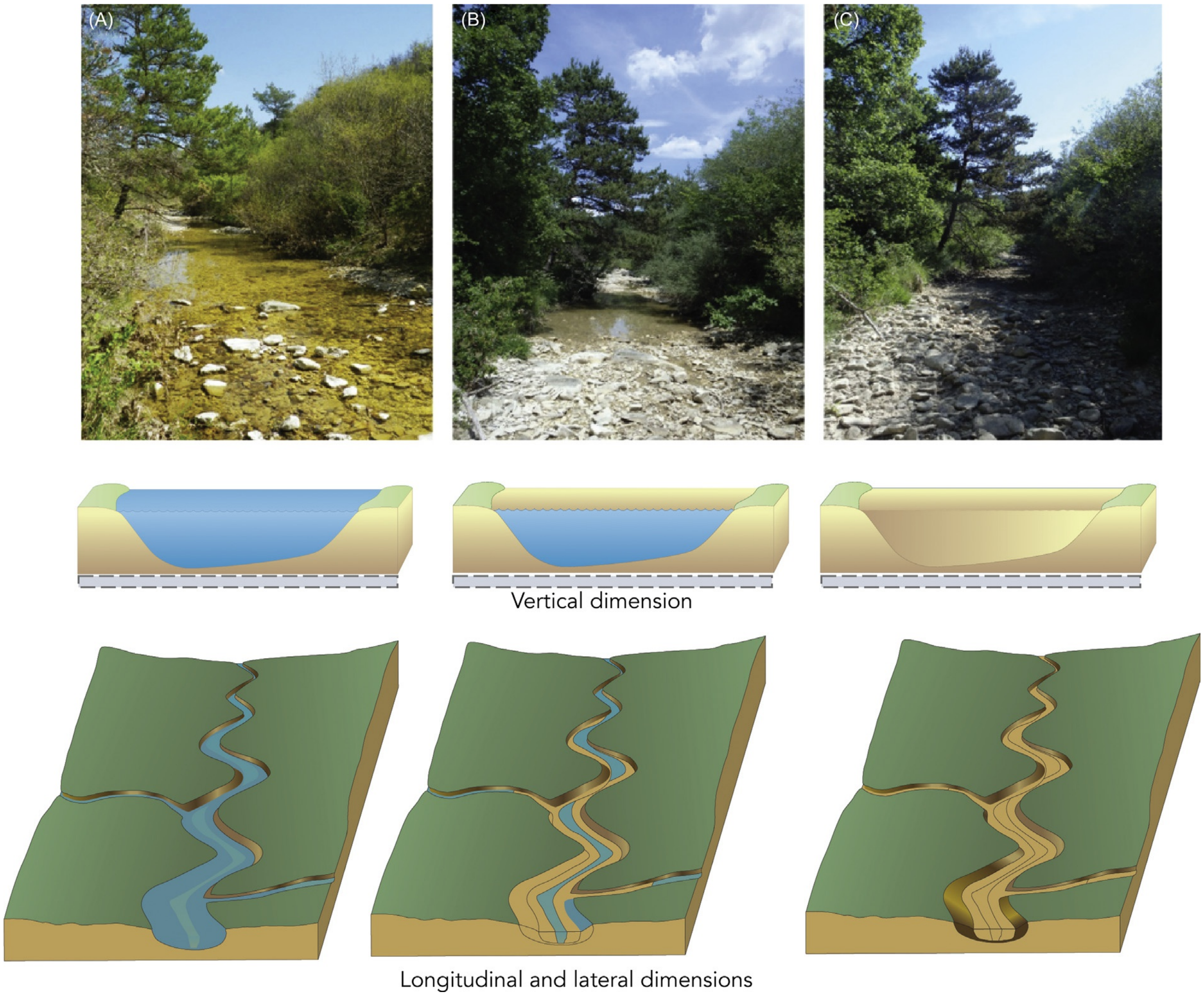

Fig. 2 Alternating lotic (flowing) (A), lentic (non-flowing) (B) and terrestrial (dry) phases (C) in an intermittent river of France (Calavon River). Below each photo is a graphical depiction of the likely vertical and longitudinal and lateral dimensions of each flow-state. Gray box below stream channel (vertical dimension) represents the hyporheic zone that may remain saturated even during surface drying events. Photo credits: Bertrand Launay.

the mosaic of lotic, lentic, and terrestrial environments creates patches of sub-ecosystems that interact differently among each other and with the terrestrial matrix. The flows of matter and energy, which affect biogeochemical cycles and ecosystem functioning, change with alternating dry and wet phases and depending on network position (Datry et al., 2017; von Schiller et al., 2017). Lateral flows of organisms and resources with the surrounding terrestrial habitat are likely to be enhanced during the dry phase when terrestrial organisms colonize dry riverbeds. However, little is known about the spatiotemporal variability of these flows and their effect on biogeochemical cycles and ecosystem functioning at the entire river network scale.

Biogeochemical Dynamics in Intermittent Rivers and Ephemeral Streams

Streams and rivers transport a variety of dissolved and particulate compounds, such as nutrients (e.g., nitrogen, phosphorus) and organic matter, which constitute bases for stream food webs and ecosystem functioning (Meybeck, 1982). The biogeochemical cycles, resulting from the input, removal, transformation, production, and export of these compounds, are generally controlled by factors such as humidity, temperature, flow velocity (Shumilova et al., 2019). In response to alternating lotic, lentic, and terrestrial phases over time and geographic location, IRES have temporally and spatially discontinuous biogeochemical processes with pulsed nutrient and OM inputs, processing, and transport events (von Schiller et al., 2017).

Organic matter processing (i.e., decomposition) and transport are typically halted while riverbeds are dry due to reduced activity of microorganisms (Corti et al., 2011; Sabater et al., 2016) and loss of hydrological connectivity, respectively. However, stream biofilms associated with dry sediments may continue processing organic matter (Timoner et al., 2012) and the activity of some anaerobic microbes may lead to changing levels of stream nutrients, such as nitrogen (Austin and Strauss, 2011; Merbt et al., 2016) on dry riverbeds. Colonization of the dry riverbed by terrestrial animals (e.g., insects, mammals) and plants may also modify organic matter and nutrients dynamics through imports of terrestrial compounds or utilization of the instream resources.

In pools that may remain along the dry riverbed matrix, the accumulation of organic matter combined with high respiration rates and the lack of oxygen when air temperature rises can create anaerobic or hypoxic conditions. Organic matter usually accumulates in the form of leaf litter from riparian trees, as algae growth in pools with low canopy cover, or both, and rates of decomposition are low (Corti et al., 2011). The nutrient balance is also modified due to denitrification processes, with nitrates usually decreasing and phosphate and ammonium contents increasing (von Schiller et al., 2011). Very low oxygenation at the later stages of pool drying may also lead to methane production (Gómez-Gener et al., 2016).

Flow resumption usually leads to pulses of organic matter and nutrients that are imported from the riparian zone into the stream and from upstream to downstream as the lateral and longitudinal hydrological connectivity is restored. Pulses of decomposition may then occur downstream where massive amounts of organic matter accumulates (Corti and Datry, 2012; Datry et al., 2018b).

Organic matter decomposition and microbial activity are the main drivers of carbon dioxide emissions from river ecosystems. CO_2 emissions from IRES are similar to those of their perennial counterparts during the flowing phase, globally estimated to be 1.75 g CO_2 m^{-2} day^{-1} (Raymond et al., 2013). However, these estimates do not take into account the rewetting and dry phases during which CO_2 emissions may greatly exceed those during flowing phases. Whereas dry sediments can release up to 67.5 g CO_2 m^{-2} day^{-1} (Gómez-Gener et al., 2016), pulses of decomposition and sediment respiration during rewetting events may emit up to 13.7 g CO_2 m^{-2} day^{-1} (Datry et al., 2018b, Box 1) and 21.1 g CO_2 m^{-2} day^{-1} (Gallo et al., 2014), respectively. Annual contributions of IRES to global CO_2 emissions may therefore be much greater and more important than those of perennial rivers, magnified by the spatial abundance and ubiquity of IRES across the Earth's surface.

Biodiversity in Intermittent Rivers and Ephemeral Streams

From Microbes to Elephants, IRES Support High Biodiversity

Microbiota, including bacteria, archaea, protozoa, fungi, cyanobacteria, and algae grow both in benthic habitats as well as in the water column itself and comprise the base of aquatic foodwebs (Pusch et al., 1998; Weitere and Arndt, 2003; Battin et al., 2016). Flow intermittence can cause differences between environmental conditions in IRES and perennial rivers, such as water temperature, dissolved oxygen, dissolved organic matter, inorganic nutrients, flow velocity, and light. These differences in environmental conditions likely drive differences in the composition of microbiota between IRES and perennial biomes (Romaní et al., 2017). Microbes are known to play a key role in biogeochemical processes in rivers, such as organic matter decomposition, and our understanding of microbial biodiversity continues to advance as molecular approaches make it easier and more affordable to quantify microbial diversity. For example, pyrosequencing uncovered compositional differences in bacterial communities on cobbles during flowing, non-flowing, and rewetting stages of flow intermittence in a Mediterranean IRES (Timoner et al., 2014).

Plant communities that inhabit IRES are influenced by the dynamic hydrologic conditions which create favorable environmental conditions for both vascular aquatic and riparian plants (Sand-Jensen and Frost-Christensen, 1998; De Wilde et al., 2014). Plants comprised of various functional groups, including emergent and submerged, respond differently to flow intermittence (Brock and Casanova, 1997). Some emergent helophytes, such as Cyperaceae and Juncaceae, can tolerate complete drying of above and belowground biomass. Submerged plants usually die during drying conditions except for desiccation-resistant seeds that can germinate upon rewetting (Brock et al., 2003). Thus, the availability of "seed banks" is an important attribute of plant communities allowing persistence in IRES.

Aquatic and terrestrial invertebrates are arguably the most well-studied organisms inhabiting IRES (Leigh and Datry, 2016). The dynamic environmental conditions and habitat types found within IRES influence the composition, abundance, and diversity of invertebrates (Datry et al., 2016a), often driving differences in community composition and richness between IRES and perennial rivers. In general, taxonomic richness of aquatic invertebrates in IRES is lower than that of equivalent-sized perennial rivers (Datry et al., 2014a; Soria et al., 2017). However, when the terrestrial phase of IRES is considered, total invertebrate richness, accounting for aquatic and terrestrial taxa, may be similar or even higher in IRES. Typically, community composition of invertebrates changes along a gradient of flow intermittence, with IRES communities being subsets of the species found within sites with more permanent flow (Datry et al., 2014a). IRES invertebrate community composition shifts in response to timing, duration, and frequency of lotic phases, often with distinct invertebrate communities within each hydrologic phase. For example, mayflies, stoneflies and caddisflies can typify aquatic invertebrate communities during the flowing phase, whereas odonates (dragonflies and damselflies), aquatic beetles, and true bugs may dominate during the lentic phase (Bonada et al., 2007). During the terrestrial phase, both terrestrial and semiaquatic invertebrates colonize IRES, including insects (mainly ground beetles), arachnids, centipedes, crustaceans, millipedes, snales, springtails, and worms (Steward et al., 2017).

Fishes inhabit intermittent rivers, including those in arid regions of Africa and Australia (Lévêque, 1997; Allen et al., 2002). Generally, fish diversity is lower in IRES compared to equivalent-sized perennial systems because relatively few species can cope with flow intermittence. However, some fish are adapted to breathing oxygen from the atmosphere (e.g., African sharptooth catfish [*Clarias gariepinus*]). Persistence of most fishes within IRES is facilitated more by movements into and out of drying habitats than by their ability to resist desiccation, although pools can be an important refuge for stream fishes (Magoulick and Kobza, 2003). Swimming allows fish to disperse to access food and habitat resources within IRES during their lotic hydrological phases (Kingsford et al., 2006; Wardle et al., 2013). IRES provide an important habitat type for some fish species during their life cycle. For example,

Box 1 The 1000 intermittent river network: measuring the importance of IRES to global carbon and CO_2 emission.
The "1000 Intermittent River Project": Measuring the Importance of IRES to Global Carbon and CO_2 Emissions

Drastic changes in flow regime and IRES distribution prompt fundamental questions: how are the biogeochemistry and biodiversity of river networks affected by these changes? How do these alterations vary across climatic and biogeographic regions?

To address these questions, an international group of researchers started a multidisciplinary effort called the "1000 Intermittent Rivers Project" (#1000IRP on Twitter). The project's main goal is to merge individual knowledge, forces, and passions through simple, consistent, and comparable joint experiments in IRES worldwide.

Since its 2016 inception, the project has grown to over 120 participants from 28 countries (Datry et al., 2016b). Although some regions, including Africa and Asia, remain poorly represented in this collaborative effort, the group continues to recruit new participants for future experiments.

The first coordinated experiment done by #1000IRP is recognized for contributing to the understanding of global C cycle and CO_2 emissions (Datry et al., 2018b; Shumilova et al., 2019). In this global experiment, researchers collected leaf litter and other organic matter and sediments from 212 dry riverbeds across the globe. Samples were then sent to a single laboratory for further processing.

One major finding from this experiment was that rewetting events in IRES contribute up to 10% of daily CO_2 emissions from all rivers and streams. During rewetting, dissolved organic carbon, phenolics, and nitrate are leached from sediments and organic matter are washed downstream. This indicates that rewetting phases in IRES are "hot moments" of biogeochemical activities that likely play an important role in how rivers function.

As more rivers begin to dry as a result of climate change and increased water demands, there will be a continued need to study IRES at the global scale through collaborative experiments.

Photo credits: Petr Pařil.

IRES constitute a key spawning and juvenile rearing habitat for the federally endangered coho salmon (*Oncorhynchus kisutch*) along the US Pacific Coast (Wigington et al., 2006). IRES likely provide abundant food resources through terrestrial subsidies and fish may experience lower levels of competition and predation compared to perennial rivers (Courtwright and May, 2013; Kerezsy et al., 2013).

Other wildlife, such as amphibians, reptiles, birds, and mammals use IRES for a variety of reasons, especially in arid and semiarid regions where water is limited. Most amphibians are well-suited to inhabit IRES because of their life cycles which constitute both aquatic and terrestrial stages (Wells, 2010). Many reptiles are attracted to IRES because of higher humidity compared to terrestrial habitats. Bird species that are not dependent on water often congregate in riparian areas of IRES to roost and reproduce (Shine and Brown, 2008). Mammals ranging in size from rodents (Gibson and Olden, 2014) to elephants (Elephantidae) and hippopotamuses

(*Hippopotamus amphibious*) (Kok and Nel, 1996; Lakshminarayanan et al., 2016) are also commonly found in and around IRES (Kerezsy et al., 2013). Although IRES likely attract wildlife during lotic and lentic hydrologic phases, dry riverbeds are movement corridors for all types of terrestrial vertebrates including lizards, birds, rodents, lagomorphs, carnivores, and ungulates (Sánchez-Montoya et al., 2016).

Strategies for Persistence in IRES

To persist in the dynamic conditions of IRES systems, organisms have a variety of adaptations that are often categorized into traits of either resistance or resilience to flow intermittence (Bonada et al., 2007; Robertson and Wood, 2010; Robson et al., 2011; Datry et al., 2014a). Traits are broadly characterized into physiological, morphological and life-history features of organisms. Resistance can be defined as the capacity of a species, a community, or an ecosystem to persist unchanged by and during a disturbance (Stanley et al., 1994; Vander Vorste, 2015) and includes diapause, desiccation-resistant eggs, cocoons or cells, body armoring and aerial respiration (Bonada et al., 2007; Robson et al., 2011). Resilience, or the capacity to recover from disturbance, is favored by traits such as short lifespans with early maturity, asexual reproduction, and strong aerial or aquatic dispersal ability (Bonada et al., 2007; Datry et al., 2014a; Vander Vorste, 2015). Typically, there are several sources of colonization of IRES by taxa with either resistant or resilient strategies (Fig. 3).

Organization of Metacommunities Within IRES

A metacommunity is a set of local communities connected by dispersal (Leibold et al., 2004). In a metacommunity, community assembly is determined by the capacity of species to tolerate and develop under local environmental conditions (environmental sorting) and to reach the community through dispersal (i.e., spatial connectivity and organism dispersal ability). IRES support dynamic metacommunities in which local communities experience alternating aquatic and dry phases as well as changes in hydrological connectivity, forming a mosaic of habitats that usually connect and disconnect each year (Datry et al., 2016a).

Biotic community resistance and resilience to river drying

Resistance strategies
allow organisms to survive flow cessation and persist within a stream reach

Sources of resistance in IRES

Remnant pools	As stream riffles dry, organisms can survive in remnant pools if environmental conditions remain favorable
Hyporheic zones	Once surface water is lost, some organisms can survive in saturated hyporheic zones (saturated interstitial sediments below and adjacent to the streambed.
Desiccation-resistant stages	Eggs, larvae, pupae or adult life stages that can resist desiccation for up to many years before becoming active again upon stream rewetting.

Resilience strategies
allow organisms to recolonize a previously dry stream reach from elsewhere

Sources of resilience in IRES

Dispersal by drift	Organisms entrained in water flowing downstream or on floating detritus
Crawling and swimming	Crawling and swimming upstream or downstream
Aerial dispersal	Aerial adult life stages of aquatic insects

Fig. 3 Examples of traits that enhance the resistance and resilience of aquatic invertebrates to surface water drying Adapted from Vander Vorste, R. (2015). The hyporheic zone as a primary source of invertebrate community resilience in intermittent alluvial rivers: Evidence from field and mesocosm experiments. PhD Thesis. University of Lyon 1: Lyon, France. 210 pp.

These spatiotemporal dynamics leads to recurrent changes in community assembly mechanisms (Datry et al., 2016a; Sarremejane et al., 2017).

Environmental sorting is the main driver of aquatic organism assembly during flow recession phases because drying creates a strong filter eliminating the least adapted species. On the other hand, dispersal processes should be more important when flow resumes as organisms recolonise from surrounding habitats (Datry et al., 2016a, Sarremejane et al., 2017). However, the interplay of these mechanisms is likely to differ for species adapted to lotic, lentic, and terrestrial habitats, for example, dispersal-related processes likely being more important for lotic and terrestrial species as flow recedes. More research is needed to determine which local conditions (e.g., drying frequency, flow state and water chemistry) and connectivity features (e.g., distance to perennial reaches and isolation within the river network) drive community assembly where and when in the river metacommunity. Understanding this will allow better characterization of community assembly in response to flow intermittence.

Management of Intermittent Rivers and Ephemeral Streams

Ecosystem Services Provided by IRES

IRES provide important cultural, regulating, and provisioning ecosystem services, varying between aquatic and dry phases (Datry et al., 2018a; Koundouri et al., 2017). IRES bring spiritual and inspirational enrichment and are also widely appreciated for recreational opportunities and aesthetic values. Regulating ecosystem services provided by IRES include flood protection and water purification. As discussed previously, IRES support an important role in riverine nutrient cycling and contribute to global CO_2 emissions. Provisioning ecosystem services provided by many IRES include fresh water and food. The dynamic flow regime of IRES also influences provision and types of these various ecosystem services. For example, IRES can support recreational fishing during wet phases but be used as a path by walkers or as foraging areas for livestock during dry phases.

Protection and Management of IRES

Relatively little attention has been given to IRES protection and management, perhaps because dry channels have, until recently, been perceived as lifeless symbols of human impacts or poorly functioning river systems. In many countries, IRES are not legally recognized as part of the river network (Acuña et al., 2014), and although their recognition has increased in the past decade, their status as waterways that are worth protecting is still debated by authorities in the United States (Marshall et al., 2018, Box 2). In Europe, IRES protection status depends on how "waterbodies" are classified by regional authorities or each river basin, with differences in the ways that IRES are perceived and protected across countries (Fritz et al., 2017). In Australia where IRES are prevalent, they are included in most management plans and legislation. Nevertheless, IRES are sometimes included within protected areas and, when this is so, their conservation focuses on maintaining their natural flow regime and the connectivity to aquatic refuges (e.g., pools, Leigh et al., 2015). Ephemeral streams, i.e., those dry most of the time, are typically prone to being dismissed from management plans, and limited knowledge about their ecosystem services often hinders their conservation (Boulton, 2014).

IRES are often omitted from ecological monitoring programs implemented to characterize the ecological quality of rivers. Most biomonitoring techniques have been developed for perennial rivers and often perform poorly in IRES, particularly because reference communities (i.e., under those experiencing little or no human impact) usually have fewer taxa than those in their perennial counterparts (Stubbington et al., 2018a). Typically, biomonitoring index scores decrease with flow intermittence as well as with human impacts (Wilding et al., 2018). Biomonitoring tools therefore need modification to account for the natural variability of IRES communities and to efficiently disentangle the effect of flow intermittence from human impacts (Stubbington et al., 2018a). However, characterization of communities across the range of aquatic and terrestrial conditions that occur in IRES—including responses to natural hydrological variability and to human stressors is still needed. Such research will enable the development of effective biomonitoring strategies, which include terrestrial and lentic phases, therefore recognizing the dynamism of these ecosystems (Stubbington et al., 2018b).

Future of IRES and Global Change

In IRES, flow cessation and drying can have natural and non-natural causes. Disentangling these causes is rarely easy (Gallart et al., 2017), and often, multiple causes interact. Different processes generate natural drying in IRES: transmission losses (e.g., infiltration of surface water into porous streambeds), evapotranspiration, downward shifts in groundwater tables, hillslope runoff recession, and freeze-up (Larned et al., 2010). Anthropogenic drying can be due to one or more of the following human activities: alteration of land-use patterns, flow regulation, surface or groundwater extraction, and reduced precipitation and increased evaporation resulting from climate change (Palmer et al., 2008; Steward et al., 2012).

The flow regimes of streams and rivers are prone to severe alterations worldwide, mainly in response to drying climates across much of the globe coupled with rapidly increasing human demands. Consequently, the occurrence and spatial and temporal extent of IRES are both increasing over time (Larned et al., 2010; Datry et al., 2018a). Shifts from perennial to intermittent flow regimes are projected by the 2050s for streams and rivers across much of the globe, including north-eastern and south-western Australia, Brazil, California, the Caribbean, southern Africa, West Africa and around the Mediterranean Basin (Döll and Schmied, 2012). Conversely,

Box 2 Case study of current environmental protection of IRES systems in the United States.
Does Environmental Policy Protect Intermittent and Ephemeral Streams?

Case Study: Waters of the United States (WOTUS)

In the United States, the Clean Water Act (CWA) provides legal protection of the ecological health of rivers. However, a debate over whether intermittent and ephemeral streams should be included in these protections was sparked in 2006 in the U.S. Supreme Court. Guidance by the Supreme Court decision stated that rivers with permanent or seasonal hydrologic connections to Traditionally Navigable Waters should be protected. Without a relatively permanent hydrologic connection, streams with a connection through hydrological and ecological factors that affect the chemical, physical, and biological health of navigable waters should also be protected.

Following the Supreme Court decision, inclusion of intermittent and ephemeral streams in the CWA by the US Environmental Protection Agency (USEPA) has wavered. Freshwater scientists have been in favor of including intermittent streams within the jurisdiction of waters of the United States, in part, due to the recognition that these streams provide "many ecosystem services, including water provision and purification, that contribute substantially to securing water quantity and quality" as stated in Marshall et al. (2018). Following an independent review of >1200 scientific publications, USEPA's Science Advisory Board informed a Clean Water Rule in 2015 aiming to recodify the waters of the United States to include intermittent streams. As of 2019, the US federal government has failed to implement the Clean Water Rule despite direct advice from freshwater scientists (Acuña et al., 2014; Marshall et al., 2018; Sullivan et al., 2019). Without adequate protection, the US puts 58% of all waterways in the contiguous US at risk of degradation (Marshall et al., 2018).

Photo credits: Ross Vander Vorste.

some natural IRES are predicted to become perennial in Siberia and parts of Canada and Alaska due to warmer winters (Döll and Schmied, 2012). Similarly, many natural IRES are becoming more intermittent and dry periods are getting longer (Larned et al., 2011). However, trends of increasing drying are not universal and controlled releases from dams and weirs, discharge of agricultural, industrial and urban effluents, inter-basin transfers and snow melt can contribute to decreased intermittence of many IRES, turning some of them artificially perennial (Hassan and Egozi, 2001; Steward et al., 2012). In some water-scarce areas, the baseflow of urban rivers is maintained by wastewater effluents (Luthy et al., 2015). Reversal of seasonal patterns of drying are observed in other areas, where channels are used to carry irrigation flows released from upstream dams: peak flows from dam releases occur when flows in the channel used to cease whereas dams retain water, sometimes causing flow to cease at a time when the downstream river historically flowed (Barnett and Pierce, 2009).

Summary

Intermittent rivers and ephemeral streams contribute substantially to global biogeochemical processes and help sustain biodiversity. In many regions of the world, this biome dominates as the main freshwater ecosystem type compared to their perennially flowing counterparts. A dynamic flow regime is what sets IRES apart from other aquatic ecosystems; creating opportunities for lotic, lentic, and terrestrial organisms. Many of these organisms have specific trait adaptations that allow them to persist through phases of flowing water, pooling, and completely dry channels. Across the landscape, biotic communities can change quickly from phase to phase because they are connected by dispersal forming metacommunities. IRES likely play a major role in how metacommunities are organized because of their dynamic nature. Although IRES are becoming more widely recognized for their importance in providing ecosystem services, they are increasingly under threat by global change. Under future climate change, many more perennial rivers are expected to become intermittent or ephemeral and drying may become more severe. Protection of this biome, which is currently limited compared to perennial rivers, continues to be an issue to be resolved.

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