

Thermocron iButton and iBBat temperature dataloggers emit ultrasound

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Abstract Thermocron iButton dataloggers are widely used to measure thermal microclimates experienced by wild animals. The iBBat is a smaller version of the datalogger, also commercially available, that is used to measure animal skin or core body temperatures when attached externally or surgically implanted. Field observations of bats roosting under a bridge suggested that bats avoided locations with iButtons. A heterodyne bat detector revealed that the dataloggers emitted ultrasound which was detectable from a distance of up to 30 cm. We therefore recorded and quantified the acoustic properties [carrier frequency (Hz) and root mean square sound pressure level (dB SPL)] of iButton and iBBat dataloggers. All units emitted a 32.9 kHz pure tone that was readily picked up with a time expansion bat detector at a distance of 1 cm, and most were detected at a distance of 15 cm. The maximum amplitude of iButton dataloggers was 46.5 dB SPL at 1.0 cm—a level within the

range of auditory sensitivity for most small mammals. Wrapping iButtons in plastic insulation severely attenuated the amplitude of ultrasound. Although there was a statistically significant reduction in rates of warming and cooling with insulation, this effect was small and we suggest that insulation may be a viable solution to eliminate unwanted ultrasonic noise in instances when small delays in thermal response dynamics are not a concern. We recommend behavioural studies to assess if the electronic signals emitted by iButtons are disturbing to small mammals.

Keywords Bats · Chiroptera · Disturbance · Thermocron iButton · Mammals · Ultrasound

Introduction

Thermal microclimates exert strong influence on the lives of vertebrates, and the ability to quantify microclimate conditions experienced by wild animals is important for understanding their physiology, ecology, and behaviour (Boyles 2007; Hill et al. 2008; Withers 1992). The fact that many endothermic species are capable of pronounced heterothermy has also fuelled interest in measuring patterns of body (T_b) or skin temperature (T_{sk}) in free-ranging and captive individuals (Geiser 2004). The recent availability of miniature dataloggers has made collecting data on ambient temperature (T_a) and T_b much easier (Boyles 2007). For example, Thermocron iButton dataloggers (Maxim Integrated Products, Sunnyvale CA USA) have become a favorite with many biologists because they are small (~18 mm diameter by 6 mm thick), can store large numbers of time and date-stamped measurements (1,024–8,192 depending on the model), are easy to program and interface with, are rugged enough for field use (stainless steel

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casing), and, perhaps most importantly, they are relatively inexpensive.

Thermocron iButtons have proven useful for measuring thermal microclimates of nests, burrows, and roosts of a variety of species (e.g., Boyles et al. 2008; Mzilikazi and Lovegrove 2005; Warner and Shine 2007; Willis and Brigham 2005, 2007). They have also been used to monitor T_b or T_{sk} in heterothermic endotherms and ectotherms (e.g., Davidson et al. 2003; Fietz et al. 2003; Lovegrove 2009; Munro et al. 2005; Mzilikazi and Lovegrove 2004; Seebacher et al. 2003; Warnecke et al. 2007). Some studies have even used iButtons to monitor nest occupancy behaviour based on the assumption that warm endotherms elevate temperature inside the enclosed nest space (Freezer 2005; Willis et al. 2005). Recently, to reduce the size and mass of iButtons and allow for monitoring of T_b or T_{sk} in small animals, custom dataloggers have been built by removing the internal components (battery, thermistor, clock and data storage chip) from the stainless steel canister and encasing them in plastic or similar material. These size-reduced dataloggers can be glued to the skin or attached via a collar, or coated with a biologically inert wax for surgical implantation (Landry-Cuerrier et al. 2008; Lovegrove 2009; Robert and Thompson 2003). Similar units are commercially produced under the names iBBat or iBCollar (Alpha Mac Inc. Mont St-Hilaire, Quebec, Canada).

There is no doubt that iButton technology has facilitated important insights and provided new data on microclimates and body temperature variation that would have been extremely difficult, if not impossible, to obtain by other means. However, to our knowledge, there are no studies comparing the behaviour or physiology of animals outfitted or exposed to iButtons with that of control animals. Similarly, there are no behavioural studies of animals instrumented with different kinds of electronic devices used to record field temperature data (e.g., iButtons vs. temperature-sensitive radio transmitters).

Some electronic devices emit sounds in the frequency range audible to humans (i.e., between 20 and 20,000 Hz), whereas others may emit ultrasound (i.e., sound frequencies above human hearing) (Schiek et al. 2006). Thermocron iButtons do not emit audible acoustic signals, but it is unknown if they emit ultrasound. Among vertebrates, birds appear to have low sensitivity to ultrasonic frequencies (Pytte et al. 2004), but many terrestrial mammals are sensitive to ultrasound (e.g., Heffner et al. 2001). Indeed, many mammals use ultrasonic signals for acoustic communication (Kalcounis-Rüppell et al. 2006; Sewell 1970; Wilson and Hare 2004), and for orientation and navigation (Sales and Pye 1974). If Thermocron iButtons generate electronic ultrasound and are placed in mammalian nests or burrows, the devices could potentially influence habitat selection (e.g., by affecting nest or roost abandonment), interfere

with activity cycles, or disrupt patterns of thermoregulation. In turn, this could directly influence the quality of our physiological and behavioural data. The potential for disturbance seems even more likely when the devices are attached to an animal to record T_{sk} . In addition to affecting behaviour of a focal animal wearing the device, emitted signals could interfere with acoustic communication or otherwise influence interactions with conspecifics.

Given their reliance on high frequency sounds for echolocation (Popper and Fay 1995), microchiropteran bats could be especially vulnerable to disturbance from electronically generated ultrasound. This is potentially of concern as researchers have used iButtons to measure roost microclimates (e.g., Neubaum et al. 2006; Solick and Barclay 2006, 2007; Willis and Brigham 2005, 2007) and to record T_{sk} of hibernating bats in the laboratory (Dunbar and Tomasi 2006). Currently, there is tremendous interest in the hibernation biology of bats because of the emergence of white-nose syndrome (WNS), a potential fungal pathogen devastating populations of bats hibernating in the northeastern United States (Bleher et al. 2009; Boyles and Willis 2009). WNS appears to disrupt energy balance during hibernation (Boyles and Willis 2009) so there has been considerable effort to quantify hibernacula microclimates and T_{sk} of hibernating bats, and much of this effort depends on iButton technology. If iButtons emit ultrasound, this could disturb bats in their hibernacula or in summer roost sites. Moreover, if the noise masks detection of echoes from objects in the environment when glued to a bat's back, then iButtons could interfere with echolocation and therefore, orientation and/or foraging during the active season (e.g., see Schaub et al. 2008).

Our interest in the potential of Thermocron iButtons to emit ultrasound was raised when we observed apparent behavioural changes of bats after placement of dataloggers in a roost. On 8 July 2008, five iButtons were placed under a bridge in central Indiana, USA to monitor microclimates of favored roosting sites selected by little brown bats (*Myotis lucifugus*), Indiana bats (*Myotis sodalis*), big brown bats (*Eptesicus fuscus*), and tri-colored bats (*Perimyotis subflavus*). The week following installation, no bats were observed roosting near the devices. During the next several weeks it became apparent that neither species of *Myotis* roosted near the iButtons, and big brown bats typically roosted no closer than 0.3–0.6 m. Based on these preliminary observations, we wondered if iButtons emit ultrasound that may be disturbing to bats. When we placed the microphone of a broadband heterodyne bat detector (Mini-2 Bat Detector, Ultra Sound Advice, London, UK) adjacent to an iButton, a signal between 30 and 40 kHz was detected to a distance of 30 cm. We monitored three models of Thermocron iButtons with the bat detector and ultrasound was detected from every unit. We also monitored four iBBat skin temperature dataloggers and detected ultrasound from those units as well.

Here we provide the first description of electronically generated ultrasound emitted by iButton and iBBat dataloggers. Our goal was to describe temporal and spectral features of iButton ultrasound and measure its amplitude to determine if the signal level was sufficiently loud to be detected by, and possibly disturb, bats and other small mammals. We tested a method of damping electronically generated ultrasound by wrapping iButtons in plastic foam insulation. We also tested whether the insulation interfered with the accuracy of thermal measurements collected by the dataloggers and their rates of heating and cooling.

Materials and methods

Sounds were recorded from three models of Thermocron iButtons (DS1921G, $n = 7$; DS1921L, $n = 1$; and DS1922L, $n = 7$) that were identical in external appearance (i.e., stainless steel canister) but that differed in functionality (Lovegrove 2009; Robert and Thompson 2003). The iButtons ranged in age from several months to several years, so our description of their sounds spans multiple lot numbers and is not specific to manufacturing date. We also recorded ultrasound from four iBBat dataloggers, which are essentially an iButton circuit board that has been removed from the casing, connected to a smaller battery, and coated in light plastic with two wire leads for data communication. Two of the iBBats had electronics from a DS1922L iButton, and two were built from DS1921G electronics.

Sounds were detected and/or recorded with the broadband microphone of a tunable heterodyne/time expansion bat detector (Model D240x; Pettersson Elektronik AB, Uppsala Sweden) set to a time-expansion factor of 10. Most recordings took place inside a $1.5 \times 1.5 \times 0.6$ m anechoic chamber, constructed from 5 cm thick dimpled memory foam (i.e., mattress material), located in a quiet room in the Department of Biology at the University of Winnipeg. We mounted the bat detector in the centre of the chamber and connected it to a computer (outside the chamber) running SonoBat v2.6 (Arcata, CA). All other electronics, except one bank of fluorescent room lighting, were switched off during recording. The primary source of background noise was the building ventilation system. The bat detector was set to automatically record a 1.7 s sound sample when triggered by a finger snap. We also recorded background sounds with no datalogger inside the chamber (Fig. 1).

Ultrasound emissions were independently confirmed for five iButtons (three DS1921G, two DS1922L) and three iBBats at McMaster University using a U30 heterodyne bat detector (Ultra Sound Advice) inside a IAC Model 120A-02 double wall sound isolation booth ($2 \times 2 \times 2$ m; Industrial Acoustics Incorporation, Bronx NY). We also measured the root mean square amplitude of datalogger sounds,

expressed in decibels sound pressure level (rms dB SPL re 20 μ Pa), using a Brüel & Kjær (B&K) Type 4135" condenser microphone (flat ± 3 dB 5–120 kHz; diaphragm 0° incidence, protective grid on) connected to a B&K Type 2610 Measuring Amplifier and calibrated with a B&K Type 4228 Pistonphone (124 dB SPL @ 250 Hz) and again with a B&K Type 4231 Acoustical Calibrator (94 dB SPL @ 1,000 Hz). To eliminate low frequency room noise, the microphone signal was band-pass filtered (Krohn-Hite Model 3500; -3 dB high-pass cutoff = 23 kHz and low-pass cutoff = 43 kHz) before the measuring amplifier.

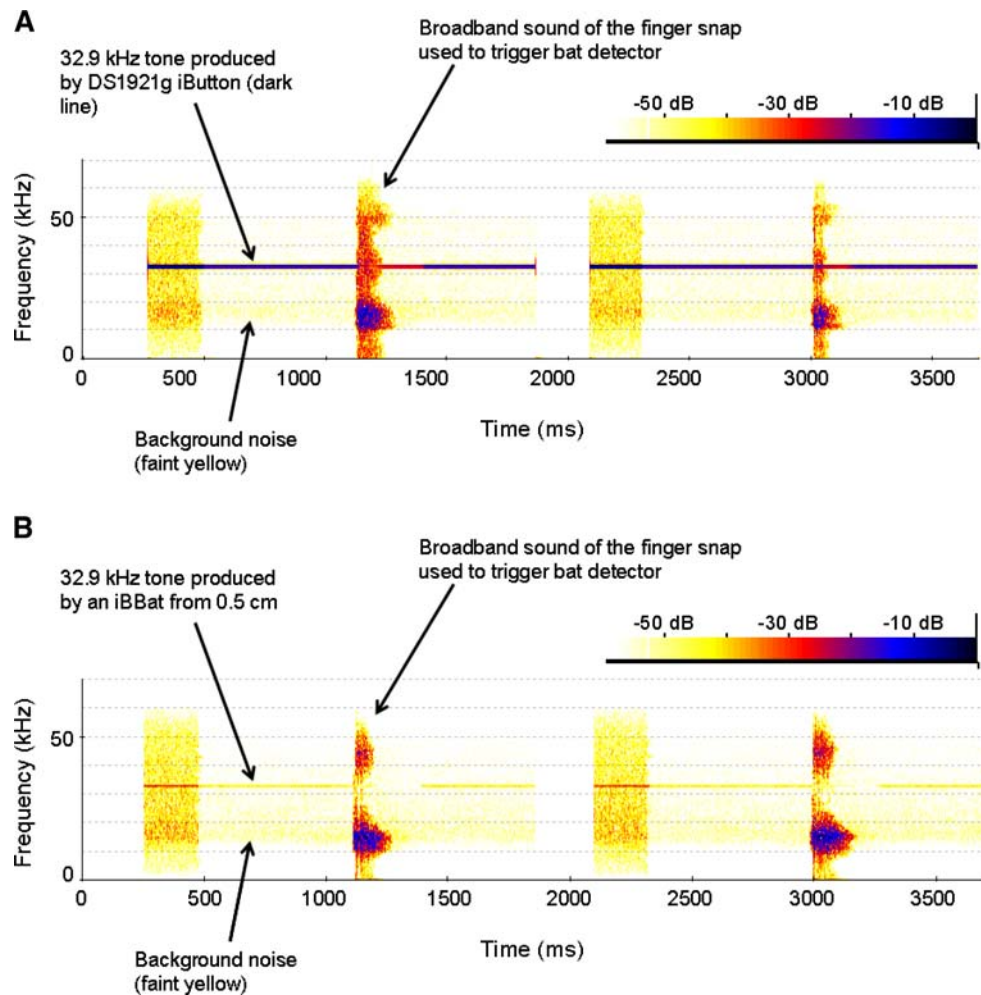
The iButtons were recorded at a distance of 1, 15 and 30 cm; iBBats were recorded at 0.5 and 1 cm. We recorded the iBBats at shorter distances to estimate the SPL received at the ear of a bat with a datalogger attached to its back or of a small mammal outfitted with a collar. A 1 cm distance is also relevant to bats in hibernation because it approximates the distance from the head of one bat to a datalogger attached to an adjacent conspecific in a cluster. Prior to recording, iButtons and iBBats were programmed to log temperature records every 10 min, a typical sampling interval for field studies. However, based on our observations with bat detectors, dataloggers emit ultrasound regardless of whether or not they are programmed and recording temperatures.

Time-expansion sound files were analyzed with Bat-Sound Pro (version 3.31a, Pettersson Elektronik AB) and SASLab Pro software (Avisoft Bioacoustics, Berlin, Germany). We selected a 400 ms window from the oscillogram [amplitude versus frequency (Hz)] and computed the magnitude spectrum [relative power (dB) versus frequency (Hz)] using a Fast Fourier Transform (FFT) analysis. We also computed the magnitude spectrum of background room noise with no datalogger present.

We tested an approach to dampen ultrasound emissions of iButtons, at least in situations where size and weight of the device are not of concern, by individually wrapping DS1921G iButtons ($n = 5$) in three layers of 4 mm plastic packaging of the type used to wrap electronic components and then monitoring wrapped and unwrapped iButtons with the D240x bat detector. We also determined whether the plastic wrapping adversely affected recording properties of the dataloggers when programmed to log temperature records every minute. Prior to wrapping for sound recordings, the five DS1921G iButtons were allowed to acclimate to room temperature (23°C) for at least 1 hour before we placed them in a custom-built temperature-controlled cabinet with T_a set to $\sim 7^\circ\text{C}$. After 1 h at 7°C , the dataloggers were removed and allowed to re-warm to 23°C . The experiment was repeated with the same five iButtons after they were wrapped in plastic for ultrasound recordings.

Temperature-sensitive radio transmitters are also used to measure T_b or T_{sk} in free-ranging and captive animals, often

Fig. 1 Spectrograms of the 32.9 kHz tone produced by **a** a Thermocron DS1921G iButton recorded from a distance of 1 cm, and **b** an iBBat skin temperature datalogger recorded from 0.5 cm



alongside iButtons (e.g., Landry-Cuerrier et al. 2008; Lausen and Barclay 2006; Willis et al. 2006) so we conducted sound recordings of four activated BD-2T temperature-sensitive radio transmitters (Holohil Systems Ltd, Carp, ON, Canada) with the D240x bat detector. Transmitter electronics were coated in the layer of inert, waterproof epoxy applied by the manufacturer.

Data values are reported as the mean \pm standard deviation (SD). Statistical analyses were performed with Systat v9 (SPSS Inc.). Analysis of variance (ANOVA) was used to compare peak signal levels above background at 32.9 kHz between iButtons and iBBats and group means were compared in post hoc analyses using Scheffe's tests. All statistical tests employed a comparison-wise error rate of $\alpha \leq 0.05$ (Zar 1984).

Results

In six of seven DS1922L iButtons, the one DS1921L iButton, and all seven DS1921G iButtons, ultrasound emissions were readily detected using the broadband microphone of a

heterodyne/time expansion bat detector at a distance of 1 cm (Fig. 1a). The signal was a continuous sine wave tone at a frequency of 32.9 kHz. Five of the seven DS1922L iButtons emitted ultrasound that could be detected at 15 cm, while only one was detectable at 30 cm. Six of seven DS1921G iButtons emitted a 32.9 kHz continuous tone that could be detected at 15 cm, and five were detected at 30 cm. We also detected ultrasound emissions in the one DS1921L iButton at 15 and 30 cm. The four iBBats emitted 32.9 kHz ultrasound that could be detected at 0.5 and 1 cm (Fig. 1b).

Background noise levels in the IAC sound isolation booth were low, averaging 29.2 ± 0.4 dB SPL ($n = 8$) in the frequency band between 23 and 43 kHz. The low noise permitted us to directly measure the SPL of three of five iButtons (43.2 ± 4.2 dB SPL) and one of three iBBats (31.5 dB SPL) at a distance of 1 cm. The DS1921G iButtons were louder (46.5 and 44.5 dB SPL) than the DS1921L (38.5 dB SPL) iButton.

We measured the height (in dB) of the 32.9 kHz signal, relative to background, in the power spectra of iButton and iBBat recordings obtained with the D240x bat detector

(Fig. 2). For recordings at 1 cm, there was a significant difference in peak signal level above background between the DS1921G iButtons (29.0 ± 11 dB), DS1922L iButtons (11.7 ± 9.6 dB) and iBBats (8.6 ± 3.7 dB; ANOVA, $F_{2,14} = 7.5$, $P = 0.006$). Post hoc analyses revealed that DS1921G iButtons had a significantly louder peak signal level above background at 32.9 kHz than both DS1921L iButtons ($P = 0.016$) and iBBats ($P = 0.021$). The peak signal height above background was not significantly different between DS1921L iButtons and iBBats ($P = 0.89$) at 1 cm.

Not surprisingly, wrapping iButtons in plastic packing foam dramatically reduced the peak signal level recorded at 32.9 kHz from 30.1 ± 9.7 to 5.9 ± 3.3 dB (re background level) at 1 cm. We also found that plastic-wrapped iButtons were slightly more sluggish in recording temperature changes. Control iButtons without plastic wrapping took 13.1 ± 1.1 min to cool from 23 to 6.5°C, and 20.6 ± 1.3 min to re-warm to 23°C, whereas iButtons wrapped in plastic took 10.5 ± 2.4 min longer to reach their final (stable) minimum temperature, and 6.3 ± 3.9 min longer to re-warm to room temperature (Fig. 3). The temporal delay

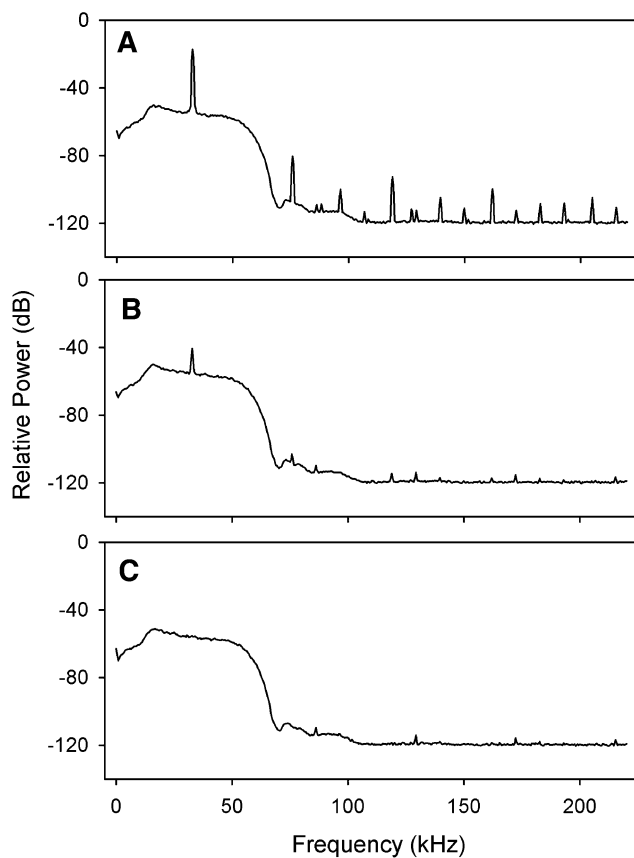


Fig. 2 Fast Fourier transform power spectra of the sound recorded from **a** a DS1921G Thermocron iButton, **b** an iBBat skin temperature datalogger, and **c** the background noise in the anechoic chamber used for recordings at the University of Winnipeg. In **a**, the fundamental frequency of the emitted signal at 32.9 kHz and its higher harmonics can easily be seen

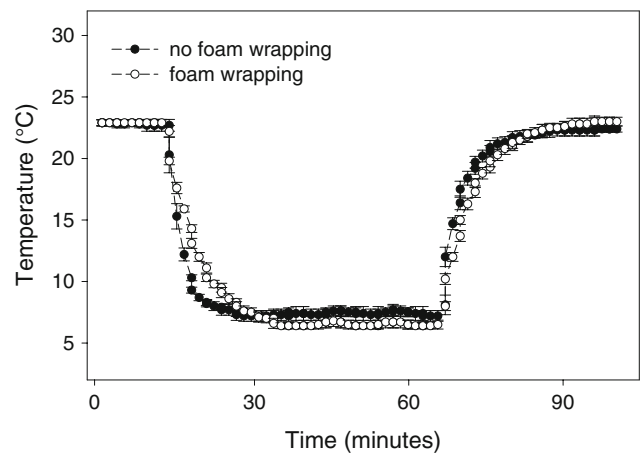


Fig. 3 Mean \pm SD temperatures recorded once per minute by iButtons ($n = 5$) acclimated to a 23°C room, then placed in a temperature-controlled cabinet at 7°C for 1 h, and then returned to 23°C room temperature. In one set of measurements, iButtons were wrapped in plastic foam packing material to attenuate the ultrasound emitted by the devices (open circles) while in the other set of measurements the iButtons were not wrapped (filled circles)

caused by the plastic wrapping resulted in small but significant difference in rates of both cooling (paired t test, $t = -8.5$, $P < 0.001$, $df = 4$) and warming ($t = -4.1$, $P = 0.014$, $df = 4$). There was no difference in warm temperatures recorded by wrapped (23.0 ± 0.4) versus unwrapped iButtons (22.9 ± 0.3 , paired t test, $t = 1.0$, $P = 0.37$, $df = 4$) but there was a small but significant difference in the minimum cold temperature recorded by wrapped (6.2 ± 0.5) versus unwrapped iButtons (7.2 ± 0.4 , paired t test, $t = -6.3$, $P = 0.003$, $df = 4$).

In contrast to iButtons and iBBats, active Holohil temperature-sensitive radio transmitters did not emit ultrasound that could be detected with the D240x bat detector.

Discussion

Our results indicate that most, but not all, Thermocron iButton temperature dataloggers generate electronic ultrasound at a frequency of ~ 33 kHz and at a maximum amplitude of ~ 47 dB SPL (re 1 cm). We also found that iBBat dataloggers generate 33 kHz ultrasound, albeit 15–20 dB quieter than iButtons. Ultrasound emissions were not detected in active Holohil temperature-sensitive radio transmitters. Presumably, custom-built devices that employ iButton technology also emit ultrasound (e.g., Landry-Cuerrier et al. 2008; Lovegrove 2009; Robert and Thompson 2003), but this remains to be confirmed. Our measures do not address how the signals were generated nor do we know if the difference in SPL between iButtons and iBBats resulted from signal amplification within the stainless steel

housing of intact iButtons (i.e., resonance), or from attenuation of sound passing through the wax/plastic coating on the iBBat exterior (i.e., damping). Additional research is required to address these questions.

We were unable to measure the rms amplitude of every iButton and iBBat we tested in the sound-isolation chamber but our data suggest that there is modest variation in the maximum amplitude of ultrasound emissions even between iButtons of the same model. Interestingly, on several occasions at the Indiana bridge roost—where we first noticed bats that appeared to be avoiding locations with iButtons—we saw 1 or 2 big brown bats roosting immediately adjacent to and even on top of iButtons. This suggests that not every unit emits ultrasound or, alternatively, that the emitted signal is not disturbing to all bats. Nevertheless, the maximum amplitude of iButton and iBBat datalogger sounds we measured varied between 38 and 47 dB SPL (re 1 cm), which is equivalent to residential ambient noise levels and well within the range of auditory sensitivity of many small mammals (Table 1). That datalogger sounds represent a potential source of disturbance for small mammals is cause for concern because the devices may alter the expression of behavioural and physiological traits being monitored. The potential for disturbance may be especially high if an iButton is inserted into an enclosed microhabitat like a burrow, nest or roost cavity where animals may be forced into close contact with the device, or if the device is placed in habitats with extremely low levels of background noise, such as caves. In the case of bats carrying dataloggers, there is also potential for disruption of echolocation ability as extraneous noise can influence prey capture success of bats foraging in a lab (Schaub et al. 2008). Ultrasound disturbance could also impair the ability of individuals carrying dataloggers to interact normally with conspecifics. Social thermoregulation is important for reproduction (Willis and Brigham 2007) and is likely critical for survival during hibernation (Boyles et al. 2008, Boyles and Brack 2009). If individuals carrying dataloggers are rejected by potential cluster-mates, this could severely compromise thermoregulatory ability and survival. Encouragingly, the more recent model of iButton, the DS1922L, produced less intense ultrasound than the DS1921G, and the single DS1921L iButton we examined also produced less intense sound than the DS1921G but at 20 dB above background at 1 cm, well within the range of sensitivity for many small mammals.

Though beyond the scope of this report, additional observations and experiments are required to determine if bats and other mammals alter their behaviour and/or physiology as a result of exposure to electronically generated ultrasonic tones from iButton and iBBat dataloggers. Some observations suggest that, at least for some species of mammals, iBBats may cause relatively little disturbance. For

example, Landry-Cuerrier et al. (2008) used both radio transmitters and collar-mounted iBBats (iBCollar, Model 1922L) to monitor torpor and arousal patterns of eastern chipmunks during hibernation. Although they did not specifically look for differences in arousal patterns between individuals carrying the two devices, they presented no evidence to suggest that chipmunks carrying iBCollars behaved differently from those outfitted with radio transmitters. Willis and Brigham (2007) inserted DS1921G iButtons into tree cavities inhabited by big brown bats to monitor roost microclimates. As many as four iButtons were placed into some roosts to monitor spatial variation in microclimate, and encouragingly, no obvious differences in the pattern of roost use or frequency of roost switching was observed for bats living in trees with and without iButtons. On the other hand, some iButtons were occasionally removed from roosts, presumably by red squirrels (*Tamiasciurus sciurus*) that used the cavities when bats were not present. Many sciurids rely on high frequency sounds for communication (e.g., Wilson and Hare 2004), so removal of iButtons from tree cavities may represent a behavioural response by squirrels to ultrasonic disturbance. To our knowledge, behavioural audiograms have not been measured for red squirrels, but fox squirrels (*Sciurus niger*) have a detection threshold of 17 dB SPL at 32 kHz (Jackson et al. 1997, Table 1), a sensitivity that is an order of magnitude lower than the maximum amplitude of iButton ultrasonic emissions.

For iButtons deployed within mammalian roosts or nesting cavities, we recommend wrapping the units with sound attenuating insulation. Our experiment showed that plastic insulation virtually eliminated the 33 kHz ultrasonic tone emitted by iButtons, and caused only a small delay in the measured rates of cooling and warming. Curiously, the wrapping appeared to cause a slight change in accuracy at $\sim 7^\circ\text{C}$; wrapped dataloggers recorded temperatures about $0.5\text{--}1.0^\circ\text{C}$ colder than unwrapped ones, despite exposure to identical T_a . However, the effect did not occur at the higher test T_a ($\sim 23^\circ\text{C}$) and it was consistent for all five iButtons we tested, which suggests that it could be corrected with a simple calibration using a traceable thermometer in a water bath. In some mammalian environments—such as underground burrows, tree and rock crevices, and especially cave hibernacula—microclimate conditions are relatively stable and T_a changes more gradually than in the laboratory conditions we used for our warming/cooling experiment. Thus, insulating units to attenuate ultrasound is likely to have a minor effect on microclimate data collected in the field. We also recommend monitoring dataloggers with a heterodyne bat detector before and after wrapping to confirm that the insulation has attenuated the ultrasound. Prior to surgical implantation, iButtons are typically coated in a biologically inert wax (e.g., Lovegrove 2009). We did not measure the

Table 1 Published values of threshold sensitivity to sounds at 32 kHz for a range of representative mammals (based on behavioural audiograms) and a bird (based on neural recording)

Species	Common name	Threshold at 32 kHz ^a	Reference	Notes
Bats				
<i>Cynopterus brachyotis</i>	Dog-faced fruit bat	18.25	Heffner et al. (2006)	Non-echolocating
<i>Eidolon helvum</i>	Straw-colored fruit bat	36.5	Heffner et al. (2006)	Non-echolocating
<i>Eptesicus fuscus</i>	Big brown bat	11.2	Koay et al. (1997)	
<i>Myotis lucifugus</i>	Little brown bat	18	Dalland (1965)	At 35 kHz
<i>Noctilio leporinus</i>	Greater bulldog bat	5	Wenstrup (1984)	
Primates				
<i>Lemur catta</i>	Ring-tailed lemur	15	Gillette et al. (1973)	
<i>Pan troglodytes</i>	Chimpanzee	83	Kojima (1990)	
<i>Papio cynocephalus</i>	Yellow baboon	23	Hienz et al. (1982)	
Rodents				
<i>Acomys cahirinus</i>	Spiny mouse	31.5	Heffner et al. (2001)	
<i>Mus musculus</i>	House mouse	8	Heffner and Masterton (1980)	
<i>Phyllotis darwini</i>	Darwin's mouse	24	Heffner and Heffner (1985a)	
<i>Onychomys leucogaster</i>	Grasshopper mouse	27	Heffner and Heffner (1985a)	
<i>Sigmodon hispidus</i>	Cotton rat	10	Heffner and Masterton (1980)	
<i>Tamias striatus</i>	Eastern chipmunk	24	Heffner et al. (2001)	
<i>Sciurus niger</i>	Fox squirrel	17	Jackson et al. (1997)	
<i>Meriones unguiculatus</i>	Mongolian gerbil	17	Ryan (1976)	
Carnivores				
<i>Mustela nivalis</i>	Least weasel	8	Heffner and Heffner (1985b)	
Ungulates				
<i>Sus scrofa</i>	Domestic pig	25	Heffner and Heffner (1990)	
Birds				
<i>Lampornis clemenciae</i>	Blue-throated hummingbird	>90	Pytte et al. (2004)	Tested up to 90 dB with no response

^a (in dB SPL re 20 μ Pa)

sound attenuating properties of a wax-coating on iButtons or iBBats, but presumably the wax would also dampen ultrasound emissions.

Miniature temperature dataloggers, like iButtons, are clearly of tremendous value for research on animal metabolism, thermal physiology, habitat selection and hibernation, and we support their use in studying these and other aspects of physiology, behaviour, and ecology. It remains to be determined if iButton dataloggers disturb free-living animals but our preliminary field observations and sound level measurements suggest it is a possibility. Therefore, we also identified a simple solution to reduce or eliminate the likelihood of disturbance in some circumstances. We emphasize that future studies should carefully examine potential influences of any electronic monitoring device on study animals to avoid undue stress on the animals and to avoid disrupting the patterns of physiology and behaviour that we aim to understand.

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