Micropower Lesser Horseshoe Bat Sensor

*A new design for a low-power bat sensor has been deployed at five major regional cave sites for the winter months of early 2020. **Stuart France** presents data logger results showing similar timings across all these caves suggesting that hibernating bats are roused by common factors such as external weather patterns and then influenced by such thereafter. Relatively low counts at one entrance suggests that its substantial locked gate is impacting bat access to potential habitat within.*

The Usk Valley and its Major Caves

The Usk Bat Sites [1] Special Area of Conservation (SAC) in South East Wales is a designated area for the protection of European endangered bat species. This area combines several features needed by bats, including extensive limestone caves for hibernation and shelter, woodland and undeveloped moorland adjoining the valley to provide food sources, and a number of suitable old buildings and structures used as summer roosts.

This area's caves have been monitored by annual manual bat counts done on a single day during winter hibernation since at least the 1990s. These surveys generally show increasing hibernating bat numbers. The most well-known of the caves is Agen Allwedd, which is home to the largest colony of Lesser Horseshoe bats in the UK, with individuals hibernating anywhere from a hundred metres to a kilometre into the cave system. Cavers have uncovered new cave entrances in recent decades which have added new habitats.

Agen Allwedd (AA) has two entrances – the original one preferred by bats is rather small and tortuous for cavers, while the newer engineered entrance is larger and has a substantial padlocked gate for which bona fide cavers have keys. Inside are 32km of mapped passages. The next large cave along the same escarpment is Daren Cilau (DC) with an infamous 500m long wet crawl of an entrance, unfriendly to both cavers and bats, and in consequence is not locked. Cavers connected a minor cave called Ogof Cnwc to DC in 2002, making an easier dry entrance to the main cave which the bats have exploited as additional habitat in enormous passages beginning 100m from the Cnwc entrance and then extending 26km. This route is secured, but a wide slot enables bats to fly easily, both in and out.

The third cave in this study, Ogof Craig a Ffynnon (OCAF) is in a side valley on the same escarpment and is the site of 'historic battles' between the original discoverers who tended to monopolise the cave and other cavers deprived of reasonable access who then removed several gates (as happened at Agen Allwedd prior to a rational key system). The result is a Fort Knox style gate on OCAF which is virtually bat-proof. Inside are 8km of large passages very suitable for bat hibernation – but little exploited, as reported here.

The limestone massif on the east side of the valley containing OCAF also faces the Usk valley and contains Ogof Draenen (OD) which at 70km is the longest cave in Wales. This was only discovered in 1994 and again there has been a troubled relationship between the ruling committee and other cavers over access, resulting in many padlocks being removed along with gates. The final result is a solid metal locked gate which is totally bat-proof. Cavers then created several alternative entrances to this cave which include two openings that remain gateless, Drws Cefn and the Nunnery, and these are included in this study as they provide bats with straightforward flight paths to and from the main cave system.

Previous Work

In 2001, the Countryside Council for Wales asked me to develop some inexpensive bat detectors which could be deployed for a week or two at a time to screen underground sites for bat activity [2]. This was an end-of-financial-year job and it meant delivering products by 31st March to receive payment, in other words to design and manufacture against the clock. My equipment was run for several years in Agen Allwedd [3] after first using that cave to confirm the design. The detector was a tiny hearing aid microphone now costing £30 with a wide spectrum phase lock loop capturing bat calls. A bat call generator which comprised an inexpensive piezo buzzer disc driven with a PIC was built to test sensors.

This sensor does not identify the bat species, which could be done later by returning to any promising sites with a

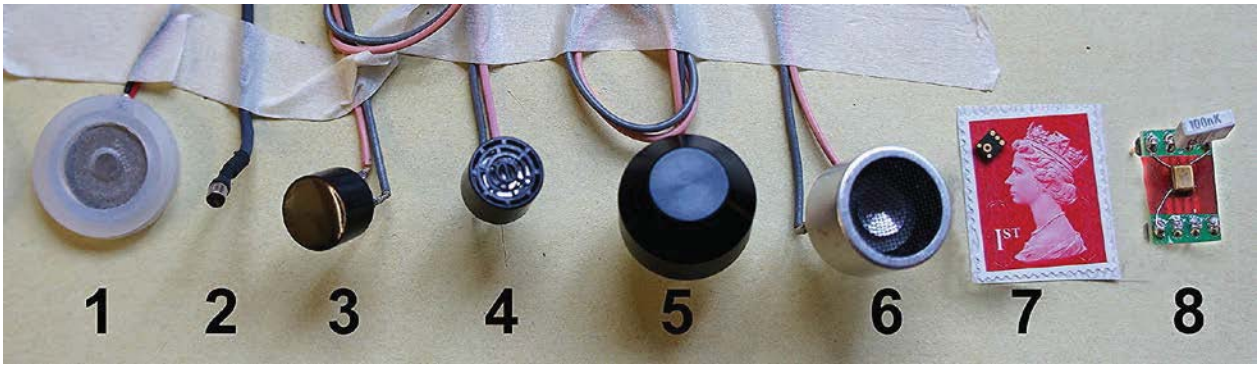


Figure 1 – Candidate bat microphone line up

***1** atomizer disc, **2** Knowles hearing aid microphone from our 2001 project, **3&5** waterproof ultrasonic range finders (e.g. car reversing aids), **4&6** non-waterproof ultrasonic detectors (e.g. alarms), **7** Knowles SMT microphone solder side (e.g. for mobile phones) on a postage stamp, **8** shows top side of 7 soldered with fine wire filaments to a pluggable module.*

commercial bat detector capable of recording audio and then analysing the sonograms which are characteristic of each bat species. The commercial units tend to have limited battery life, from a few hours to a few days, and need expensive delicate microphones operating in the 20-120kHz frequency band. On an evening cave visit with this sort of gear, it is largely a matter of luck if anything of interest will be recorded, and a couple of hours is hardly a statistically meaningful sampling period for enormous cave habitats.

The access battles at Ogof Draenen still continue after 20 years, with the ruling clique concreting alternative cave entrances, or threatening to, then concrete being removed or bypassed in the surrounding ground, legal solutions also were sought, and ultimately one concrete faction was arrested for the alleged destruction of protected-species habitat. In the process of all that strife and denials, a local bat ecologist and I conducted some evening bat surveys using Wildlife Acoustics equipment and a modified Magenta detector tuned for Lesser Horseshoe bats and linked to a timestamp data logger. We supplied reports to the landowner, the cave committee, the national statutory conservation body, and the local police, so none of them could excuse themselves through ignorance about the bat colonies.

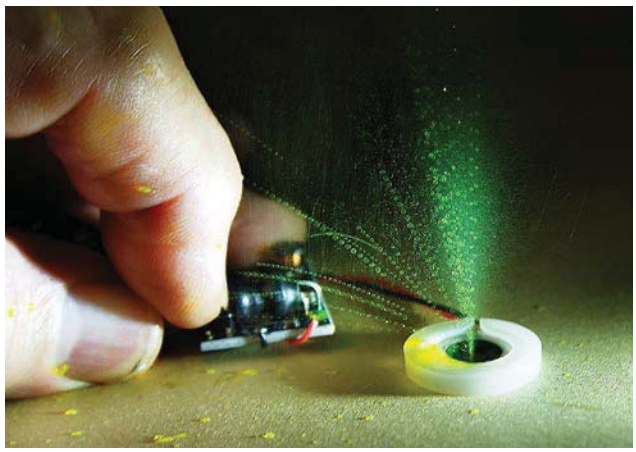
Given that backdrop, it seems worthwhile to run the Ogof Draenen bat monitoring on a long-term basis and extend it to comparable local caves. The dominant local bat species is Lesser Horseshoes (LH), at least on the basis of hibernating bats easily noticed by cavers, although many bats of other species have been found by licensed bat trapping at cave entrances. Thus, there was a need for cheap, easily built detectors specifically for LH bats that had very low power requirements so as to run autonomously, ideally throughout a whole winter. The outline design and results presented here are the initial results from that work.

New Sensor Development

The bat species of interest echo-locates on 108kHz. The 2001 project showed that small piezo buzzer discs costing pennies can be used as ultrasonic loudspeakers although not with linear audio output as they are resonant at particular but not necessarily useful frequencies. A number of low-cost microphones, including piezo buzzer discs used in reverse, were tested in 2019. One was resonant by sheer luck at 108kHz – see *Figure 1*.

This buzzer disc, which is intended for an atomizer product to dispense timed puffs of deodorant into rooms (see *Figure 2*), was thus water-resistant and so ideal as a cave bat microphone.

Op-amps have advanced greatly in the past 20 years in terms of performance at low power for high gain at 100kHz. The selected atomizer disc audio output requires a high-gain microphone amplifier. This was designed to be sharply resonant at 108kHz (bandpass filter) using such a dual op-amp. The amplified filtered audio signal is fed into narrow band low-power phase lock loop (LMC567) which drives an open-collector output when locked on to bat calls. Finally, an



Figures 2 and 3 – The 108kHz disc

As used in an atomizer (above) and as a cave microphone mounted on the side of a Pelicase (below) which is aimed at a narrowing on the bat flight path.

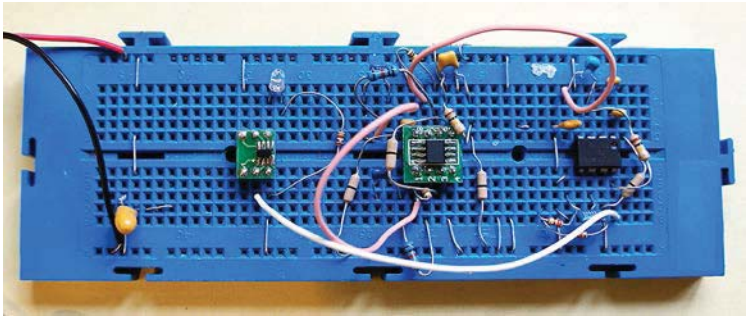


Figure 4 – The breadboarded design with ICs which are available only in SMT packages soldered to plug-in boards.

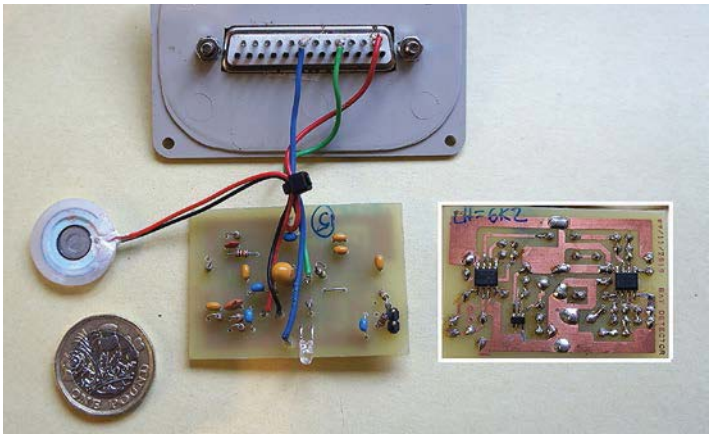


Figure 5 – The final PCB, as deployed in the caves

All ICs are now SMT components soldered to the track side of a single-sided board and the through-hole components are all on the upper side. PLL tuning is done with a resistance box connected via a 2-pin header, then the correct setting is implemented as a pair of series resistors. Sensors and loggers are built in separate boxes connected with old-fashioned DB25 sockets which have gold-plated pins and a ruggedness which resists most challenges. A robust plug-in control box with an LCD screen and buttons exploits the same DB25 socket to set up data loggers in the outdoors, rather than risking a PC or equivalent gear in caves.

inverter creates a positive-going rail-to-rail square wave (logic) to drive a connected data logger. The audio section parts cost about £5 in total, of which the atomizer disc microphone is only pence.

The above circuit works in the range of 2.7-4.8V, as do my data loggers which run on three AA-size alkaline batteries. The power for the whole bat sensor and data logger assembly is at most 800µA. Three AA alkaline cells last three months, while a single D-size lithium cell would last well over one year. A three-AA cell battery would drop across the above voltage range during its working life while a lithium battery delivers a fairly constant 3.6V throughout its life. The logger box accepts either type of battery, but not a mix.

Re-tuning the sensor for detecting Greater Horseshoe (GH) bats and other species of interest is a work in progress. Initial results with LH bats are very promising in terms of system performance, battery endurance and the cost of the parts, but if the resonant atomizer disc proves unusable at lower frequencies, then a search will begin for other parts which could be used as inexpensive cave-proof microphones for the other bat species.

Experimental Fieldwork

Pelicases are a reasonable enclosure choice for caves although they are not necessarily waterproof for long-term use that is measured in months. Diurnal air temperature variations cause air flow across the lid seals, which allow moist air to enter, the dampness condenses inside the case, and some air is expelled when ambient temperature rises, and condensation increases as the cycle repeats. Pelicases perform very well with short-term exposure to water or damp, such as when tied to a tree during rainfall or when capsizing a kayak, but they have definite limitations in some caves and when

Cave	Entrance	Legend
Agen Allwedd	Bat entrance	AABATS
Daren Cilau	Ogof Cnwc entrance	CNWCBATS
Ogof Craig a Ffynnon	Main entrance	OCAFBATS
Ogof Draenen	Drws Cefn entrance	DRWSBATS
Ogof Draenen	Nunnery entrance	NUNBATS
Nunnery Passage	Cave air temperature	NUNTEMP
Tretower (village)	Air temperature	TTTEMP

Table 1 – Counter locations and chart series names

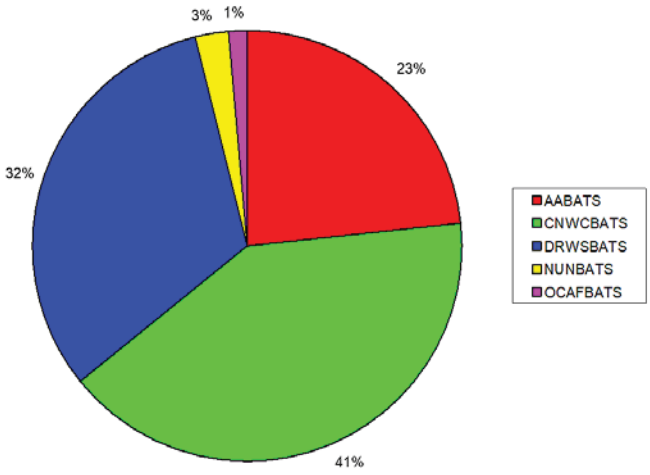


Chart 1 – Total bat counts per entrance for the period.

Three caves are relatively well used by bats while the other two are not. This raises questions…

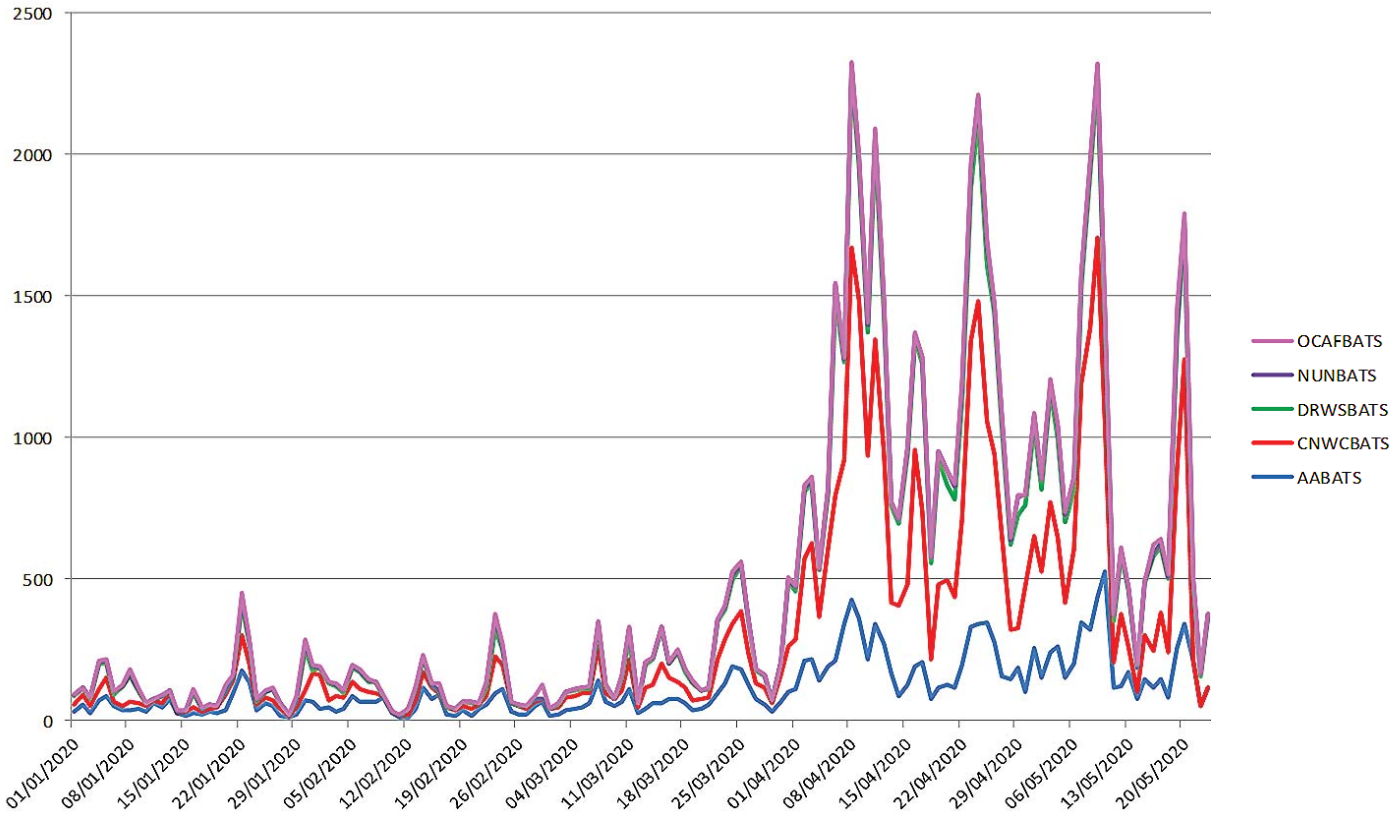


Chart 2 – Daily totals per sensor, series stacked, hibernation ending in early April 2020.

The bat colonies in all five different cave entrances reached the same conclusions at the same time and independently of one another, suggesting a common cause like the weather.

buried in soil for other covert operations.

A small block of acetal engineering plastic (30x30x10mm) was machined to house the piezo disc in a solid object screwable to the outside of a Pelicase, and all edges sealed with neutral-curing silicone sealant. A modular approach was taken, expecting that the microphones would not last long in cave conditions, however none of the microphones failed or showed any deterioration during last winter.

Figure 6 – The 2002 Ogof Cnwc gate with wide slot for bat in-flight access

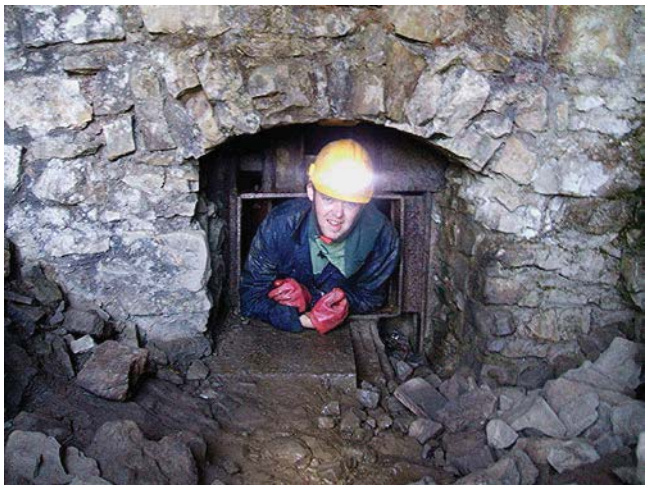


Figure 7 – The OCAF gate with only fist-sized apertures between girders, which prevent bat flight

There were 30 times fewer bat flights recorded at OCAF, even though its discovery was in the 1970s

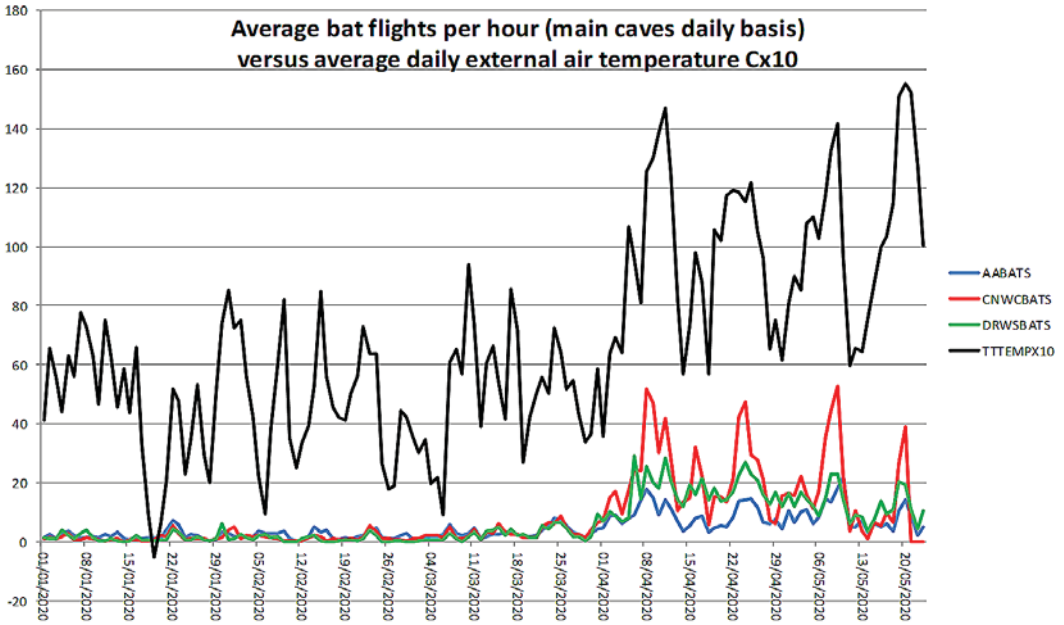


Chart 3 – Average bat flights per hour and average external air temperature x 10, both calculated daily.

Some weather checking by hopeful bats seems to have taken place between 13-28th March with a big exodus from all the caves from the end of that month. Generally, a big swing in temperature from relatively low to relatively high seems to make the bats inquisitive – such as on 19-25th February and around 7th March. In the absence of any calendar, how can the bats otherwise know when spring has duly arrived, other than by investigating a trigger such as a prominent temperature swing outside the cave environment?

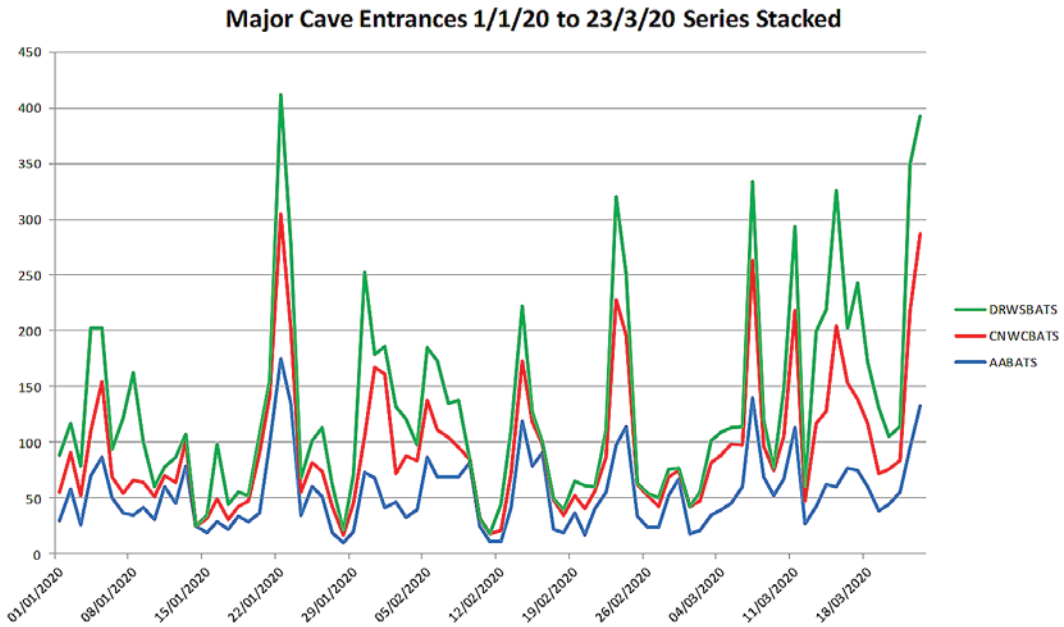


Chart 4 – Daily totals of recorded bat flights.

This shows synchronous colony behaviour during the hibernation period despite the geographic separation of these major caves

For the Ogof Draenen entrances in this study, given their troubled history, the piezo disc was housed in a piece of aluminium tube painted brown and on a 30cm cable. The whole assembly was concealed underneath rocks in the cave but for the microphone tube having sight of flying bats. These units were not found or disturbed by any cave visitors.

In the other three cave entrances, the Pelicases were placed in full view of cavers and they had the microphone in the acetal block on the side, as in *Figure 3*. The system in AA would not have been seen by cavers as it was placed on the bats' entry route. The system in DC was untouched, but the Pelicase in OCAF was moved by someone from a low rock shelf at a narrowing to the floor in a wider chamber but otherwise was not meddled with – and it seemed to continue counting bats well enough despite its later lower position.

The experiments, which started just before New Year 2000, went on longer than was intended due to the COVID-19 pandemic and the lockdown in the UK. The systems were retrieved in May 2020 after local travel for recreation was allowed again. The lockdown may have helped in terms of their security too as fewer people were about.

Experimental Results

Table 1 provides the legend for each of the counters featuring in subsequent charts. Tretower is my local village at 100m above sea level where the external air temperature is recorded on an hourly basis in a screened enclosure. The cave entrances are between 150-400m altitude, which will be 1-2°C cooler than Tretower. An air temperature logger was also placed well within Nunnery Passage on top of a large block of rock the size of a fridge giving it exposure to cave air currents in the main flight path.

Chart 2 shows the daily number of bat flights past the sensor for each site in the course of the study. This is not the same as the absolute number of individual bats since the bats probably returned to the cave after leaving it in the winter months. The bats would have been sleeping elsewhere in the spring months, entering the cave only to rest or for other purposes. Bats also might fly circles in the cave or otherwise linger and thus add multiple counts per individual. The logger has a retriggerable adjustable software timer set to two seconds in this instance, which enforces a 2-second silent gap between incrementing

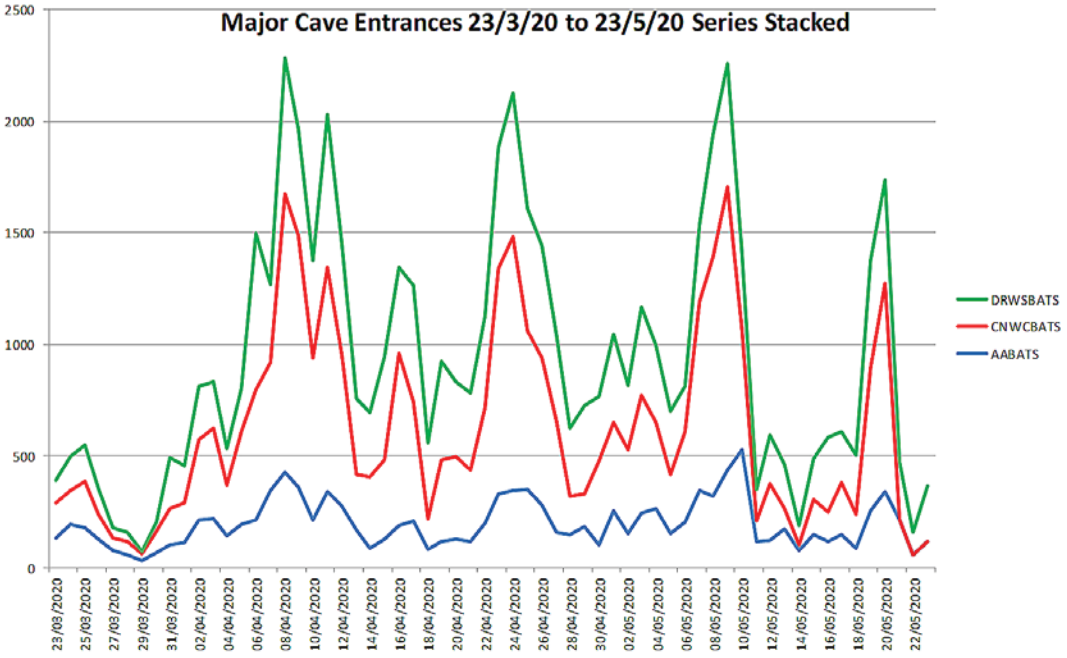


Chart 5 – Bat behaviour remains in step across the same caves even after the hibernation period ends.

Whatever the bats are then doing, it is not for sleeping as in the winter.

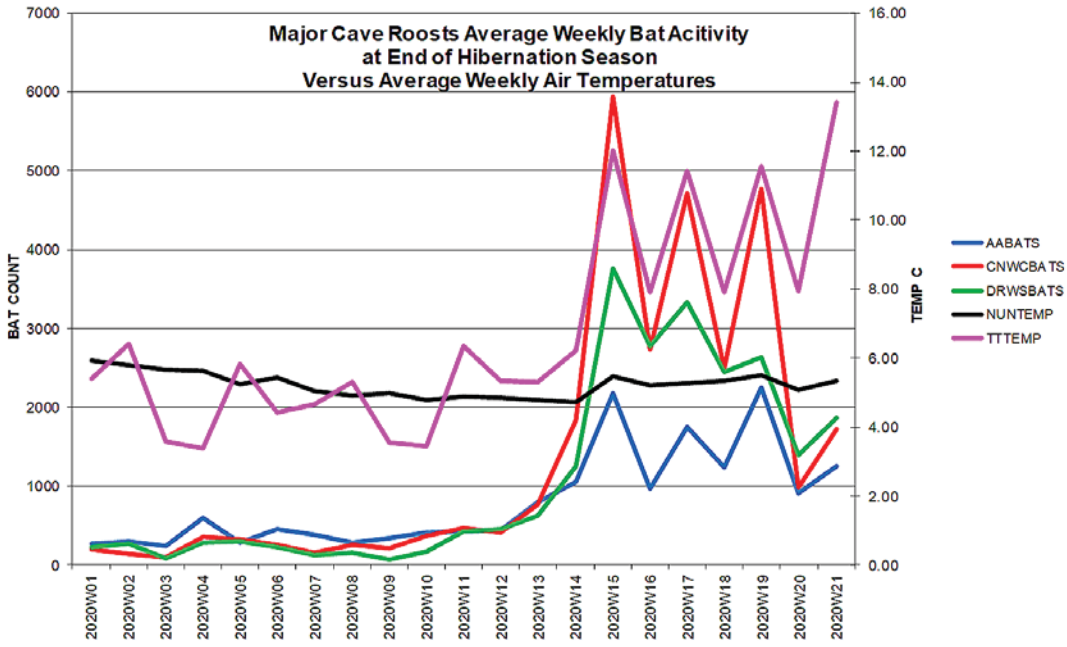


Chart 6 – Bat counts per week for the three main caves versus average air temperature calculated weekly.

It is obvious that bat activity is coupled to the valley air temperature (TTTEMP), not to the cave air temperature (NUNTEMP). Furthermore, bats tend to find sheltered hibernation places. So we suggest that the slight cave air currents and tiny cave air temperature variations are imperceptible to bats and therefore they determine external conditions by the simple expedient of making occasional inspections, as evidenced by the low but not zero bat flights during weeks 1-12 as seen above, rather than by inference.

the bat count. Our data presented here is thus a bat activity index that approximates to bat fly-pasts.

From a caver's perspective, the caves look very similar where a very short section of smaller passage connects quite quickly to large open dry passages that bats would hibernate in. So why were two of the entrances so little used?

It is suggested that the Nunnery has low usage because this entrance has been open only since mid-2016 (i.e. since the winter of 2016-17 from a bat viewpoint) and a large colony has developed in the nearby Drws Cefn entrance which has been open since the winter of 2009-10. We know from caver observations that Nunnery Passage bat numbers, though modest, have doubled every year for four in a row, and this might represent defections from Drws Cefn to Nunnery Passage which is a much nicer passage both for cavers and bats.

The high counts in Drws Cefn and Ogof Cnwc are confirmed by the sheer quantity of bat droppings. It was a surprise to see their high counts exceed Agen Allwedd's which is thought to be the most significant roost in the whole area. This prompts further research next winter, including the possibility that the position of the AA bat counter being much further into the cave than the other bat counters which might mean less 'frivolous' flying about by bats being recorded than if a counter had been put very close to the entrance. The plan is to discontinue the OCAF counter (more on this later) and place it just inside the AA bat entrance while maintaining the earlier AA bat counter further in for comparison.

OCAF is a great cave for cavers where a short hands-and-knees crawl leads to some very big well-decorated passages in little time. However, bats will not see it in that way. This cave has a monstrous gate, and stone blockwork wall around it, that is almost bat-proof because the tiny gaps left between welded girders prevent flight. The reason the count is low is that most bats cannot get past the gate, there being no other obvious off-putting feature. Cave management responsibility here has recently passed from Natural Resources Wales (the national nature conservation body) to an ad hoc group of local cavers whom we expect will see to altering the gate design, so it no longer prevents bat usage.

There is now a wealth of data available for further analysis and what is presented here is but the tip of an iceberg. There are about 18,000 hourly bat counts and corresponding hourly air temperature readings available in last winter's dataset. It can be downloaded as an Excel Spreadsheet [4]. The author can be contacted via **caving.wales** and welcomes correspondence providing further insights into cave bat behaviour and suggestions as to directions for this project and its novel equipment that enables cave bat monitoring to be undertaken automatically and economically at regional and seasonal scale.

Lesser Horseshoe Bat

References

[1] Countryside Council for Wales (2008) Core Management Plan [for the] Usk Bat Sites Special Area of Conservation (SAC): **naturalresources.wales/media/674281/Usk%20Bat%20Sites%20Management%20Plan%20Feb%2008.pdf**

[2] France, Stuart (2001) *Generating & Detecting Bat Calls*, CREGJ **44**, pp9-10.

[3] France, Stuart (2003) *What Turns on Bats? Data Logging at Agen Allwedd*, CREGJ **53**, pp26-27.

[4] France, Stuart (2020) *Spreadsheet for the Winter 2020 Usk Bat Sites Caves Dataset*: **caving.wales/data/uskbatdata2020.xls**

Web Watch

Lots of links this time, from batteries to power tools and satellites to thermal imaging, from ***Peter Ludwig****.*

Plenty of battery news this time: **pocket-lint.com/gadgets/ news/130380-future-batteries-coming-soon-charge-in-seconds-last-months-and-power-over-the-air**

and **greentechmedia.com/articles/read/us-storage-companies-quietly-grow-bets-on-solid-state-batteries**

When you have to explain brushless power tools: **cordlessdrillzone.com/drill-wars/brushless-vs-brushed-motor**

The upcoming Starlink internet access system from SpaceX could also be useful for us in remote places: **starlink.com**

While this site is focused on marine issues, it is also a good source of information for us, especially concerning electrical and electronic parts: **marinehowto.com**

A nice-looking laser engraver for marking your caving gear: **k6.wainlux.com**

A good gear testing site: **kit.co/alishanmao**

A very small and fast thermometer: **thermbot.ai**

Finally, I have one of these thermal cameras for my iPhone: **thermal.com/compact-series.html**