The application of temperature and light intensity as intermittency sensors in a temporary pond in Jamaica

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Key Points

- Temperature and light intensity can be used as sensors of intermittency in temporary water bodies.
- Maximum temperature, diel temperature range, and rate of change of temperature were most powerful in distinguishing hydrological state.
- Flooding and drying events were discernible in temperature and light intensity data.

Abstract

As climate change progresses, hydrological regimes of temporary and perennial water bodies are projected to change, affecting biodiversity and ecosystem functions. Researchers have successfully employed the use of satellite imagery, camera traps and site visits to map these changes in hydrological regimes. Though effective, their use can come with considerable cost at high temporal and spatial resolution. A more affordable measure in mapping hydrological regimes has been the use of data loggers of conductivity, but the use of data loggers of temperature and light intensity is uncommon. Using validated data of 213 days of the aquatic and terrestrial phases of a temporary pond, we show that temperature and light intensity data can be used to discern hydrological state. The aquatic phase had lower measures of both parameters when compared to the terrestrial phase. This was caused by the stability of the aquatic environment. The most powerful measures in discerning hydrological state were diel maximum temperature, diel temperature range, and rate of change of temperature. Greater distinctive power was obtained through the use of multiple measures of the parameters. In addition, key events such as flooding and drying were discernible within the temperature and light intensity data. High-resolution temperature and light intensity data are able to aid in understanding these dynamics of hydrological state and can be used to monitor ecosystem functions amid changes in temporary and perennial water bodies.

Plain Language Summary

Monitoring the presence of surface water will become an important factor for ecosystems as climate change progresses. Researchers have used satellite imagery, camera traps and site visits to determine the presence of surface water in permanent and temporary water bodies, but these methods may have considerable costs associated with them. The considerable costs limit data collection across space and time. To circumvent this, researchers have used data loggers of conductivity to determine the presence of surface water at high temporal and spatial resolution. In adding to this, we used different measures of temperature and light intensity to determine the presence or absence of water in a temporary pond in Jamaica. Measures of temperature and light intensity were typically lower in the presence of water when compared to those in the absence of water, a result of water's stability. Daily maximum temperature, daily temperature range, and rate of change of temperature were most powerful in distinguishing between the presence and absence of surface water. Combining different measures of the parameters allowed for better determination of the presence or absence of water.

Keywords: temporary pond, daily maximum temperature, hydrological state, data logger, phase

1. Introduction

One of the key features of temporary water bodies is the hydroperiod length in each inundation and inversely, the length of each terrestrial phase. The aquatic and terrestrial phases associated with a temporary water body are referred to as aquatic-terrestrial ecosystems (Stubbington et al., 2017). To determine hydrological state, satellite data has been successfully used to detect and map temporary water bodies at relatively high temporal resolution (Haas et al., 2009; Arledler et al., 2010). High-resolution aerial imagery (Gallart et al., 2016) and *in situ* mapping (Turner & Richter, 2011) have been successful in detecting flow in intermittent streams. Stream gauges, depth data loggers and camera traps have also been employed in monitoring temporary water bodies through space and time (Fovet et al., 2021).

To monitor water bodies at higher spatial and temporal resolution, numerous researchers have developed models of intermittency using loggers of environmental data, termed intermittency sensors (Assendelft & van Meerveld 2019; Jensen et al., 2019). These intermittency sensors utilize key changes in parameters to detect changes in hydrological state and infer information on connected environmental conditions throughout time, such as community composition, infiltration, groundwater recharge, and biogeochemical processes (Bogan et al., 2013; Gómez-Gener et al., 2021; Ronan et al., 1998). Collecting data on water presence allows for observation of characteristics as lotic systems cycle through arheic and dry phases (Bonada et, al., 2020; Gallart et al., 2017). Local differences in geomorphology and environmental conditions are also important in determining hydrological regimes across small spatial scales (Gallo et al., 2020). Intermittency sensors are commonly used in intermittent rivers and ephemeral streams (IRES), but adjacent temporary lentic habitats are largely understudied (Paillex et al., 2020), despite their contributions to aquatic-terrestrial ecosystems.

Of the intermittency sensors, the use of conductivity has been most prominent and allows the strict delimitation of aquatic and terrestrial states, as well as the determination of flow (Bhamjee et al., 2016; Chapin et al., 2014; Kaplan et al. 2019). Key events can also be detected using conductivity-based intermittency sensors, such as rainfall, freezing and, the deposition of sediment (Gallart et al., 2016). Other intermittency sensors utilize temperature and depth data to determine hydrological state (Celi & Hamilton, 2020).

Despite their efficacy, intermittency sensors are not yet widely used (van Meerveld et al., 2020). While numerous models have been developed by researchers, validation studies in aquatic-terrestrial ecosystems in the field are limited, notably within the Csaribbean. This study sought to test the application of high-resolution temperature and light intensity data as intermittency sensors to distinguish hydrological state in a tropical temporary pond.

2. Methodology

2.1. Site Description

The study site, named Dragonfly Pond-Meadow, is located on the campus of the University of the West Indies in Kingston, Jamaica, at the coordinates: 18.00339181, -76.74462356. It is at an elevation of 185 metres above sea level and measures 2,540 m^2. To protect the nearby buildings, soil was deposited to form an earthen embankment to trap and divert surface runoff, forming a pond. The area alternates between a terrestrial meadow and an aquatic pond as two phases of a complete ecosystem, representing an aquatic-terrestrial ecosystem: Dragonfly Pond-Meadow.

2.2. Data Collection and Analysis

A HOBO® Pendant Temperature/Light data logger (Model UA-002-08) was deployed at the deepest point within the Dragonfly Pond-Meadow, secured to a circular, white plastic lid (diameter 10 cm) then anchored to the substrate. The logger recorded temperature and light intensity every 10 minutes from May 2020 to January 2021. The pilot phase of the project was executed in the early rainy season in May 2020. The main phase of the project ran from mid-June 2020 to January 2021, encompassing both the dry and rainy seasons. Full days were those which had data points for every 10-minute interval within a 24-hour period. However, some days, had a lapse of 1 to 5 data points, which was associated with offloading data, redeployment of the logger and acclimatization; these were all considered full days. From July 2020 to January 2021, each month had a minimum of 24 full days of data collection. Aquatic or terrestrial phase of the pond was by validated site visits, prompted by daily monitoring of rainfall. The aquatic phase was determined by the presence of any surface water, regardless of depth, while the terrestrial phase was determined by the complete loss of surface water.

Days on which flooding or drying occurred were excluded from statistical analyses, thus only full days, which were either wholly aquatic or wholly terrestrial, were used. Fully aquatic days totalled 71, while fully terrestrial days totalled 142 ($N = 213$ days). The diurnal period extended from 6:00 a.m. to 5:50 p.m. on each full day, while the nocturnal period extended from 6:00 p.m. to 5:50 a.m. Where appropriate, log transformation or angular transformation was executed before analysis. All statistical analyses were performed in R© (R Core Team 2021) through RStudio© (RStudio Team 2021). The Wilcoxon Sum Rank test was used to determine differences in parameters between the 2 phases upon the failure to meet parametric assumptions after Log_{10} transformation or angular transformation. Data were also analysed to identify trends in the transitional flooded and drying phases. All correlations were performed using Kendall's Rank Correlation. Visualizations were created in both Microsoft® Excel® 2019 and R©.

3. Results

The mean hourly temperature of the aquatic phase remained faily stable throughout the day. Mean hourly temperature of the terrestrial phase was greater than that of the aquatic phase between 7:00 a.m. and 5:00 p.m. At night, the mean hourly temperature of the aquatic phase was greater than that of the terrestrial phase. The temperature difference between the phases was greater during the day than at night.

[CHART]

Figure 1. Mean hourly temperature of the aquatic and terrestrial phases of Dragonfly Pond-Meadow.

Median values of diel and diurnal mean temperature and light intensity were significantly higher in the terrestrial phase than in the aquatic phase ($p < 1.7*10^{-7}$). Diel and diurnal temperature and light intensity values were more widespread in the terrestrial phase than in the aquatic phase.

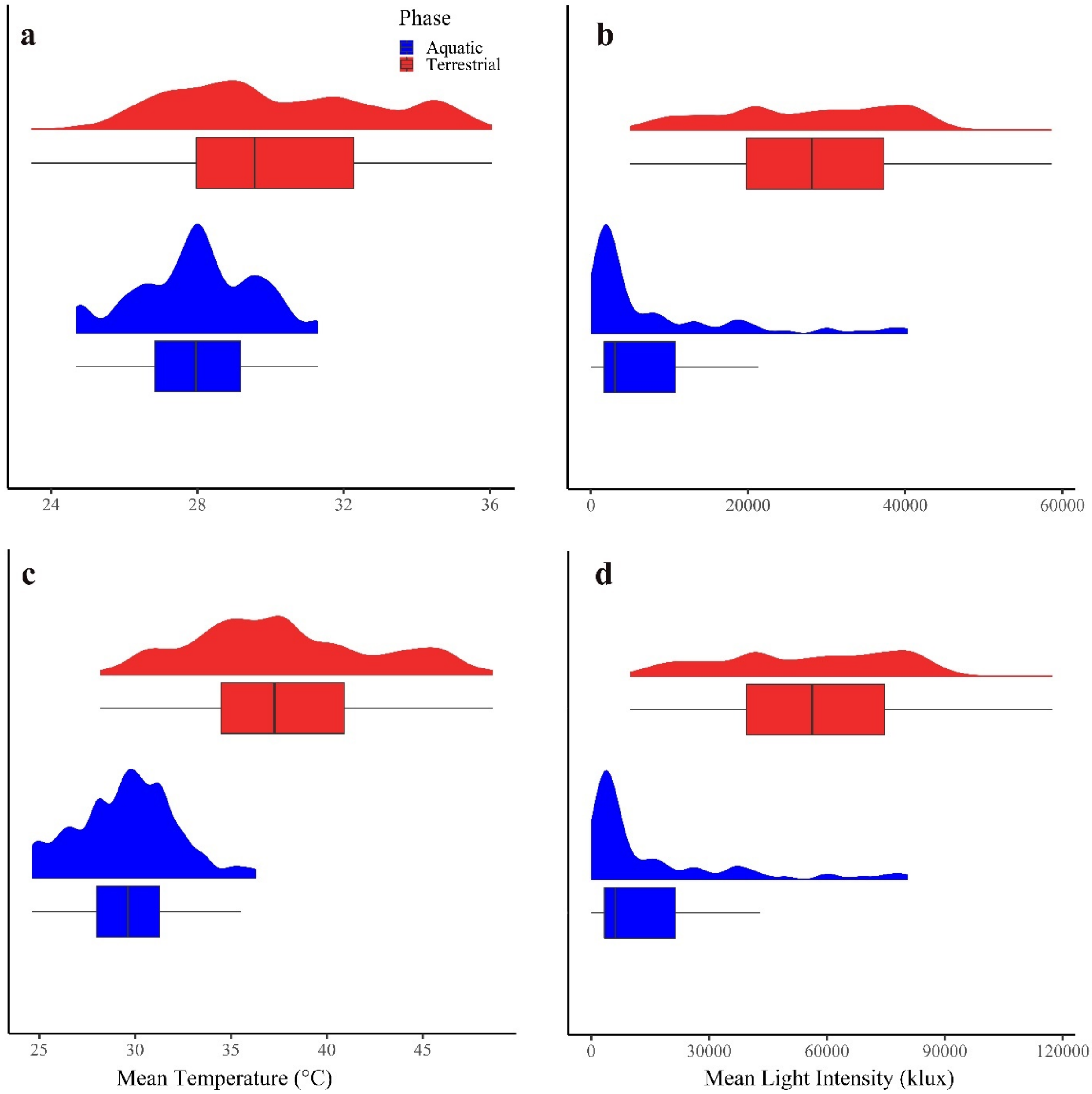

Figure 2. The distribution of mean temperature in the aquatic and terrestrial phases of Dragonfly Pond-Meadow. a: diel mean temperature; b: diel mean light intensity; c: diurnal mean temperature; d: diurnal mean light intensity.

Rate of change refers to differences in values between each 10-minute interval. Medians of the mean rate of change of temperature and light intensity were significantly different between the terrestrial and aquatic phases ($p < 2.2*10^{-16}$) at the diel and diurnal time scale. Mean values were lower and less widespread in the aquatic phase.

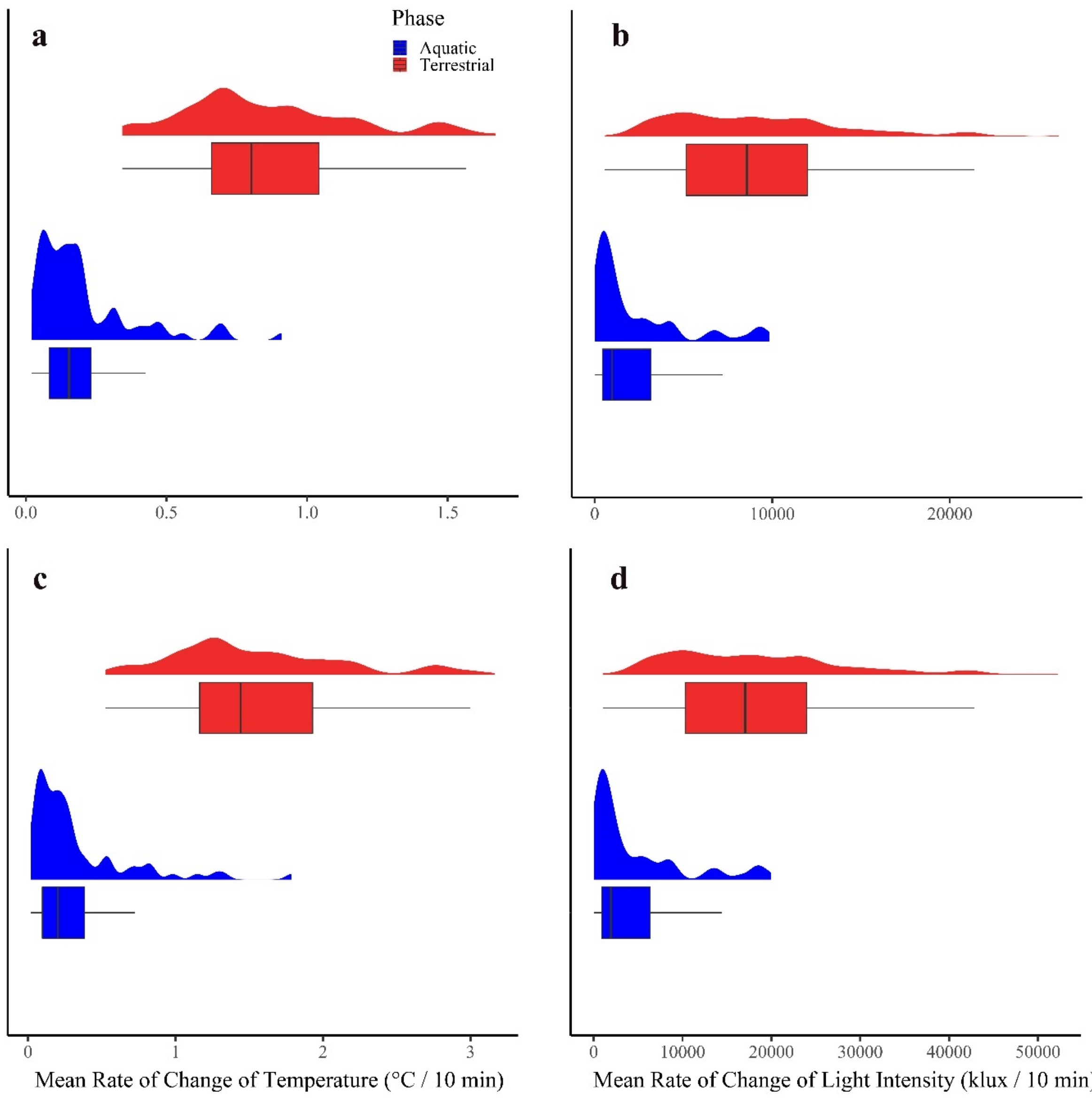

Figure 3. Diel and diurnal rates of change of temperature and light intensity in the aquatic and terrestrial phases of Dragonfly Pond-Meadow. a: diel mean rate of change of temperature; b: diel mean rate of change of light intensity; c:

diurnal mean rate of change of temperature; d: diurnal mean rate of change of light intensity.

A strong correlation between mean temperature and mean light intensity was recorded in both phases and the diel and diurnal time scales ($p < 2.2*10^{-16}$). Dependency was greater in the terrestrial phase than in the aquatic phase in both cases.

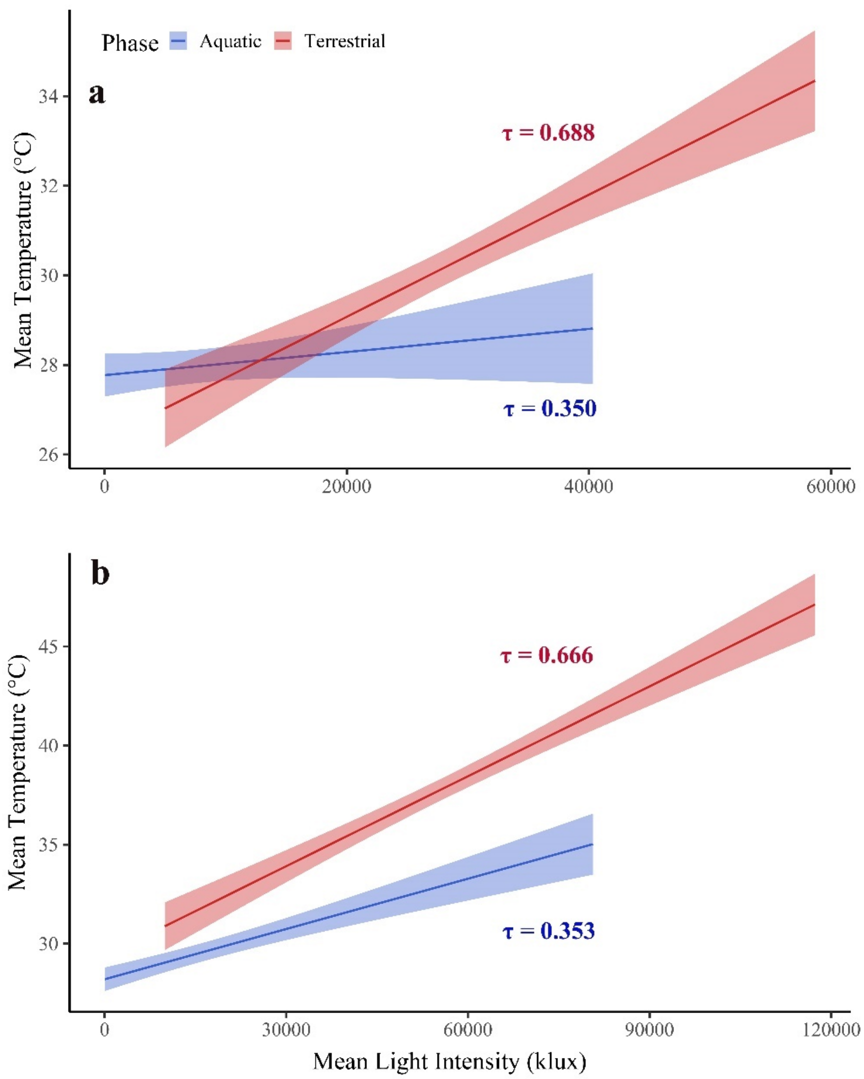

Figure 4. Correlations between light intensity and temperature in the aquatic and terrestrial phases of Dragonfly Pond-Meadow. a: diel mean temperature as a function of diel mean light intensity; b: diurnal mean temperature as a function of diurnal mean light intensity.

In analysis of temperature and light variables in principal component analysis, the first axis (PC1) explained 74.4 % of variation, while the second (PC2) explained 14.1 %. PC1 was most distinguished by the diel measures of maximum temperature (MaxTemp), temperature range (DTR), mean rate of change of temperature (RoCT), maximum light intensity (MaxLight), and mean light intensity (Light). PC2 was most distinguished by diel measures of minimum temperature (MinTemp), mean temperature (MeanTemp), and mean rate of change of light intensity (RoCL). All parameters were significantly different between phases ($p < 2.2*10^{-16}$).

Table 1

Eigenvalues and Eigenvectors of Measures of Temperature and Light Intensity in the Aquatic and Terrestrial Phases of Dragonfly Pond-Meadow.

Diel parameter	**PC1**	**PC2**
Maximum Temperature	0.3986222	0.04446
Temperature Range	0.398128	-0.09533
Mean Rate of Change of Temperature	0.3829515	-0.00048
Maximum Light Intensity	0.3815048	-0.03378
Mean Light Intensity	0.3642147	-0.06814
Mean Rate of Change of Light Intensity	0.352146	0.182878
Mean Temperature	0.2664048	0.655013
Minimum Temperature	-0.2505315	0.721571

The terrestrial phase was defined by greater diel measures of most measures of temperature and light intensity.

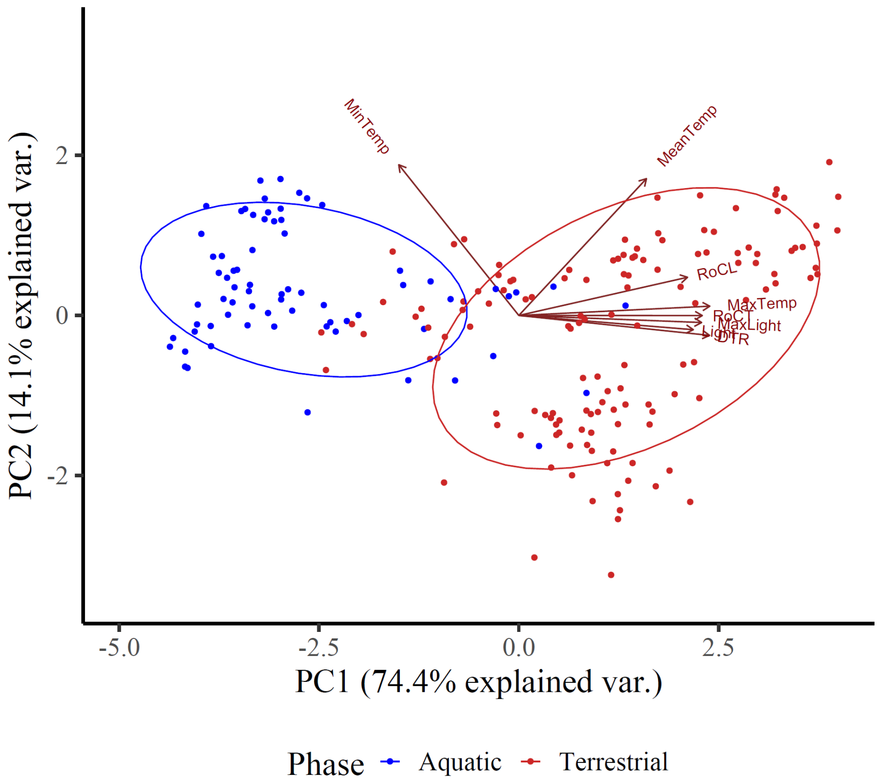

Figure 5. Principal component analysis of temperature and light intensity parameters in the aquatic and terrestrial phases of Dragonfly Pond-Meadow.

Overlaps existed in the ranges of values of the aquatic and terrestrial phases. All parameters except diel minimum temperature had ranges of values which were exclusive to either the aquatic or terrestrial phase. Lower values were more common in the aquatic phase than in the terrestrial phase.

Table 2

Limits of Temperature and Light intensity Measures in the Aquatic and Terrestrial Phases of Dragonfly Pond-Meadow.

Parameter	**Phase**	**Lower limit**	**Upper limit**	**Exclusive lower limit**	**Exclusive upper limit**
Diel Mean Temperature (°C)	Aquatic			N/A	N/A
	Terrestrial				

Parameter	Phase	Lower limit	Upper limit	Exclusive lower limit	Exclusive upper limit
Diel Mean Light Intensity (klux)	Aquatic				
	Terrestrial			N/A	
Diel Temperature Range (°C)	Aquatic				
	Terrestrial				
Diel Maximum Light Intensity (klux)	Aquatic				
	Terrestrial				
Diel Maximum Temperature (°C)	Aquatic				
	Terrestrial				
Diel Minimum Temperature (°C)	Aquatic			N/A	N/A
	Terrestrial			N/A	N/A
Mean Rate of Temperature Change (°C / 10 min)	Aquatic				
	Terrestrial				
Mean Rate of Light Intensity Change (klux / 10 min)	Aquatic				
	Terrestrial			N/A	

Figure 6 illustrates hourly temperature, hourly light intensity, rate of change of temperature, and light intensity recorded daily in October and November 2020. The terrestrial phase had greater values than those of the aquatic phase. A sudden shift from high values to low values was associated with inundation events (*). A gradual increase in values indicated a decrease in pond depth associated with drying and shifting to the terrestrial phase ( ).

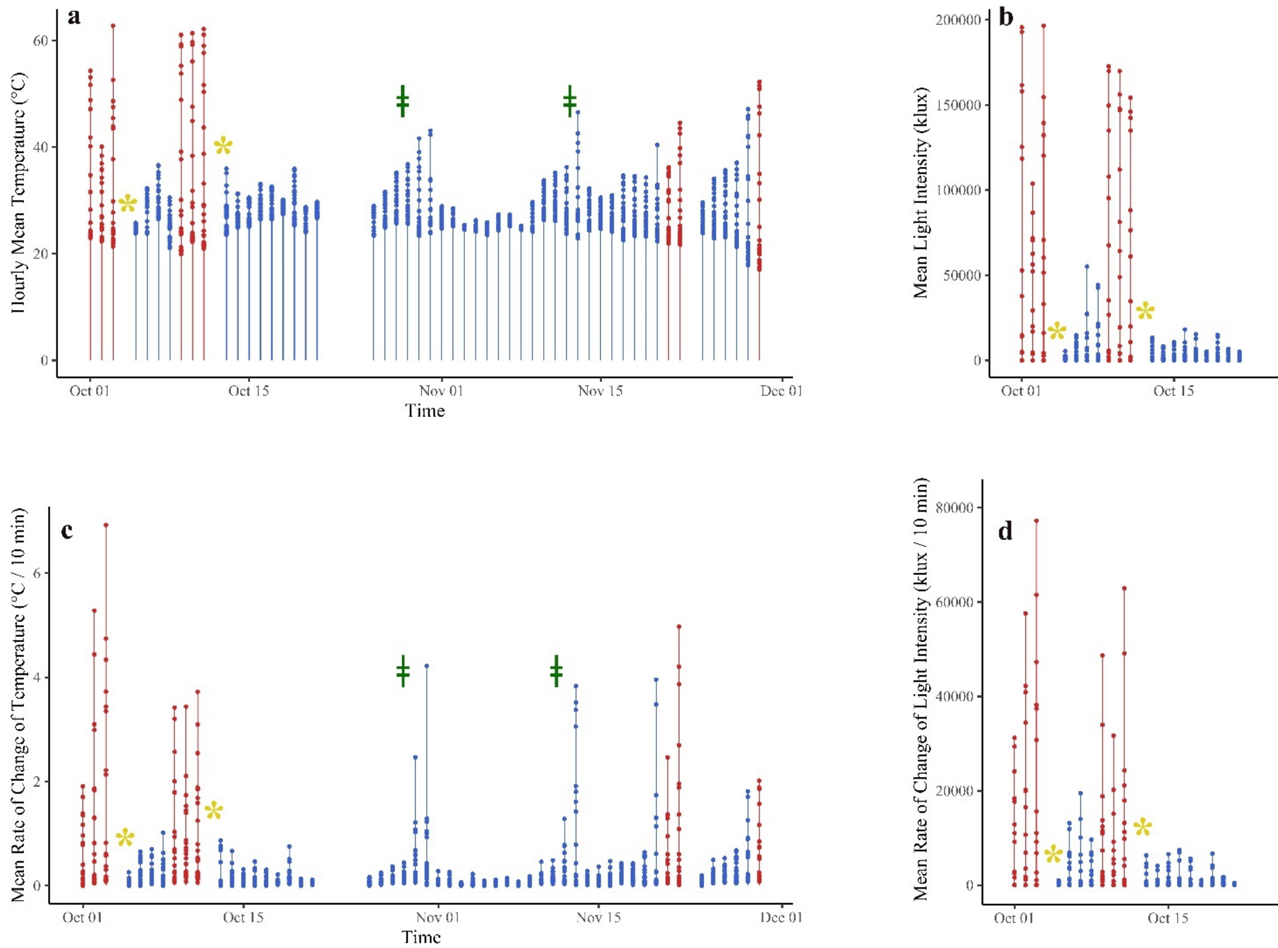

Figure 6. Event signatures in Dragonfly Pond-Meadow. Each peak is associated with the day's maximum temperature, while each trough is associated with each day's minimum temperature. a: hourly mean temperature; b: hourly mean light intensity; c: hourly mean rate of change of temperature; d: hourly mean rate of change of light intensity.

4. Discussion

Throughout a day, the terrestrial phase saw greater increases in hourly mean temperature than the aquatic phase. However, at night, the aquatic phase was warmer (Figure 1). The difference between the 2 phases during the day was greater than the difference between them during the night. This stability of the aquatic phase is well-documented, attributed to the high specific heat capacity of water which restricts temperature changes at different temporal scales (Adams et al., 2006; Assendelft & van Meerveld 2019; Shah et al., 2020). The aquatic environment buffers again temperature changes, maintaining thermal stability and limiting diel temperature range. This result added upon the successful use of diel temperature range in distinguishing hydrological state as determined by Celi and Hamilton (2020). Other patterns were noted in expanding on this work. With respect to light intensity, the aquatic phase had lower values than the terrestrial phase, despite the relatively shallow pond depth (Figure 2). As light passes through water, photons are absorbed and redirected, reducing the amount of light detected at greater depth (Ackleson, 2003). Diurnal measures of temperature and light intensity were greater than diel measures as heat was lost from both the aquatic and terrestrial phases throughout the night. However, heat was lost more readily from the terrestrial phase, resulting in its lower temperature at night. Rates of change of both temperature and light intensity reflected patterns similar to their respective parameters. Temperature was more strongly dependent on light intensity in the terrestrial phase than the aquatic phase (Figure 4). From these, it was denoted that the aquatic phase was more stable than the terrestrial phase with respect to temperature and light intensity.

While all parameters were significant markers of phase, diel maximum temperature, diel temperature range, and rate of change of temperature were the most powerful parameters in distinguishing hydrological state. The aquatic phase typically had lower values of these measures. Diurnal values of the measures of temperature and light intensity also served to better distinguish hydrological phase (Figure 4). Greater distinctive power of hydrological state was obtained by combining various measures of temperature and light intensity (Figure 5).

As the pond was inundated, the shift from the terrestrial to the aquatic phase was marked by a drastic decrease in temperature, light intensity, and rate of change of temperature and light intensity as in Figure 6. As the aquatic phase transitioned into the terrestrial phase during drying, all four parameters gradually increased daily as pond depth decreased. This represented a gradient of change between the two phases. While this gradient obscures the binary classification of hydrological state to an extent, it provides information on key processes of change within aquatic-terrestrial ecosystems (Table 2). Temperature and light intensity intermittency sensors bolster the collection of environmental data which are important to biota, including rates of temperature change and diel and seasonal changes in temperature and photoregime (Constantz, 2008). These factors play critical roles in the dispersal of fauna, determination of environmental tolerance, and the community structure of aquatic-terrestrial ecosystems (May, 2019).

Intermittency sensors can be used in addition to site visits and camera trap data for validation and to provide a better understanding of habitat complexity. Given the range of values in using temperature and light intensity data, the use of conductivity in intermittency sensors is preferred for decisively determining hydrological state. However, temperature and light intensity data can be used to monitor the gradient of changes occurring throughout the phases of aquatic terrestrial ecosystems at high spatial and temporal resolution. More research is needed for validation and refinement of these intermittency models, and for their applications to other environments. Global trends in drying (Climate Studies Group Mona 2017; Skoulikidis et al., 2017) necessitate greater investment in studying aquatic-terrestrial ecosystems for climate change mitigation and adaptation.

5. Conclusion

In an exploratory analysis of high-resolution temperature and light intensity data, we found that these environmental parameters can be used as intermittency sensors in aquatic-terrestrial ecosystems. Most notable among parameters were diel measures of maximum temperature and temperature range, as well as mean rate of change of temperature. A composite of parameters was a more powerful measure of distinguishing hydrological state. The less variable aquatic phase had lower measures of these parameters and lower rates of change of temperature and light intensity. The transition from one phase to another was also detectable using both temperature and light intensity data. Key event signatures involved in drying existed along a gradient between values of the two phases. While this gradient obscured the distinction between hydrological states, it provided important information on thermal ranges experienced within the ecosystem.

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Data Availability Statement

Data were available online at the following DOI: 10.5281/zenodo.5650989

References

Ackleson, S. G. (2003). Light in shallow waters: A brief research review. *Limnology and Oceanography*, *48*(1 II), 323–328. https://doi.org/10.4319/lo.2003.48.1_part_2.0323Adams, E. A., Monroe, S. A., Springer, A. E., Blasch, K. W., & Bills, D. J. (2006). Electrical resistance sensors record spring flow timing, Grand Canyon, Arizona. *Ground Water*, *44*(5), 630–641. https://doi.org/10.1111/j.1745-6584.2006.00223.xArledler, A., Castracane, P., Marin, A., Mica, S., Pace, G., Quartulli, M., et al. (2010). Detecting water bodies and water related features in the Niger basin area by SAR data: the ESA TIGER WADE project. *Application of Satellite Remote Sensing to Support Water Resources Management in Africa: Results from the TIGER Initiative*, *85*, 108.Assendelft, R. S., & van Meerveld, H. J. (2019). A low-cost, multi-sensor system to monitor temporary stream dynamics in mountainous headwater catchments. *Sensors (Switzerland)*, *19*(21). https://doi.org/10.3390/s19214645Bhamjee, R., Lindsay, J. B., & Cockburn, J. (2016). Monitoring ephemeral headwater streams: A paired-sensor approach. *Hydrological Processes*, *30*(6), 888–898. https://doi.org/10.1002/hyp.10677Bogan, M. T., Boersma, K. S., & Lytle, D. A. (2013). Flow intermittency alters longitudinal patterns of invertebrate diversity and assemblage composition in an arid-land stream network. *Freshwater Biology*, *58*(5), 1016–1028. https://doi.org/10.1111/fwb.12105Bonada, N., Cañedo-Argüelles, M., Gallart, F., von Schiller, D., Fortuño, P., Latron, J., et al. (2020). Conservation and management of isolated pools in temporary rivers. *Water (Switzerland)*, *12*(10), 1–24. https://doi.org/10.3390/w12102870Celi, J. E., & Hamilton, S. K. (2020). Measuring floodplain inundation using diel amplitude of temperature. *Sensors (Switzerland)*, *20*(21), 1–10. https://doi.org/10.3390/s20216189Chapin, T. P., Todd, A. S., & Zeigler, M. P. (2014). Robust, low-cost data loggers for stream temperature, flow intermittency, and relative conductivity monitoring. *Water Resources Research*, *50*. https://doi.org/10.1002/2013WR014979.ReplyClimate Studies Group Mona. (2017). *The State of the Jamaican Climate: Information for Resilience Building (Full Report)* (Issue October).Constantz, J. (2008). Heat as a tracer to determine streambed water exchanges. *Water Resources Research*, *46*(4), 1–20. https://doi.org/10.1029/2008WR006996Fovet, O., Belemtougri, A., Boithias, L., Braud, I., Charlier, J. B., Cottet, M., et. al. (2021). Intermittent rivers and ephemeral streams: Perspectives for critical zone science and research on socio-ecosystems. *Wiley Interdisciplinary Reviews: Water*, *8*(4), 1–33. https://doi.org/10.1002/wat2.1523Gallart, 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. *Science of the Total Environment*, *565*, 1001–1010. https://doi.org/10.1016/j.scitotenv.2016.05.116Gallart, F., Cid, N., Latron, J., Llorens, P., Bonada, N., Jeuffroy, J., et al. (2017). TREHS: An open-access software tool for investigating and evaluating temporary river regimes as a first step for their ecological status assessment. *Science of the Total Environment*, *607–608*, 519–540. https://doi.org/10.1016/j.scitotenv.2017.06.209Gallo,

E. L., Meixner, T., Lohse, K. A., & Nicholas, H. (2020). Estimating Surface Water Presence and Infiltration in Ephemeral to Intermittent Streams in the Southwestern US. *Frontiers in Water*, *2*(November), 1–16. https://doi.org/10.3389/frwa.2020.572950Gómez-Gener, L., Siebers, A. R., Arce, M. I., Arnon, S., Bernal, S., Bolpagni, R., et al., (2021). Towards an improved understanding of biogeochemical processes across surface-groundwater interactions in intermittent rivers and ephemeral streams. *Earth-Science Reviews*, *220*(July), 103724. https://doi.org/10.1016/j.earscirev.2021.103724Haas, E. M., Bartholomé, E., & Combal, B. (2009). Time series analysis of optical remote sensing data for the mapping of temporary surface water bodies in sub-Saharan western Africa. *Journal of Hydrology*, *370*(1–4), 52–63. https://doi.org/10.1016/j.jhydrol.2009.02.052Jensen, C. K., McGuire, K. J., McLaughlin, D. L., & Scott, D. T. (2019). Quantifying spatiotemporal variation in headwater stream length using flow intermittency sensors. *Environmental Monitoring and Assessment*, *191*(4). https://doi.org/10.1007/s10661-019-7373-8Kaplan, N. H., Sohrt, E., Blume, T., & Weiler, M. (2019). Monitoring ephemeral, intermittent and perennial streamflow: a dataset from 182 sites in the Attert catchment, Luxembourg. *Earth System Science Data*, *11*(3), 1363–1374. https://doi.org/10.5194/essd-11-1363-2019May, M. L. (2019). Dispersal in Aquatic Insects. In *Aquatic Insects: Behaviour and Ecology* (pp. 35–73). Springer Nature Swtizerland. https://doi.org/10.1007/978-3-030-16327-3Paillex, A., Siebers, A. R., Ebi, C., Mesman, J., & Robinson, C. T. (2020). High stream intermittency in an alpine fluvial network: Val Roseg, Switzerland. *Limnology and Oceanography*, *65*(3), 557–568. https://doi.org/10.1002/lno.11324Ronan, A. D., Prudic, D. E., Thodal, C. E., & Constantz, J. (1998). Field study and simulation of diurnal temperature effects on infiltration and variably saturated flow beneath an ephemeral stream. *Water Resources Research*, *34*(9), 2137–2153.Shah, A. A., Dillon, M. E., Hotaling, S., & Woods, H. A. (2020). High elevation insect communities face shifting ecological and evolutionary landscapes. *Current Opinion in Insect Science*, *41*, 1–6. https://doi.org/10.1016/j.cois.2020.04.002Skoulikidis, N. T., Sabater, S., Datry, T., Morais, M. M., Buffagni, A., Dörflinger, G., et al., (2017). Non-perennial Mediterranean rivers in Europe: Status, pressures, and challenges for research and management. In *Science of the Total Environment* (Vol. 577). https://doi.org/10.1016/j.scitotenv.2016.10.147Stubbington, R., Bogan, M. T., Bonada, N., Boulton, A. J., Datry, T., Leigh, C., & Vander Vorste, R. (2017). The Biota of Intermittent Rivers and Ephemeral Streams: Aquatic Invertebrates. In *Intermittent Rivers and Ephemeral Streams: Ecology and Management*. https://doi.org/10.1016/B978-0-12-803835-2.00007-3Turner, D. S., & Richter, H. E. (2011). Wet/dry mapping: Using citizen scientists to monitor the extent of perennial surface flow in dryland regions. *Environmental Management*, *47*(3), 497–505. https://doi.org/10.1007/s00267-010-9607-y

Van Meerveld, H. J., Sauquet, E., Gallart, F., Sefton, C., Seibert, J., & Bishop, K. (2020). Aqua temporaria incognita. *Hydrological Processes*, *34*(26), 5704–5711. https://doi.org/10.1002/hyp.13979