The 1000 intermittent rivers experiment

Datry T, Corti R, Foulquier A, Von Schiller D., Tockner K., 20 April 2015

1. Context

Intermittent rivers and ephemeral streams (IRES, these rivers which stop flowing or dry up at some point in time and space) are prevalent in all climates and dominate river networks in many regions (Larned et al. 2010, Acuña et al. 2014, Datry et al. 2014a). For example, IRES represent 30-40% of the larger rivers and 69% of the low-order streams below 60° latitude (Raymond et al. 2013). Over the next century, the number and length of IRES will further increase due to climate and land-cover change, and increasing abstraction for public water supply, irrigation and other economic uses (Gleick & Palaniappan 2010, Döll & Schmied 2012, Steward et al. 2012).

Historically, IRES have been perceived to be outside of the scope of both terrestrial and aquatic sciences and therefore, have been overlooked by most disciplines (Larned et al. 2010, Steward et al. 2012). As a result, the persuasive conceptual developments in river research have been generated from and for perennial rivers and are poorly applicable to IRES (Datry et al. 2014a). But after years of near-obscurity, IRES research is now blooming, driven by increasing water scarcity issues, climate change effects, and the recognition that IRES are prevalent in river networks (Leigh et al. 2015). One of the most important and recent progresses has been the recognition that IRES are bio-geochemical reactors with a pulsed dynamic (Acuña & Tockner 2010, Larned et al. 2010, Von Schiller et al. 2011; 2015, Corti & Datry 2012, Datry et al. 2014a).

During dry phases, large quantities of particulate organic matter (POM; e.g. leaves, dead biofilms, fine organic matter) accumulate in dry riverbeds (Acuña & Tockner 2010, Datry et al. 2014a). Low water availability causes high mortality of microbes and other decomposers and reduces their activity through direct physiological effects, reduced diffusion of soluble substrates and lowered mobility (Humphries & Baldwin, 2003; Amalfitano et al., 2008). As a result, POM processing is considerably reduced (Gurtz & Tate 1988, Boulton 1991, Corti et al. 2011, Foulquier et al. 2015). However, highly oxygenated conditions favour aerobic POM transformation processes, which together with environmental processes such as photodegradation, alter POM condition and chemistry and mediate its further decomposition under perennial, fully aquatic conditions. (Datry et al. 2011, Dieter et al. 2011, 2013). When flow resumes, often in the form of spectacular “first-pulse” events (a video here: www.irstea.fr/datry), large quantities of pre-conditioned POM can be transported to downstream reaches, where they undergo further decomposition (Jacobson et al. 2000, Corti & Datry 2012, Rosado et al. *in press*). Solutes and entrained POM at the leading edge of the flowing water can exceed baseflow concentrations by several orders of magnitude (Jacobson et al. 2000, Hladyz et al. 2011, Corti & Datry 2012). Deposited and processed CPOM can be an important carbon source for heterotrophic consumers (Jacobson et al. 2000, Corti & Datry 2012, Rosado et al. 2014), but it can also cause hypoxic blackwater events and subsequent organism kills (Hladyz et al. 2011). Furthermore, rewetting of sediments can cause a massive release of CO_2 to the atmosphere (Gallo et al. 2014).

The recognition of the pulsed dynamic of IRES is based on reach-scale observations in a few rivers; however, its significance at the scale of river catchments is unknown. According to the prevalence of IRES within river networks, it is very likely that most global estimates of carbon and nutrient processing in rivers (e.g., Tranvik et al. 2009, Seitzinger et al. 2010, Battin et al. 2011) are inaccurate, along with the estimates of how much rivers contribute to carbon dioxide release (Raymond et al. 2013, Von Schiller et al. 2014, Datry et

al. 2014b). It is thus timely to better quantify POM accumulation along dry riverbeds and understand the ecological significance of first pulse events. No meta-analysis would ever achieve this due to the small amount of data available.

The objectives of this project are to 1) quantify CPOM accumulation over dry streambeds during dry periods in multiple IRES worldwide, 2) understand the main drivers of variation in CPOM quantity and quality, including flow regime components, 3) assess the ecological consequences of first pulses on downstream receiving waters, leaching of nutrients and CO_2 release. Based on a wide, global network of stream ecologists, this project aims at conducting simultaneous, very simple but standardized experiments on as many IRES as possible in 2015/2016 to cover a wide range of climates, river types, flow regimes and vegetation.

2. Project schedule and details

The general principle is simple: we create a global network of interested stream ecologists, we all spend a few time and little expenses for a simple and exciting experiment. Pooled together, these individual experiments will generate a unique, compelling and timely dataset to address the objective above. Furthermore, it may trigger follow-up activities well beyond the present approach. In 3 words: united we stand.

The requirement of this project is to mobilize stream ecologists interested in IRES to work on multiple IRES: ideally, ~1 000, minimally > 100. A simple, cheap and time-efficient experiment carried out almost simultaneously and across a large number of IRES will provide a unique and outstanding dataset to explore. The rough quality of each single experiment, as well as the low amount of data individually generated will be largely compensated by the large number of IRES and the high consistency of the protocols used.

The first phase of the project will consist in creating this international network of volunteered stream ecologists. The second phase will be to collect environmental data and samples (coarse particulate organic matter –CPOM- on dry riverbeds, biofilms/algal mats and river sediments) on individual IRES in a consistent and simple procedure (see below). The third phase will be to ship a subsample of the collected material, to IRSTEA where they will be consistently processed. The fourth and last phase will be to analyze the data and write the associated paper(s).

3. Outputs and benefices for the participants

This joint production will lead to:

-the redaction of at least one paper targeting a high-profile journal on the significance of the pulse nature of IRES. Each participant of the project (***one per lab or one for 2 IRES sampled***) will be invited to be a co-author on the paper(s).

-the creation of an international network of river ecologists interested in the ecology and biogeochemistry of IRES. This network will continue to develop further common experiments and paper writing, will seek for international sources of funding (e.g., Future Earth program) and will be helpful for national/regional funding sources(. Participants will also meet whenever possible at international conferences (e.g., SFS, ESA, SEFS, ASLO).

4. Experimental design and protocol

The general design is to:

1) before the dry period, select **2 IRES** (of course, more if you can/want, there are no upper limits) you know or have been studied before (in case of braided rivers, please, contact us for adapting the protocol). If possible, prioritize the selection of the 2 IRES

based on the existence of flow gauging stations nearby (within the IRES or the catchment, at a distance < 200 km) with long-term hydrological time-series available.

2) select one representative reach per IRES. The reach length will be defined as 10 times the average active channel width to ensure consistent sampling effort across IRES and to cover a representative area. The active channel is defined here as the area of inundated and exposed bed sediments between established edges of perennial, terrestrial vegetation and/or abrupt changes in slope.
3) measure the environmental variables required (see below 4.1).
4) during the dry period, collect the different CPOM type falling/growing in the dry active channel as well as biofilms/algal mats and riverbed sediments in a standardized way (see below 4.2),.
5) back to the lab, process the collected material (see below 4.3).
6) ship subsamples to IRSTEA (see below 4.3).

4.1. Environmental variables to collect

At the catchment scale:

Stream order, stream length, distance to source, distance to downstream main confluence, distance to the closest flow recorder, number of active flow recorders in the catchment, catchment areas, climate zone (Koppen system, http://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification), landscape uses (forest, agricultural lands….), % of the network being intermittent (estimations), average annual precipitation.

At the reach scale:

Active channel width, width of the floodplain when relevant, estimate the % cover of the following substrate types (silt/sand/gravel/cobble/boulder/bedrock) across the reach, riparian cover (estimated visually as a %), riparian vegetation (absent/herbs/shrubs/trees), the 3 dominant riparian species, estimates of the drying period duration and timing, type of drying (flow cessation with dried riffles and persistent disconnected pools, or complete drying), X, Y (in WSG84) and altitude (m asl).

Take a few pictures of the study reach.

4.2. Collecting material

The collection of the material can be done once or several times during the dry period. The material needs to be collected **before the flow resumption**, and **the time during which CPOM had accumulated (dry period duration at the collection date) estimated** (with a 1-2 week precision, using either loggers, repeated observations, local knowledge, etc, depending on your situation).

At each collection date, estimate the area of the selected reach (length * average active channel width). Then, calculate the surface from which you need to collect CPOM to sample at least 5% of the reach surface using 1 m² quadrats. For example, for a stream with an active channel of 5 m, the reach will be 5*10= 50 m long and has a surface of 250 m^2, indicating a minimum of 12 quadrats will be required.

Note in case of active channels <2m (eg. headwater streams), the size of the quadrat can be adapted (eg. using quadrats of 0.5*0.5, 0.2*0.2 m), respecting 1) the definition of the reach length, 2) the rule of collecting material from at least 5% of the reach surface area, and 3) making sure the heterogeneity of the reach is encompassed. If the reach is really small (1st

order streams), ensure you can collect **~60g of leaves** and indicate the associated sampled surface (see 4.3.).

Then collect the 3 types of material from each quadrat, which you place across the active channel, with half of quadrats in the center of the channel and the other half on the margins of the active channel (this may not apply for rivers with active channels < 2 m). Overall, make sure the quadrats are being placed so you encompass the heterogeneity of the whole reach (for example, place transects equally spaced along the reach and spread the quadrats across them).

The 3 fractions are **CPOM, biofilm/algal mats** and **riverbed sediments**.

CPOM (***photo 1***) includes all organic materials deposited at the surface of the streambed, including leaves, wood, fruits, catkins and the "fresh" vegetation (ie. herbs, shrubs) developing. **CPOM** can be collected by hands and stored in plastic bags. Each CPOM type has to be stored separately, but pooling together all samples (eg. central and lateral samples) per reach (because the interest is not on within-reach heterogeneity). For large pieces of wood in jams originating from flowing periods, estimate roughly its volume.

Biofilm/algal mats (***photo 2***) are the layers deposited over the sediments which can remain from the flowing period. For each quadrat, once the CPOM has been collected, subsample an area of 20*20 cm to collect **biofilm/algal mats** by removing mats and/or scrapping stones with a razor blade into a different plastic bag (Ziploc), tightly closed with the air-expelled. Pool together all samples per reach. If the riverbed has no biofilm/algal mats, skip this step.

Riverbed sediments (***photo 3***) are the sediments composing the riverbed. Once the biofilm/algal mats have been collected, collect some **riverbed sediments** from a depth of 0-10 cm from the quadrat using a spoon or a shovel (no surface area needed, try to get ~3 L in total across the reach). Collect the fine fraction only (typically gravel, sand and clay). Sometimes, you may need to remove large cobbles to access the finer fraction underneath; however, in any case don't go deeper than 10 cm). Store this sediment into a different plastic bag (Ziploc), tightly closed with the air-expelled. Pool together all samples per reach. If the riverbed is composed of coarse sediments or bedrock, skip this step. A 2 mm sieve can be helpful to select the fine fraction directly in the field.

Photo 1. CPOM (leaves)

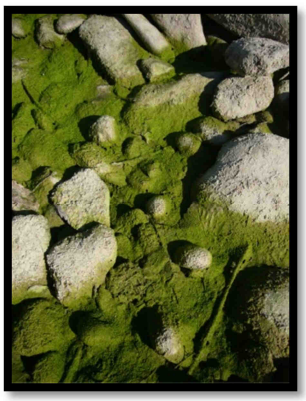

Photo 2. Biofilms/algal mats

Photo 3. River sediments

4.3. Processing the collected material

A synthesis of the protocol is provided on **Figure 1.**

4.3.1. Drying, weighting and storing

Back to the laboratory, the material has to be processed separately and **as soon as possible**.

CPOM: dry each type of CPOM in a dry oven for at least 12 hours at 60°C (but not more than 24h for leaves). Fresh material and fruits can be dried in a dry place during a week or so before being dried in the oven as above. Weight each type of CPOM (to the nearest g) to get the weight of each CPOM type per reach. Please avoid sun exposure during drying at a dry place.

Biofilm/algal mats: dry it in a dry oven for at least 12 hours at 60°C. Weight it (to the nearest g) to get the weight of biofilm/algal mats per reach.

Riverbed sediments: sieve the sediment through a 2 mm sieve and keep the fine fraction only. Dry the fine fraction in a dry place during a week, at least.

It would also be interesting to have the **% moisture of the sediments** to have an idea of the drying "severity". To do so, keep ~50g of fresh sediments from the field and make 3 subsamples of ~15g, to have triplicates. Weight each triplicate to the nearest g, dry them in the dry oven 60°C for 24h and immediately reweight them to the nearest g. The weight difference by the initial weight gives the % moisture. Report these 3 values to the data spreadsheet. Although important, this step is optional and depends on each contributor time and willingness.

4.3.2. Preparing subsamples for shipping

CPOM: use the dry leave fraction only. Grind briefly the **dry leaves** by hand to obtain relatively fine particles and pass them into a sieve (0.5 cm mesh size). Leaf stems does not need to pass the sieve.

Prepare a subsample of the filtered material of ~60g of dried, ground leaves. If leaf mass is < to 60g, put everything you have. Use 2-3 Ziplock bags combined or a solid plastic container to prepare the subsample.

Biofilm/algal material: prepare a subsample of ~60g of dry biofilm/algal material. If the mass is < to 60g, put everything you have. Use 2-3 Ziplock bags combined or a solid plastic container to prepare the subsample.

Riverbed sediments: prepare one subsample of ~160g and one of ~40g of dry riverbed sediments. If the mass is < to 200g, put everything you have in one sample. Use 2-3 Ziplock bags combined or a solid plastic container to prepare the subsample.

Left over

Store the leftover of all material type in a dark and dry room (in case more material is subsequently needed).

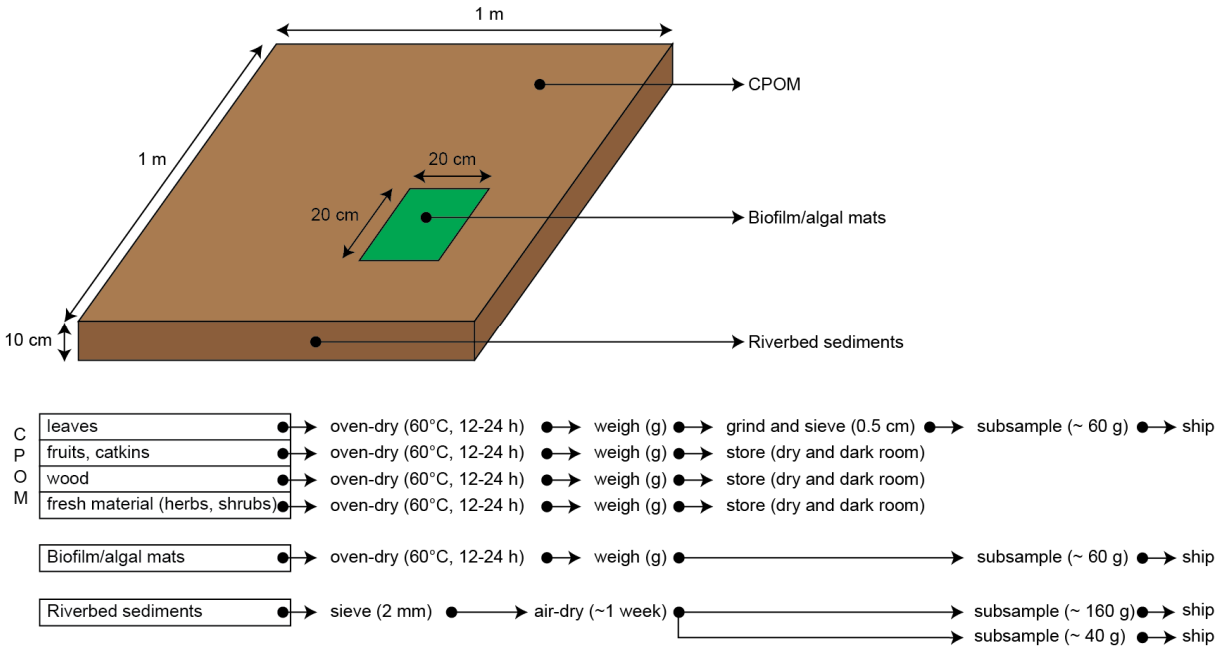

Figure 1. Synthesis of the protocol representing one quadrat (1x1m) in which CPOM and river sediments are collected, another quadrat (20x20cm) in which biofilm/algal mat is collected and the following processing a shipping procedure. See 4.2. to define how many quadrats are needed and how to put them on the study reach.

4.4. Shipping the material

Send by email the associated data (use the Excel spreadsheet sent), as well as a few pictures of the sampled reaches (thibault.datry@irstea.fr).

Make sure the subsamples shipped contain labels with a simple code, which you will report to the Excel spreadsheet. For the code, use the following system:

DATE-COUNTRY-LAB-NAME-RIVER-TYPE, where date is the collection date, country is the country where the material was collected, lab is the initial of your lab, name is your name, river is the name of the river, type is the type of material (leaves, algal/biofilm, sediment).

Ship the **subsample of dried ground leaves, the subsample of dry biofilm/algal and the 2 subsamples of sediment material** using FEDEX or DHL (they accept non-contaminant scientific samples) to Datry T, specifying the address and contact of both the senders and the receiver:

Thibault Datry,

IRSTEA-DYNAM, 5 rue de la Doua

CS70077 69626 VILLEURBANNE Cedex

France

In case of questions or comments, please contact Thibault Datry (thibault.datry@irstea.fr, Skype: thibault.datry, tel + 33 4.72.20.87.55

4.5. Further analyses which will be done by us

1) DO declines/CO2 release to measure microbial respiration induced by CPOM (using one standard inoculum)

2) DOC/DON/DOP leaching, measurement and characterization using SUVA 254 nm for assessing DOC quality

3) C/N/P content

4) AFDM measurement

5) CO2 release from rewetted sediments

6) DNA extraction from dry sediments

5. References

Acuña, V., & Tockner, K. (2010). The effects of alterations in temperature and flow regime on organic carbon dynamics in Mediterranean river networks. Global change biology, 16(9), 2638-2650.

Acuña, V., Datry, T., Marshall, J., Barceló, D., Dahm, C. N., Ginebreda, A., ... & Palmer, M. A. (2014). Why should we care about temporary waterways. Science, 343(6175), 1080-1081.

Battin TJ, Luyssaert S, Kaplan LA, Aufdenkampe AK, Richter A, Tranvik LJ. (2011). The boundless carbon cycle. Nature Geoscience 2: 598-600.

Bruder, A., Chauvet, E., & Gessner, M. O. (2011). Litter diversity, fungal decomposers and litter decomposition under simulated stream intermittency. Functional Ecology, 25(6), 1269-1277.

Boulton, A. J. (1991). Eucalypt leaf decomposition in an intermittent stream in south-eastern Australia. Hydrobiologia, 211(2), 123-136.

Butman D, Raymond PA. 2011. Significant efflux of carbon dioxide from streams and rivers in the United States Nature Geoscience 4: 839-842.

Corti R, Datry T, Drummond L, Larned ST. 2011. Natural variation in immersion and emersion affects breakdown and invertebrate colonization of leaf litter in a temporary river. Aquatic Sciences 73: 537-550.

Corti R, Datry T. 2012. Invertebrates and sestonic matter in an advancing wetted front travelling down a dry riverbed (Albarine, France). Freshwater Science 31: 1187-1201.

Datry T., Corti R., Claret C., Philippe M. 2011. Leaf litter decomposition along a gradient of flow permanence in a French temporary river: the memory of drying. Aquatic Sciences 73(4): 471-483.

Datry, T., Larned, S. T., & Tockner, K. (2014a). Intermittent rivers: a challenge for freshwater ecology. BioScience, bit027.

Datry, T., Foulquier A., Tockner, K. and Dahm, C.D. (2014b). A neglected source of CO2 outgassing from inland waters. Nature comment, http://www.nature.com/nature/journal/v503/n7476/abs/nature12760.html

Dieter, D., von Schiller, D., García-Roger, E. M., Sánchez-Montoya, M. M., Gómez, R., Mora-Gómez, J., ... & Tockner, K. (2011). Preconditioning effects of intermittent stream flow on leaf litter decomposition. Aquatic sciences, 73(4), 599-609.

Döll P, Schmied HM. 2012. How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. Environmental Research Letters 7: 14-37.

Foulquier A., Pesce S., Artigas J., Datry T. (2015). Drying responses of microbial litter decomposition and associated fungal and bacterial communities are not affected by emersion frequency. Freshwater Sciences.

Gallo, E. L., Lohse, K. A., Ferlin, C. M., Meixner, T., & Brooks, P. D. (2014). Physical and biological controls on trace gas fluxes in semi-arid urban ephemeral waterways. Biogeochemistry, 121(1), 189-207.

Gleick, P. H., & Palaniappan, M. (2010). Peak water limits to freshwater withdrawal and use. Proceedings of the National Academy of Sciences, 107(25), 11155-11162.

Gurtz, M. E., & Tate, C. M. (1988). Hydrologic influences on leaf decomposition in a channel and adjacent bank of a gallery forest stream. American Midland Naturalist, 11-21.

Hladyz S, Watkins SC, Whitworth KL, Baldwin DS. 2011. Flows and hypoxic blackwater events in managed ephemeral river channels. Journal of Hydrology 401: 114-125.

Jacobson PJ, Jacobson KM, Angermeier PL, Cherry DS. 2000. Variation in material transport and water chemistry along a large ephemeral river in the Namib Desert. Freshwater Biology 44: 481-491.

Leigh, C., Boulton, A.J., Datry, T., Courtwright, J.L., Fritz, K, May, C.L., & Walker, R.H., (2015). Ecological research in intermittent rivers: an historical review. Freshwater Biology, in press.

Larned ST, Datry T, Arscott D, Tockner K. 2010. Emerging concepts in temporary-river ecology. Freshwater Biology 5: 717-738.

Raymond, P. A., Hartmann, J., Lauerwald, R., Sobek, S., McDonald, C., Hoover, M., ... & Guth, P. (2013). Global carbon dioxide emissions from inland waters. Nature, 503(7476), 355-359.

Rosado J., Morais M., & Tockner K. (2014) Mass dispersal of terrestrial organisms during first flush events in a temporary stream. River Research and Applications, n/a–n/a

Seitzinger SP, Mayorga E, Bouwman AF, Kroeze C, Beusen AHW, Billen G, Van Drecht G, Dumont E, Fekete BM, Garnier J, et al. 2010. Global river nutrient export: A scenario analysis of past and future trends. Global Biogeochemical Cycles 24: GB0A08.

Steward AL, von Schiller D, Tockner K, Marshall JC, Bunn SE. 2012. When the river runs dry: human and ecological values of dry riverbeds. Frontier in Ecology and Environment 10: 202-209.

Tranvik LJ, Downing JA, Cotner JB, Loiselle SA, Striegl RG, Ballatore TJ, Dillon P, Knoll LB, Kutser T, Larsen, S. et al. 2009. Lakes and reservoirs as regulators of carbon cycling and climate. Limnology and Oceanography 54: 2298-2314.

Von Schiller D, Acuña V, Graeber D, Marti E, Ribot M, Sabater S, Timonier X, Tockner K. 2011. Contraction, fragmentation and expansion dynamics determine nutrient availability in a Mediterranean forest stream. Aquatic Sciences 73: 485-498.

von Schiller, D., Marcé, R., Obrador, B., Gómez, L., Casas, J. P., Acuña, V., & Koschorreck, M. (2014). Carbon dioxide emissions from dry watercourses. Inland Waters, 4(4), 377-382.

von Schiller, D., Graeber, D., Ribot, M., Timoner, X., Acuña, V., Martí, E., ... & Tockner, K. (2015) Hydrological transitions drive dissolved organic matter quantity and composition in a temporary Mediterranean stream. Biogeochemistry, 1-18.